MINIMALLY INVASIVE PROCEDURES IN ORTHOPAEDIC SURGERY / 4

Atlas of Minimally Invasive Hand and Wrist Surgery

Edited by
John T. Capo
Virak Tan

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Atlas of Minimally Invasive Hand and Wrist Surgery

Minimally Invasive Procedures in Orthopedic Surgery

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Thomas Jefferson University and the Rothman Institute,
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Edited by

John T. Capo

New Jersey Medical School
Newark, New Jersey, USA

Virak Tan

New Jersey Medical School
Newark, New Jersey, USA

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healthcare

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Foreword

Valuable medical reference books fall generally into one of two categories—authoritative, breakthrough information about new scientific, technical, or technological developments; or comprehensive, generally accepted, factual information on a particular subject. This textbook is a commendable example of the former.

This useful book will serve the reader well as a reference for the execution of many of the newest techniques in hand and wrist surgery. It includes well-organized chapters on the developments in minimally invasive procedures that can reduce the risks and inconveniences patients face in the surgical treatment of certain traumatic and degenerative disorders of the upper extremity. The references of these chapters will also stimulate additional reading of authoritative articles in the medical literature.

Orthopedic surgery—and hand surgery, in particular—has evolved into a specialty with brilliant potential based on advantageous new technologies, implants, and task-specific instruments. Technically assisted visualization, enhanced with the arthroscope, the intra-operative use of C-arm X-ray, and more extensive use of pre-operative magnetic resonance imaging, is discussed in great detail in this text. The pros and cons of various implant materials are reviewed with critical assessment. There is an enlightening chapter on the chemistry of osteo-inductive ceramic bone substitutes as they are becoming not only commonplace, but the mainstay for filling bone voids, replacing biologic bone graft tissues.

Extensive attention is devoted to internal fixation of small bone and distal radius fractures. Included are comparative biomechanical assessments of cannulated and compressive orthopedic screws, as well as the surgical details for their implantation. These fixation devices are used commonly today for acute fractures, nonunions and fusions of the small joints of the hand and wrist. Additionally, the rationale and techniques for minimally invasive fracture stabilization with external fixators and internal fixators, as well as the newer conceptual developments of extra-osseous and even intra-osseous nail plates and bridge plates, are discussed with superb illustrations and technical precautions.

New minimally invasive approaches to the treatment of common soft tissue problems are addressed with a background of extensive experience and a particular interest in patient safety. Included are compressive and entrapment disorders of peripheral nerves and tendons, and even minimally invasive approaches to Dupuytren's contractures and tendon sheath infections.

Although many minimally invasive surgical techniques are included for thoroughness, they do not uniformly represent the endorsement or recommendation of the authors. Accordingly, this text provides invaluable commentary on the pros and cons of each surgical technique and implant discussed, enabling readers to exercise their own judgment in the care of their patients. In summary, as the advantages of minimally invasive and less traumatic surgical techniques gain more widespread acceptance, *Minimally Invasive Hand and Wrist Surgery* provides a concise resource for most new developments in the treatment of bone and joint problems in the distal upper extremity.

It is a pleasure to commend the exceptional efforts that have gone into the organization, preparation, and illustration of this textbook. I am confident it will be an informative reference for hand surgeons well into the foreseeable future.

Terry L. Whipple
American Self, PLC, and
Orthopaedic Research of Virginia,
Richmond, Virginia, U.S.A.

Preface

When we were first approached to assemble this volume on minimally invasive techniques in the wrist and hand, we were unsure whether enough novel and valuable material existed to merit a book. However, in putting together a rough outline, we easily came up with over 40 chapters. This told us something about the evolution of hand and wrist surgery over the last several years. The surgeon leaders in the field have been motivated to improve upon existing operations in many ways. Significant advances have been achieved by making the surgical experience more appealing to the patient by developing procedures that are less invasive with smaller incisions and shorter rehabilitation times. This work has been largely motivated by forces in society at large, with patients expecting a better aesthetic result, less morbidity, and an earlier return to function. This, of course, must be coupled with proper treatment of the pathology and equal or better technical results than the traditional open techniques.

The focus of the text, *Minimally Invasive Hand and Wrist Surgery*, is to describe many of these new and exciting techniques for treatment of traumatic and chronic conditions in the hand and wrist. Technology has advanced significantly over the last 10 years, and several new surgical methods have been developed that utilize percutaneous and minimally invasive techniques. These include percutaneous screw fixation for scaphoid nonunions that obviates the need for a large incision at the wrist, and also eliminates the often troublesome bone graft exposure at the iliac crest. These new methods have been developed primarily by hand surgeons, but also with significant input from the sports medicine and arthroscopic subspecialty trained surgeons. New developments in arthroscopy have expanded the indications within the wrist joint and also extended the applicability to other smaller joints, such as the thumb basal joint. These advances are resulting in improved outcomes with higher patient satisfaction and earlier return to functional activities.

No book currently exists that contains these techniques and concepts all in one volume. A few can be found in various large surgical texts, and others have only been published as journal articles. We have striven for this volume to contain the true current "state-of-the-art" techniques, so many of these procedures may have not appeared before in print. The time from manuscript submission to publication has been consciously accelerated to get these new techniques to you as quickly as possible. We hope that the compilation of this information into one concise volume adds significantly to the orthopedic literature.

The text was designed to serve both as a reference atlas and a work that may be read a section at a time. The reader should be able to turn to a surgical technique section and firmly grasp how to do a specific procedure in 5 to 10 minutes. The chapters have been assembled in a consistent format throughout the text. The "Introduction" is meant to be brief and to describe the motivation for and evolution of the minimally invasive technique. Within the "Indications" section, authors describe how the technique differs from and improves upon the similar open procedure. The surgical technique is really a "how to" section with step-by-step instructions and accompanying photographs and figures. The outcomes described are published series (when available) for the specific and similar techniques and often contain the authors' personal patient series. Unpublished work and data that were presented only at national meetings are also included to be as complete and accurate as possible. Finally, we asked all authors to include a bulleted summary section to clearly define the advantages, risks, and benefits of these new and often technically demanding techniques.

We would like to thank the many authors who contributed to this work for taking time from their busy schedules to add "another book chapter" to their long lists of accomplishments. Many of these "giants" of hand surgery have taught us many things through the years and have been inspirational with their teaching and leadership. We hope that this volume adds something unique and of significance to the world of hand and wrist surgery.

John T. Capo
Virak Tan

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Contributors

Julie E. Adams Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota, U.S.A.

Vikrant Azad Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Marie A. Badalamente Department of Orthopedics, State University of New York, Stony Brook, New York, U.S.A.

Rocco A. Barbieri, Jr. Southern Bone & Joint Specialists, Hattiesburg, Mississippi, U.S.A.

Pedro K. Beredjiklian Department of Orthopedic Surgery, Hospital of the University of Pennsylvania, Presbyterian Medical Center, Philadelphia, Pennsylvania, U.S.A.

David J. Bozentka Department of Orthopedic Surgery, University of Pennsylvania Medical Center, Philadelphia, Pennsylvania, U.S.A.

Jay T. Bridgeman Department of Orthopedics and Rehabilitation, Penn State University College of Medicine, Hershey, Pennsylvania, U.S.A.

John T. Capo Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

James C.Y. Chow Orthopaedic Center of Southern Illinois, Mount Vernon, Illinois, U.S.A.

Aaron Daluiski Department of Orthopedic Surgery, Hospital for Special Surgery and Weill Medical College of Cornell University, New York, New York, U.S.A.

Charles S. Day Department of Orthopedic Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, U.S.A.

Gregory K. Deirmengian Department of Orthopedic Surgery, Hospital of the University of Pennsylvania, Presbyterian Medical Center, Philadelphia, Pennsylvania, U.S.A.

Drew Engles Summit Hand Center, Crystal Clinic, Inc., Akron, Ohio, U.S.A.

Orrin I. Franko Department of Orthopedic Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, U.S.A.

Alan E. Freeland Department of Orthopedic Surgery and Rehabilitation, University of Mississippi Medical Center, Jackson, Mississippi, U.S.A.

David A. Fuller Cooper University Hospital, University of Medicine and Dentistry of New Jersey, Camden, New Jersey, U.S.A.

Ankur Gandhi Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

William B. Geissler Department of Orthopedic Surgery and Rehabilitation, University of Mississippi Medical Center, Jackson, Mississippi, U.S.A.

Thomas J. Gillon Department of Orthopedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut, U.S.A.

Steven H. Goldberg Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York, U.S.A.

Thomas J. Graham The Curtis National Hand Center, Union Memorial Hospital, Baltimore, Maryland, U.S.A.

Ranjan Gupta Peripheral Nerve Research Laboratory, Department of Orthopedic Surgery, Anatomy & Neurobiology, and Biomedical Engineering, University of California, Irvine, Irvine, California, U.S.A.

Karol A. Gutowski Division of Plastic and Reconstructive Surgery, University of Wisconsin, Madison, Wisconsin, U.S.A.

Scott R. Hadley Peripheral Nerve Research Laboratory, Department of Orthopedic Surgery, University of California, Irvine, Irvine, California, U.S.A.

Douglas P. Hanel Section of Hand and Microvascular Surgery, Department of Orthopedics and Sports Medicine, University of Washington, Seattle, Washington, U.S.A.

James P. Higgins The Curtis National Hand Center, Union Memorial Hospital, Baltimore, Maryland, U.S.A.

Lawrence C. Hurst Department of Orthopedics, State University of New York, Stony Brook, New York, U.S.A.

Igon Indriago Miami Hand Center, Miami, Florida, U.S.A.

Charles M. Jobin Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York, U.S.A.

Min Jong Park Department of Orthopedic Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea

Jesse B. Jupiter Orthopedic Hand Service, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, U.S.A.

Mark L. Kavanagh Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Tosca Kinchelow Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Anthony J. Lauder Department of Orthopedic Surgery and Rehabilitation, University of Nebraska Medical Center, Omaha, Nebraska, U.S.A.

Sheldon Lin Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Frank Liporace Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Christophe L. Mathoulin Institut de la Main, Clinique Jouvenet, Paris, France

Margaret M. McQueen Royal Infirmary of Edinburgh, Edinburgh, Scotland, U.K.

Roy A. Meals Department of Orthopedic Surgery, David Geffen School of Medicine at UCLA, Los Angeles, California, U.S.A.

Kenneth R. Means, Jr. The Curtis National Hand Center, Union Memorial Hospital, Baltimore, Maryland, U.S.A.

Greg Merrell Department of Orthopedics, Brown University School of Medicine, Providence, Rhode Island, U.S.A.

Bruce A. Monaghan Orthopedics at Woodbury, Woodbury, New Jersey, U.S.A.

Sanjiv H. Naidu Department of Orthopedics and Rehabilitation, Penn State University College of Medicine, Hershey, Pennsylvania, U.S.A.

Damon Ng Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

José M. Nolla Department of Hand and Upper Extremity Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, U.S.A.

Jorge L. Orbay Miami Hand Center, Miami, Florida, U.S.A.

Athanasios A. Papachristos Orthopaedic Research Foundation of Southern Illinois, Mount Vernon, Illinois, U.S.A.

Regis L. Renard Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Lance A. Rettig Department of Orthopedic Surgery, Indiana University School of Medicine, Indianapolis, Indiana, U.S.A.

Melvin P. Rosenwasser Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York, U.S.A.

Tamara D. Rozental Department of Orthopedic Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, U.S.A.

David S. Ruch Department of Orthopedics, Duke University Medical Center, Durham, North Carolina, U.S.A.

Vincent Ruggiero Staten Island University Hospital, Staten Island, New York, U.S.A.

Ednan Sheikh Department of General Surgery, New York Presbyterian Hospital/Weill Cornell Medical Center, New York, New York, U.S.A.

Emran Sheikh Department of Orthopedics and Plastic Surgery, Rothman Institute, Thomas Jefferson University, Philadelphia, Pennsylvania, U.S.A.

Joseph F. Slade III Hand and Upper Extremity Service, Department of Orthopedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut, U.S.A.

Scott P. Steinmann Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota, U.S.A.

Robert J. Strauch Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York, U.S.A.

James W. Strickland Department of Orthopedic Surgery, Indiana University School of Medicine, Indianapolis, Indiana, U.S.A.

Kenneth G. Swan, Jr. Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Virak Tan Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

Amel Touhami Miami Hand Center, Miami, Florida, U.S.A.

Yi-Meng Yen Steadman-Hawkins Clinic Vail, Vail, Colorado, U.S.A.

Part I: Introduction

1

Technical Considerations and Anatomical Basis for Minimally Invasive Hand Surgery

Virak Tan and John T. Capo
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Anatomic structures in the hand and wrist lie in close proximity to each other and are critical for precise functioning of the upper extremity. Therefore, minimally invasive surgery (MIS) in this region of the body is of particular interest because of the desire to restore hand function as quickly as possible after a surgical procedure. Oftentimes, the pain, discomfort, and other morbidity associated with surgery are due to the surgical dissection to access the area of interest rather than from the procedure itself. As such, decreased surgical trauma and tissue disruption will lead to decreased postoperative pain and swelling, shorter recovery period, and a faster return to activities of daily living. These advantages not only benefit patients, but also the health care system because most procedures can be done on an outpatient basis; and when required, hospital stays are usually shorter than those for traditional open procedures.

Disadvantages to MIS are the steep learning curve for the surgeon and staff, and higher costs (1). In the early part of the learning curve, MIS is considered more technically demanding than traditional open surgical methods. Surgeons are working in smaller areas through smaller incisions, and need to employ a three-dimensional mental picture of the anatomy. Using instruments like trocars, endoscopes, and cameras requires some degree of "hand–eye" coordination and technological know-how by the surgeon and his or her assistants. Arthroscopic instruments can be more difficult to maneuver and manipulate because the working end is further away from the surgeon's hands. Often, the surgeon is not looking directly at the three-dimensional operative field but at a two-dimensional video screen, which may add to the difficulty of the procedure. Because of this, there is a possibility of causing iatrogenic trauma to surrounding tissue that is not in view of the camera or fluoroscopic image. However, these problems can usually be mastered with training, experience, and precise knowledge of the anatomy.

ADVANCES IN HAND AND WRIST MIS

There have been several factors that have led to advances in wrist and hand MIS. First, improvements in fiber-optic technology (and its use in the arthroscope and endoscope) have enhanced visualization of intra- and periarticular anatomy that previously could not be seen on standard open exposures. At the time of this writing, arthroscopy is generally agreed to be the gold standard for diagnosis of intra-articular wrist pathology (2). In conjunction with improved visualization of the joint, dedicated and appropriately sized arthroscopic instruments have been developed for the surgeon to treat pathologies in the hand and wrist (3). For example, triangular fibrocartilage complex tears can be debrided or repaired through the scope (4). Similar to the larger joints, small joint arthroscopic surgery has gained a place in the upper extremity and continues to push the field of MIS forward.

The mini C-arm image intensifier has also been a major contribution to MIS of the upper extremity, combining superior image quality, ease of use, and relatively low doses of emitted radiation (5–7). A typical mini C-arm has a focus X-ray tube that uses 0.02 to 0.10 mA of current with a tube potential of 40 to 75 kV and a narrow field, resulting in less ionizing radiation than the bigger C-arms. The patient's arm can be placed close to the image intensifier to generate high-quality digital images, yet there is enough room to perform the surgery (Fig. 1). This capacity to perform an operation under dynamic, real-time fluoroscopy allows for percutaneous reduction and fixation of a fracture, thereby lessening the invasiveness of the procedure.

Another area of MIS advancement in the hand and wrist is the development of implants and surgical devices specific to minimally invasive techniques. For example, the MICRONAIL (Wright Medical Technology, Arlington, Tennessee, U.S.A.) was designed to be inserted by percutaneous means through the "bare spot" between the first and second dorsal compartment tendons; it is a rigid fixation device for distal radius fractures and malunions (8,9). For metacarpal and proximal phalangeal shaft fractures, flexible prebent intramedullary nails can be inserted through a small incision at the base of the bone with the aid of a prefabricated awl (Small Bone Fixation System, Hand Innovations, LLC, Miami, Florida, U.S.A.) (10). Minimally invasive carpal tunnel release can be performed with one of several systems (11) that were designed specifically for the purpose of dividing the transverse carpal ligament without violating the overlying skin and subcutaneous tissue, as is done with the traditional open method. Another example of a specially designed instrument is the HAKI knife (BK Meditech Inc., Seoul, South Korea), which was developed for percutaneous trigger finger release (12). In addition, there are other devices that are not described in this book and more that are being developed, which will also contribute to the MIS field.

ANATOMIC BASIS FOR HAND AND WRIST MIS

The wrists and hands are particularly suitable for minimally invasive procedures because for the most part the anatomic structures are subcutaneous. Additionally, tendon excursion is

FIGURE 1 Use of a mini C-arm during percutaneous scaphoid fixation. The C-arm is draped out sterilely and used in the horizontal fashion with the wrist close to the image intensifier side. *Source*: Courtesy of Virak Tan, MD.

of major importance to the function of the hand, and procedures that limit postoperative swelling and tendon adhesions, such as MIS, are of great value. The major neurovascular structures in the wrist and hand are located volarly; therefore, the majority of arthroscopic portals, limited incision surgical approaches and locations of percutaneous Kirschner (K)-wire placement for minimally invasive techniques are situated dorsally (Fig. 2). As such, the extensor tendons are most at risk for injury, but most of these injuries are relatively minor.

Arthroscopic portals are based with respect to the extensor tendons (Fig. 2). The 3/4 portal lies between the third and fourth extensor compartments, and the 4/5 portal is between the fourth and fifth compartments, where there is minimal risk to neurovascular structures. The dorsal ulnar sensory nerve is in close proximity to the 6U and 6R portals, which are located just ulnar and radial to the extensor carpi ulnaris tendon, respectively. The interval between the abductor pollicis longus and extensor carpi radialis longus tendons (at the base of the anatomic snuffbox) is the location for the 1/2 portal, entry point of the MICRONAIL, and radial-sided percutaneous K-wires. Care must be taken in this area of the wrist due to the proximity of the radial sensory nerve and deep branch of the radial artery (Fig. 3). With surgical approaches to the thumb carpometacarpal joint, the radial sensory nerve is still at risk. In most instances, the described approaches for minimally invasive procedures of the metacarpals and metacarpophalangeal joints require only avoidance of the extensor tendons. A mini C-arm may be helpful for localization of the joint or bone.

There are only several minimally invasive procedures that utilize the volar side of the hand. Endoscopic carpal tunnel release is performed with small volar skin incision(s) that is in the corridor between the hook of the hamate and the palmaris longus tendon (Fig. 4). Instruments that are placed too far ulnarly will potentially injure the ulnar neurovascular bundle in Guyon's canal, and those too radial may injure the median nerve. Kaplan's cardinal line serves as a landmark for the distal edge of the transverse carpal ligament and is proximal to the superficial palmar arch (13). For percutaneous trigger release and palmar incisions for drainage of suppurative flexor tenosynovitis, knowledge of the flexor sheath and pulley anatomy is essential (Fig. 5). Studies have demonstrated that the proximal edge of the first annular pulley coincides with the proximal palmar crease in the index finger, halfway between the proximal and distal palmar creases in the middle finger, and at the distal palmar crease in the ring and little fingers (14,15). In the thumb, the metacarpophalangeal crease overlies the middle portion of the A1 pulley, but specific attention must be given to the radial digital nerve because it traverses from ulnar to radial across the metacarpal in close proximity to the pulley (16).

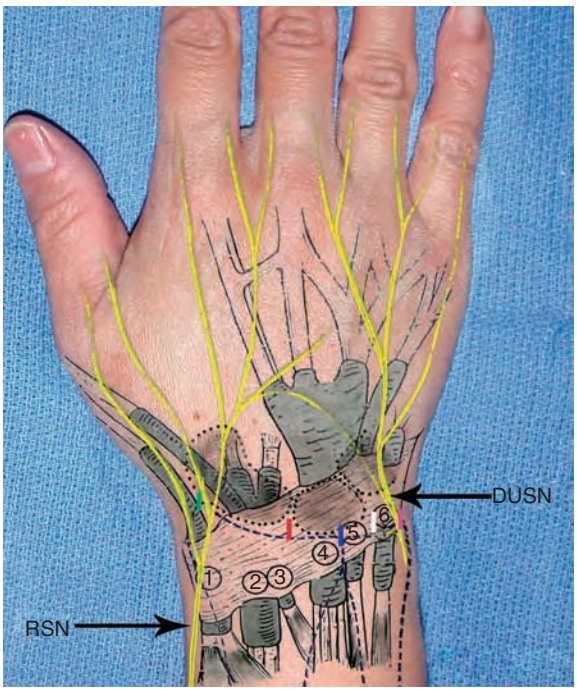

FIGURE 2 Surgical anatomy of the wrist and hand. Injuries to the extensor tendons can be minimized with blunt dissection to mobilize them from the surgical approach. The RSN and DUSN are most at risk of injury at the wrist during radial and ulnar sided approaches, respectively. Portals for wrist arthroscopy are named according to the dorsal extensor compartments: green (1/2), red (3/4), blue (4/5), white (6R) and pink (6U). *Abbreviations*: DUSN, dorsal ulnar sensory nerve; RSN, radial sensory nerve. *Source*: Courtesy of Virak Tan, MD.

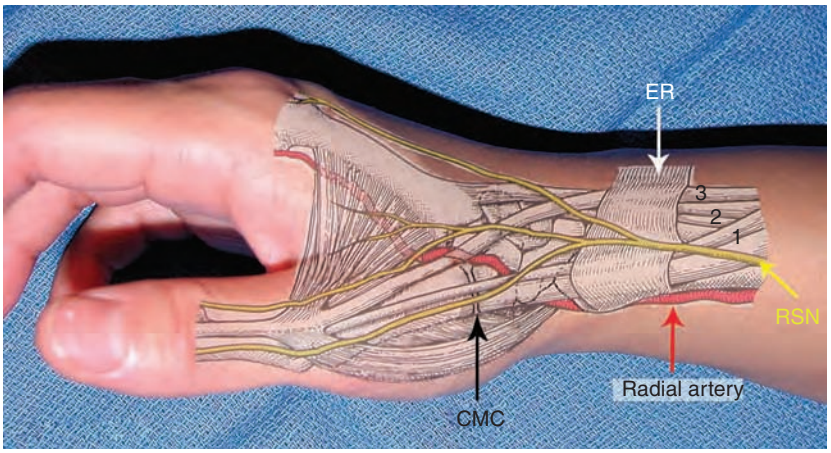

FIGURE 3 Surgical anatomy of the radial side of the wrist, showing the relative position of the RSN in relationship to the extensor tendons and underlying joints. *Abbreviations*: RSN, radial sensory nerve; CMC, thumb basal (carpometacarpal) joint; RA, radial artery; ER, extensor retinaculum. *Source*: Courtesy of Virak Tan, MD.

In the fingers, the mid-axial approach is preferred because it is dorsal to the digital neurovascular bundle. This line is established by connecting the dorsal most points of the interphalangeal flexion creases and extending it over the proximal and distal phalanges (Fig. 6). Staying dorsal to the mid-axial line minimizes the risk of injury to the digital neurovascular structures (Fig. 7).

SUMMARY

The various anatomic structures in the hand are in close proximity to each other and are critical for precise functioning of the upper extremity. The hand and wrist act together as a specialized unit that has multiple functional requirements: fine sensation, prehensile power grip, motion in several planes, and fine dexterity. These requirements rely on the appropriate alignment and integrity of several tissue types, including bone, tendon, nerve, and blood vessels. Operative procedures that can repair and/or reconstruct these structures by minimally invasive techniques with decreased trauma to the tissue and gliding planes will improve and accelerate outcomes. Novel surgical techniques and improved technologies, as described in this book, have enhanced the field of hand surgery.

Factors that have lead to advances in the hand and wrist MIS included: endoscopic/arthroscopic technology, high image

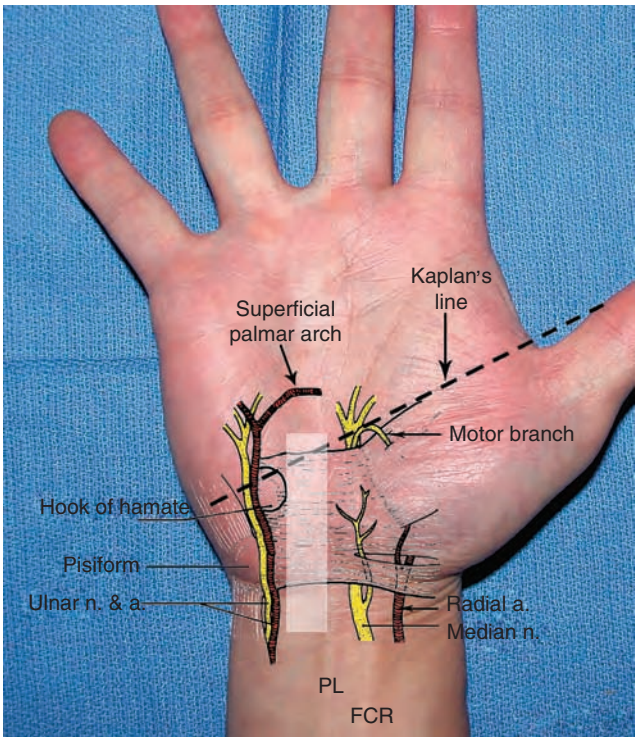

FIGURE 4 Surgical anatomy for endoscopic/minimal incision carpal tunnel release. The "safe zone" is in the corridor (white rectangular area) between the palmaris longus tendon and hook of the hamate. *Source*: Courtesy of Virak Tan, MD.

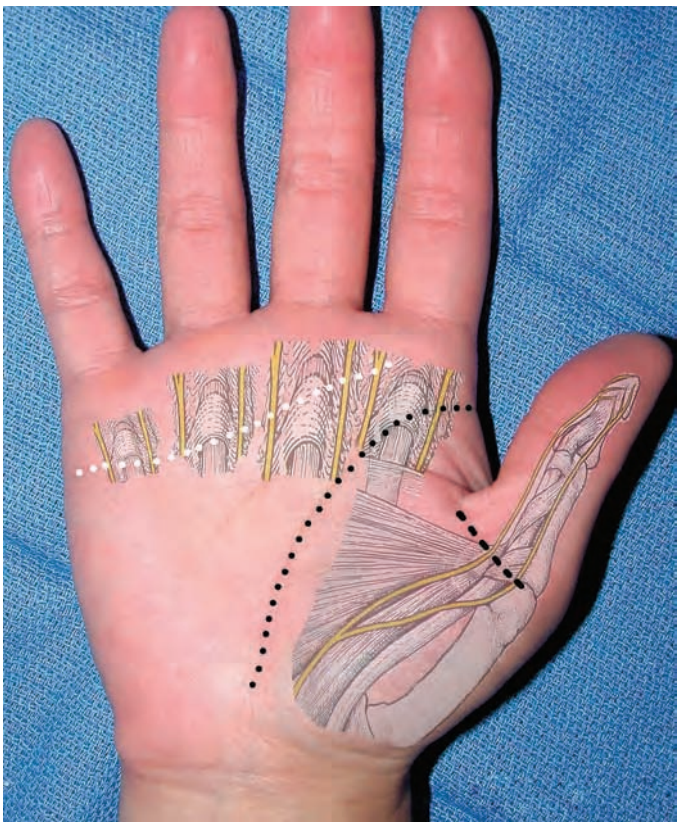

FIGURE 5 Positions of the A1 pulleys relative to the flexion creases in the palm. The proximal edge of the A1 coincides with the proximal palmar crease (black dotted line) in the index finger, halfway between the proximal and distal palmar creases in the middle finger, and the distal palmar crease (white dotted line) in the ring and little fingers. In the thumb, metacarpophalangeal crease (black dashed line) indicates the middle of the A1 pulley. *Source*: Courtesy of Virak Tan, MD.

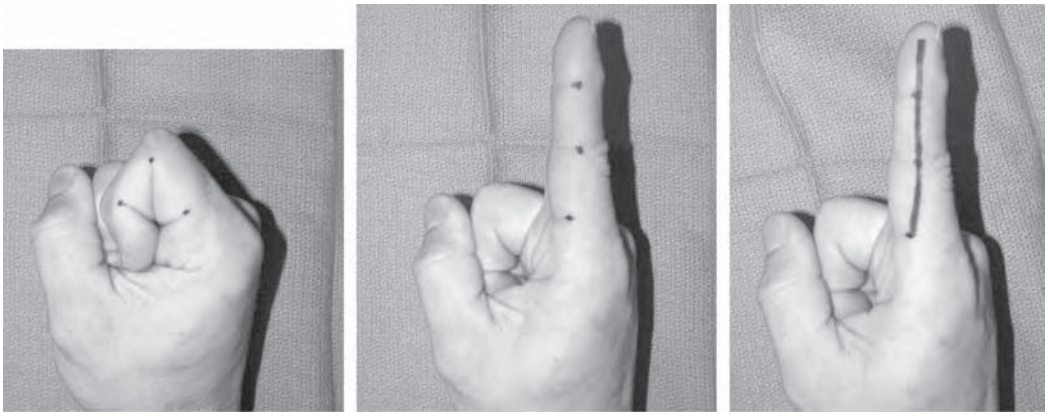

FIGURE 6 The mid-axial line of an index finger. The dorsal most points of the interphalangeal joint flexion creases are marked with the finger flexed (*far left*). The dots are connected, establishing the mid-axial line over the proximal and distal phalanges (*middle and far right*). *Source*: Courtesy of Virak Tan, MD.

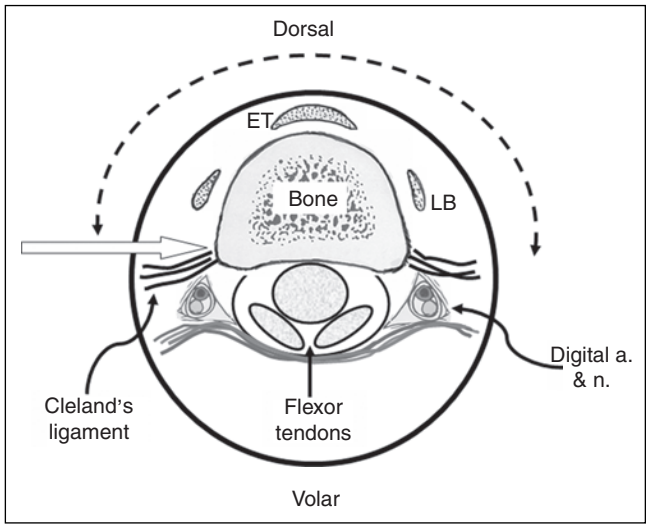

FIGURE 7 Diagram of a cross section of a digit. The mid-axial approach (*open arrow*) is dorsal to the digital neurovascular bundle. Any surgical approach that is in the arc dorsal to the mid-axial line (*dashed line*) carries a low risk of injury to the digital arteries and nerves. *Abbreviations*: ET, extensor tendon; LB, lateral band. *Source*: Courtesy of Virak Tan, MD.

quality mini C-arm, and MIS-specific devices and implants. Although there is a steep initial learning curve, precise knowledge of the anatomy and surgical techniques will allow for safe application of these procedures and faster recovery for patients.

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2

Use of Suture Anchors in Hand Surgery

Aaron Daluiski
Department of Orthopedic Surgery, Hospital for Special Surgery and Weill Medical College of Cornell University, New York, New York, U.S.A.

Virak Tan
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

In hand surgery, it is often necessary to repair soft tissue to bone. Prior to the advent of suture anchors, tissue such as capsule, ligament, or tendon was attached to bone by direct suture to periosteum, or use of bone tunnels with pullout sutures or sutures tied over a bone bridge. Although useful and cost-effective, all of these techniques have a certain limitations and do, at times, require longer or separate incisions and significantly more soft tissue dissection and stripping.

One of the traditional methods of soft tissue reattachment to bone is suturing the soft tissue over a bone bridge. This is performed by creating two or three drill holes in the bone and passing the soft tissue, such as a slip of tendon, or suture on either side of the tunnel and tying it over the bone bridge. If done through the same incision, the skin and soft tissue dissection needs to be extended to gain adequate exposure of the bony cortical surface. Alternatively, the bone bridge can be at the far cortex, but this requires a second incision (Fig. 1). Additionally, the use of the bone bridge is limited to the larger bones of the hand and wrist because creating bone tunnels in small bones carries substantial risks. It is possible to either make the bone tunnels too small for the tendon to pass through, or to make the holes in the bone too large risking fracture of the adjacent bone bridge that is necessary for fixation. These risks increase as the size of the bone decreases. Furthermore, the repair is often bulky, making subsequent skin closure more difficult.

When the size of the bone does not allow for bone tunnels, a button can be used as a substitute to the bone bridge to provide fixation. The use of this technique requires the use of a pullout smooth suture or wire that is placed in the soft tissue in a non-locking fashion. The two ends of the suture are then passed through (or on either side of) the bone, out of the skin and tied over a padded button (Fig. 2). This externally placed button diffuses the pressure across the underlying soft tissue but may still cause skin irritation or breakdown and, in rare cases, damage the superficial nerves in the region. After appropriate soft tissue-to-bone healing has occurred, typically about six weeks, the button is then cut from the suture and the pullout suture removed by traction, that is why it must be placed in non-locked fashion initially. The use of this technique can be technically challenging, often requires more extensive dissection, and cannot be used with a grasping or locking stitch, which can theoretically reduce the overall resistance to gapping of the construct [though there is some data to the contrary (1,2)]. Additionally, there can be poor tolerance by patients.

With the development of suture anchors, stable fixation of soft tissue to bone can be achieved with less technical difficulty, smaller incisions, and minimal dissection. Although benefit to the patient in terms of improved outcomes has been shown only for some procedures (1), there is increasing acceptance of the use of suture anchors for many hand and wrist surgeries. The development of smaller devices has allowed wide use of anchors, from the wrist all the way to the distal phalanx in most patients.

INDICATIONS

The indications for use of suture anchors are identical to the use of any other soft tissue to bone fixation. A variety of common orthopedic hand procedures have been described using suture anchors as a method of repair, including ligament repair or reconstruction (1,3–11) [i.e., metacarpophalangeal (MP) collateral and scapholunate interosseous ligaments], repair of flexor digitorum profundus (FDP) avulsions (1,10,11), swan-neck corrections (12), wrist or digit extensor tendon reinsertion (12), and joint capsulodesis procedures (12–14). The design and manufacture of newer small implants has allowed these devices to be used in essentially all bones of the hand including the distal phalanges (Table 1).

CONSIDERATIONS IN SUTURE ANCHORS

Numerous suture anchors are commercially available for use in the wrist and hand. The most important consideration is the size of the anchor relative to the bone for which it is to be inserted. For the distal radius, anchors should be less than 3 mm in diameter and 1 cm in length. Smaller anchors (in the range of 2.3×5 mm) should be used in the carpal and metacarpal bones and yet even smaller ones in the phalanges.

The surgeon may choose either metallic (nonabsorbable) or bioabsorbable anchors which are usually made of polylactic acid polymers. The decision is based on surgeon preference and comfort level. The advantages of the metal anchors are their sturdiness during insertion and the potentially greater pullout strength. Lack of a metallic implant to obscure x-ray views is a benefit of bioabsorbable anchors. Additionally, in the unfortunate circumstance of suture breakage, the surgeon can overdrill the absorbable anchor and use the same pilot hole in the bone.

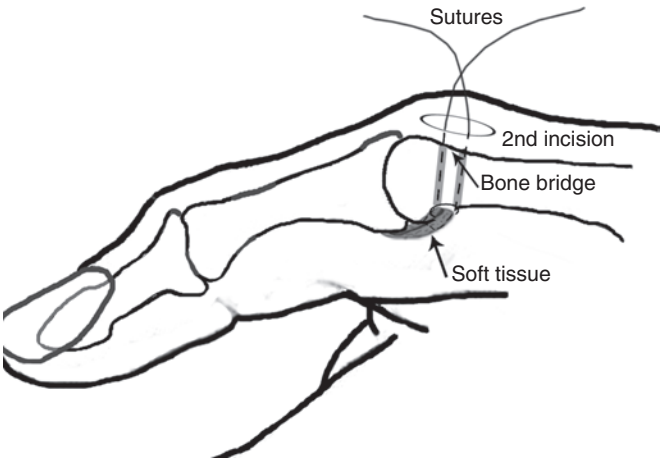

FIGURE 1 Diagram of a typical configuration of soft tissue repair to bone using a bone bridge on the far cortex. *Source*: Courtesy of Virak Tan and Aaron Daluiski.

Another design consideration is the type of fixation of the anchor to the bone. Three basic designs are in use: flanges, toggle, and threaded screw-in. Anchors with flanges operate based on the spring principle in which the flanges collapse in the direction of insertion, but then deploy to embed in the bone when tension is applied in the opposite direction (Fig. 3); some flanged anchors have interference fit. The toggle mechanism works because of eccentric placement of the suture eyelet on the anchor itself. After seating the anchor into the pilot hole, tension on the sutures will rotate (i.e., "toggle") the anchor, wedging it against the sides of the pilot hole (Fig. 4). Threaded anchors are screwed into the bone and purchase is determined by the outer diameter of the anchor, the length of engagement in the bone, the quality of the bone, and screw thread depth and pitch (Fig. 5). The type of fixation has implications when creating the pilot hole. For flange and toggle types, the pilot hole is slightly larger than the diameter of the anchor. On the other hand, a threaded anchor requires a smaller pilot hole than its outer diameter. Bioabsorbable threaded anchors may need tapping prior to their insertion because of the lower strength of the material.

A compiled list of small bone suture anchor devices is presented in Table 1. It should be noted that this is by no means an inclusive list but contains the devices that the authors typically use.

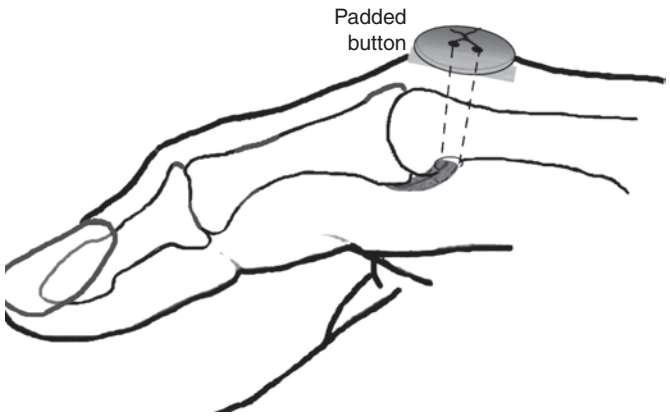

FIGURE 2 Diagram of a typical configuration of soft tissue repair to bone using a pullout suture tied over a padded button. *Source*: Courtesy of Virak Tan and Aaron Daluiski.

GENERAL SURGICAL TECHNIQUE

Regardless of the location, or which soft tissue type needs to be attached to bone by suture anchor(s), the general surgical technique is similar. Once the exposure is performed, the soft tissue of interest is assessed for adequate length, tension, and quality; the end is freshened accordingly. The repair or reconstruction should be done without undue tension or gapping at the soft tissue–bone interface. The bony bed is prepared by lifting the periosteum and abrading the cortical surface to increase the healing potential of the soft tissue to bone. The next step is to select the appropriate size anchor and suture material. For most anchors, the pre-loaded suture can be replaced by the surgeon's choice suture. The pilot hole is created in the bony bed, usually with a drill, making sure to achieve adequate depth in the bone but avoiding penetration into the joint or far cortex. This is followed by insertion of the anchor. Stability of the anchor is checked by pulling tension on the sutures and there should not be any prominence of the anchor.

Suturing of the soft tissue can be done in a number of ways. A common technique is to run a grasping or locking stitch through the soft tissue with one end of the suture, followed by a series of square knots, pushing the tissue down to the bony bed. Alternatively, the second limb is sutured through the tissue in a non-locking fashion and tied down as a mattress stitch. Locking the second limb will prevent sliding of the suture and risks gapping at the soft tissue–bone interface. Tying knots onto the suture anchor in this fashion has a different tactile feel because the tissue is being pushed instead of being pulled down to the bone. To get the "normal" feel of drawing the tissue to bone, two suture anchors can be used. One suture limb from each anchor is sewn through the tissue and tied together. Tension is applied to the free ends of the sutures; thereby pulling down the tissue. Tying is then performed in the usual manner.

Thumb MP Joint Ulnar Collateral Ligament Repair

By far the most common use of suture anchors in hand surgery, as cited in the literature, is repair or reconstruction of the thumb MP joint collateral ligament (Fig. 6) (3–9,12,15,16). After standard regional or general anesthetic agent and prep, a longitudinal incision is made directly over the thumb MP joint along its ulnar mid-axial border under tourniquet control. Initial dissection following the skin incision is meticulously performed to examine for a Stener lesion [i.e., retraction of the ulnar collateral ligament (UCL) proximal to the adductor aponeurosis] which sometimes is apparent at this level. If no Stener lesion is present, the adductor aponeurosis is carefully identified and incised along its ulnar border taking care not to injure the extensor mechanism. Care is also taken to protect the branch of the superficial radial nerve at the volar extent of the wound (Fig. 6A). Once this is complete, the underlying capsule of the thumb MP joint is identified. Oftentimes a frank capsular tear will be present and the UCL exposed.

A dorsoulnar incision in the capsule is made in longitudinal fashion. Great care must be taken in the distal transverse extension of this incision to open the joint, especially when the UCL has been completely torn but a Stener lesion is not present. It is necessary to ensure that the dissection is carried out far enough distal with the longitudinal capsular incision in order not to sacrifice any of the fibers of the UCL. It is often found that the UCL, once ruptured from the base of the proximal phalanx, can scar to the palmar plate making it appear more volar than

TABLE 1 Selection of Small Bone Soft Tissue Fixation Devices

Anchor	Manufacturer	Absorbable	Drill/anchor diameter (mm)	Suture	Needle	Fixation	Deployment
Ultrafix Micromite (Fig. 2)	Conmed Linvatec	No	1.8/1.5	2-0 Nonabsorbable braided polyesther		4 Flanges	Gun-type device
Mini-Revo	Conmed Linvatec	No	1.5/2.7	#2 Nonabsorbable braided polyester		Screw-in	Handheld, screw-in
Minilok Quickanchor Plus	Mitek	Yes (polylactic acid)	2.0	#0, 2-0, 2-0 Panacryl	Os-2 (#0), V-5, or RB-1 (2-0)	Toggle	Handheld, mallet
Microfix Quickanchor Plus (Fig. 4)	Mitek	Yes (polylactic acid)	1.3	3-0, 4-0 Ethibond	V-4 (3-0), C-1, or P-3 (4-0)	Toggle	Handheld, mallet
Mini Quickanchor Plus (Fig. 3)	Mitek	No	2.1	2-0, #0 Ethibond	Os-2 (#0), V-5 (2-0)	2 Flanges	Handheld insertion device
Micro Quickanchor Plus (Fig. 3)	Mitek	No	1.3	3-0 or 4-0 Ethibond	V-4 (3-0), C-1, or P-3 (4-0)	2 Flanges	Handheld insertion device

its typical insertion on the base of the proximal phalanx. In addition, great care must be taken to ensure that the collateral ligament has not healed back upon itself (Fig. 6B). If the fibers are not carefully traced, the ligament may appear much shorter than its true length. If this is not recognized, it may appear as though there is inadequate length for direct repair and a tendon graft may be used inappropriately. It is the authors' experience that it is rare to require a tendon graft for the repair of acute ligamentous (i.e., injuries that are not the result of chronic ligamentous attenuation such as traditional "gamekeepers" injuries) rupture.

Once it is ensured that adequate ligament length is available for repair, the base of the proximal phalanx is prepared by roughening the periosteum and cortical bone (Fig. 6C). The joint is then explored. A suture anchor is carefully placed into the base of the proximal phalanx and checked to ensure that it is adequately anchored to the bone (Fig. 6D). The ligament is then repaired directly to the base of the proximal phalanx. With a single knot placed in the ligament, the ligament is then checked to ensure stability. If it is stable, the stitch is then used to add additional knots between the ligament, periosteum and capsule. The capsule is then closed in a separate layer. Capsular repair adds additional support. Once hemostasis is achieved after tourniquet is deflated, the extensor mechanism and skin are closed are in layers.

REHABILITATION AND OUTCOME

Rehabilitation protocols vary and should be tailored to each specific indication. Repair of an FDP avulsion, which requires early active range of motion, may require implants with stronger pullout strength than UCL repairs of the thumb MP joint, which can be rehabbed essentially tension-free immediately after surgery. Pullout strength of several anchor devices are at least as effective as repair over a button for FDP avulsions (11) and clinical outcomes are similar, with a decreased time of return to work in patients in whom the anchors were used (1).

Clearly, outcome data for each specific operative procedure are dependent on the procedure performed. In general, the use of suture anchors as opposed to traditional techniques has yielded similar or better outcome in part due to the reduced dissection required to achieve good fixation of soft tissue to bone. These findings have not been proven for most clinical uses.

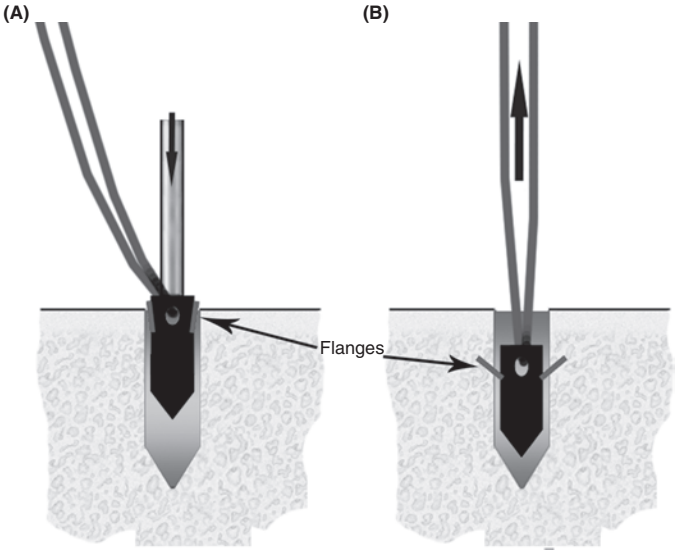

FIGURE 3 *Flanged anchor*. During insertion into the bone, the flanges collapse (**A**). After removal of the handle, with tension on the sutures, the flanges embed into the sides of the pilot hole, resisting dislodgement (**B**). *Source*: Courtesy of Virak Tan and Aaron Daluiski.

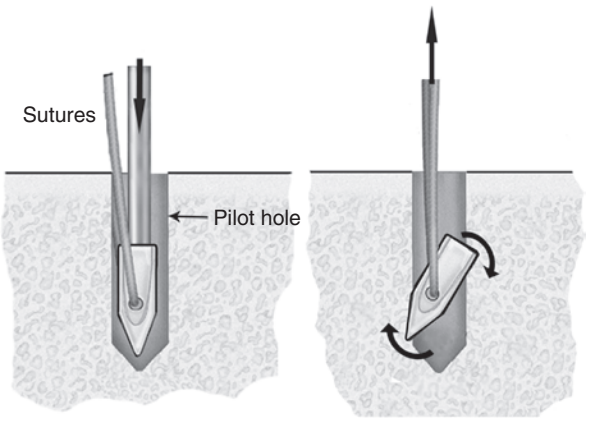

FIGURE 4 *Toggle anchor*. Due to the eccentricity of the eyeslet, tension on the sutures after insertion causes the entire anchor to rotate and embed into sides of the pilot hole, resisting dislodgement. *Source*: Courtesy of Virak Tan and Aaron Daluiski.

FIGURE 5 *Threaded anchor*: It is inserted by screwing it into an undersized pilot hole. *Source*: Courtesy of Virak Tan and Aaron Daluiski.

■ COMPLICATIONS

Complications of suture anchor use are similar to those for the open techniques and are based more on the surgical procedure performed rather than to the actual implant itself. There are, however, some implant-specific complications which are worth noting.

It is important to match the size of the implant, both diameter and length, with the size of the bone into which the soft tissue is being repaired. Use of smaller implants is absolutely required for smaller bones. If not, the implant may be too large for the bone and can cause a fracture. In addition, larger implants tend to have a drill depth commensurate with the size of the implant. Placement of a standard suture anchor volarly in a middle phalanx, for example, will lead to overpenetration of the dorsal cortex and exposure of the implant dorsally. Proper position of the implant should be verified using dynamic fluoroscopy following placement.

Suture breakage, although not necessarily a complication specific to suture anchors, can lead to quite significant

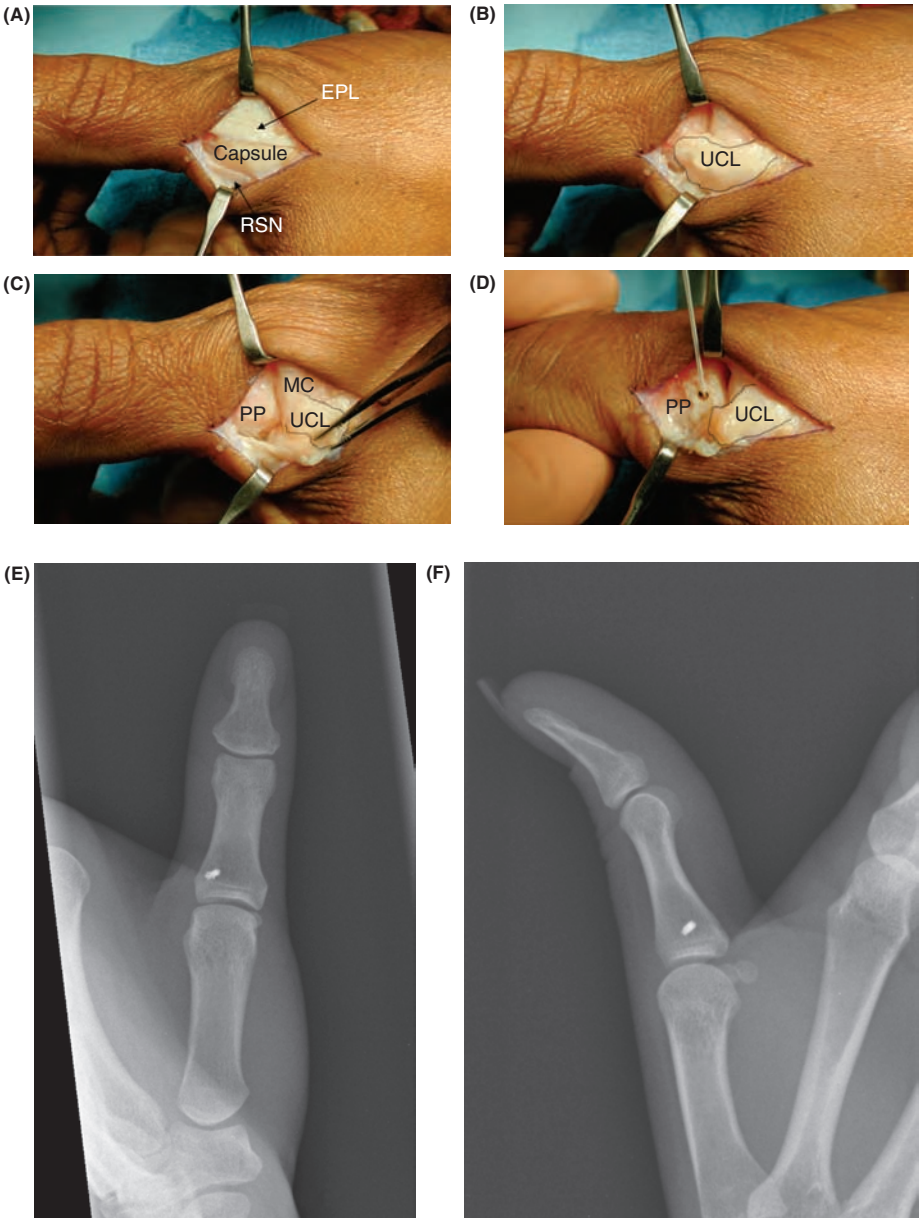

FIGURE 6 Intraoperative photographs of a right hand dominant 20-year-old with an acute left thumb UCL injury. (**A**) After dissection through the extensor mechanism, a single dorsal ulnar capsular incision was made. (**B**) The avulsed UCL was identified. (**C**) The base of the PP was carefully roughened using a #69 blade and rongeur. (**D**) A Linvatec MicroMite suture anchor was placed at the base of the proximal phalanx and the ligament along with the capsule was repaired back to the bone. This afforded an excellent repair with complete stability to radial deviation. The capsule was then closed followed by the extensor mechanism and skin. (**E** & **F**) Post-operative radiographs showing the position of the suture anchor. *Abbreviations*: EPL, extensor pollicis longus; MC, metacarpal; PP, proximal phalanx; RSN, radial sensory nerve; UCL, ulnar collateral ligament. *Source*: Courtesy of Virak Tan and Aaron Daluiski.

complications with the use of these devices. If a suture anchor has already been placed into the bone and the suture breaks, it is often necessary to drill a new hole, which can lead to fracture and destabilization of the soft tissue repair. For certain implants, such as the MicroMite suture anchor (Linvatec Corp., Largo, Florida, U.S.A.), it is possible to carefully tamp the failed implant further into larger bones and utilize the same pilot hole. For bioabsorbable anchors, re-drilling the pilot hole over the anchor is an option. This avoids the need for an additional drill hole and helps minimize iatrogenic fracture. To reduce the chance of suture breakage, it is also possible to replace the suture that comes with the anchor with an appropriately sized Fiberwire (Arthrex, Inc., Naples, Florida, U.S.A.) or equivalent suture, prior to the initial anchor insertion.

Additional complications tend to be more site specific as opposed to implant specific. Although failure of the implant in terms of bone pullout is possible, most of the implants have adequate pullout strength to withstand much of the force exerted on it during the postoperative rehabilitation (2,9,15–17). This is especially true of thumb UCL repairs where it has been shown biomechanically that repaired ligaments have three times the strength than the force that the actual ligament withstands during protected non-pinch rehabilitation (16).

There is a fair amount of attention paid to pullout strength of the suture anchors. Although it is interesting to note differences in pullout strength between different suture anchors, pullout strength is not solely limited to design of the suture anchor but also to the quality of the bone in which it is placed. In addition, since many anchors provide a pullout strength that is above what is required to hold the tissue to bone until it healed, differences between anchors are often not relevant.

SUMMARY

Suture anchors have been a useful adjunct in minimally invasive surgery by limiting the size of the incision and minimizing traumatic soft tissue dissection. They have been extremely helpful in a variety of procedures in the hand and wrist, all related to soft tissue fixation to bone. A host of anchors exist that use drill diameters as small as 1.3 mm, which allow for fixation to essentially all bones of the hand and wrist. Though there is a paucity of clinical outcomes data, numerous biomechanical studies and case series have shown adequate anchor pullout strength and acceptable clinical results. Due to ease of use and limited invasiveness, suture anchors are increasingly prevalent in hand surgery.

SUMMATION POINTS

Indications

- Repair or reconstruction of ligaments
- Repair of flexor digitorum profundus avulsions
- Correction of swan-neck deformity
- Reinsertion of wrist or digit extensor tendon
- Joint capsulodesis

Outcomes

- Similar or better outcome to open procedures to attach soft tissue to bone

Complications

- Similar to those for the open techniques
- Iatrogenic fracture or prominence of implant if the anchor is too large for the bone
- Suture breakage

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3

The Role of Bone Graft Substitutes in Minimally Invasive Surgery of the Wrist and Hand

Vikrant Azad, Ankur Gandhi, Frank Liporace, and Sheldon Lin

Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

The standard technique to facilitate bone healing process is the harvest and application of autogenous bone graft. Iliac crest autograft remains today's gold standard, since it is the only material that contains the three essential bone formation elements: cells, matrix, and critical growth factors. Approximately 340,000 patients undergo iliac crest graft harvesting procedure annually; however, autogenous bone graft comes with significant costs. Harvesting of iliac crest bone can be associated with significant clinical morbidity which includes donor site pain, scarring, increased surgical time, blood loss, and risk of infection. There is also prolonged hospitalization, delayed rehabilitation, and surgical complications, such as iliac fracture, hematoma, nerve injury, vascular injury, lumbar hernia, etc. (1–3). A review of the literature reveals that the complication rate can be as high as 31%, with approximately 27% of the patients continuing to feel pain at 24 months following surgery (4). In addition, the quantity of available graft harvested may be less than optimal. These reasons have led to the development and validation of alternative processes that are capable of replicating the performance of the iliac crest graft, while eliminating the associated complications. A variety of materials have been utilized as substitutes for autologous bone graft. Ceramics are one class of synthetic bone graft substitutes which have been very useful in many clinical orthopedic applications and have served as a useful adjunct to minimally invasive surgery for the wrist and hand.

General Overview of Ceramic Bone Graft Substitutes

Ceramics are highly crystalline materials formed by heating nonmetallic mineral salts to a high temperature in a process called sintering. The porous nature of these compounds provides an osteoconductive scaffold to which chemotactic factors, circulating osteoinductive growth factors, and mesenchymal stem cells can migrate and adhere. This scaffold provides a critical structure for progenitor cells to differentiate into functioning osteoblasts. Besides being biocompatible and bioresorbable, the crystalline structure of ceramics yields a material very similar to natural bone. Synthetic bone graft substitutes have several disadvantages which include a lack of osteogenic cells and the absence of osteoinductive potential normally found in allografts. However, the widespread availability of ceramic bone graft substitutes and the absence of allograft-induced immunogenic response or pathogen transmission provide an increasing incentive for the use of ceramics. In addition, the surgical complications of retrieving bone from an autologous donor site can be avoided (3,5,6).

General Physical Properties of Ceramics as Bone Graft Substitutes

Physical properties such as pore size and porosity are critical parameters of synthetic bone graft substitutes. Blood vessel penetration into the bone graft substitute is necessary for bone-forming cells to lay down new bone while the graft is being resorbed. To allow vascular ingrowth, the graft should have a pore size large enough to allow the vessels to grow into the graft. Previously, pore size was considered to be the most critical variable influencing bone formation within synthetic bone graft substitutes (7). Osteoid tissue forms when the pore size is greater than 100 μm with a pore size of 300 to 500 μm being ideal. Porosity, which is the interconnectivity of pores, is currently considered to be the more critical parameter compared to pore size (8). In the absence of adequate interconnectivity, the pores act like blind alleys with low oxygen tension at the pore apex. The relatively poor oxygen tension impairs the differentiation of mesenchymal cells toward an osteoblast cell lineage and instead leads to differentiation of mesenchymal cells into fibrous tissue, cartilage, or fat (9).

The in vivo degradation of cements has been another area of active research focused on making the degradation rate more predictable and closer to the rate of new bone formation. Ideally, a bone graft substitute is expected to resorb at the same rate as new bone is being synthesized and remodeled. If the rate of resorption is greater than the rate at which new bone can be laid down, the structural integrity of the bone graft substitute will collapse. On the other hand, a slow degradation rate will impede new bone formation resulting in an alteration of the local mechanical properties of bone. For example, hydroxyapatite is a slowly degrading calcium phosphate ceramic. The in vivo degradation of hydroxyapatite occurs over years and traces can be seen in the bone decades after implantation (10,11).

Currently, there are two general commercial formulations of ceramic bone graft substitutes, calcium phosphate and calcium sulfate products. Both of these bone graft substitutes are used in two physical forms, solid (pellets, blocks) and injectable (paste/putty). The remainder of this chapter is dedicated to discussion of these products and their application to minimally invasive surgery of the wrist and hand.

CALCIUM PHOSPHATE CEMENTS

Calcium phosphate exists in three basic ionic combinations with phosphate—tribasic (tricalcium phosphate, TCP), dibasic (secondary calcium phosphate), and monobasic calcium phosphate. Of these three forms, TCP is most commonly used in

the manufacturing of calcium phosphate-based cements. TCP is available in two forms, alpha and beta TCP. Both are high-temperature TCPs with a chemical composition similar to amorphous TCP with alpha TCP being more crystalline than beta TCP (12). Alpha TCP is also more soluble than beta TCP and is a major component of calcium phosphate cements (13). In addition, alpha TCP has been reported to undergo faster degradation in vivo compared to beta TCP (13). However, the literature has also shown that beta TCP can undergo a faster degradation than alpha TCP in vivo (14).

The injectable form of calcium phosphate cement is prepared by mixing various types of calcium phosphates with an aqueous solution. The resulting paste hardens to form a calcium phosphate apatite of low crystalline order and small crystal size similar to the mineral phase of bone. Brown and Chow prepared the first calcium phosphate cement that could be constituted at room temperature using equimolar concentrations of tetracalcium phosphate and calcium hydrogen phosphate (15). Initially, dicalcium phosphate dihydrate is formed with a plate-like morphology which ultimately later yields calcium-deficient hydroxyapatite. All current formulations of calcium phosphate cement are constituted via an endothermic reaction instead of exothermic reaction thereby limiting the potential for local tissue damage.

Calcium phosphate cement hardening occurs mostly within the first six hours, yielding an 80% conversion to hydroxyapatite with a compressive strength of 50 to 60 MPa. Hardening can be accelerated with phosphate solution, sodium fluoride, or sodium hydrogen phosphate. Porosity can be introduced into the bone graft substitute by the addition of soluble inclusions such as sucrose, sodium hydrogen carbonate, or sodium hydrogen phosphate with the goal of improving osteoconductivity (16). The low temperature of formation and the inherent porosity also permit the addition of antibiotics to prevent bone infections or growth factors to stimulate differentiation of mesenchymal cells.

Because the composition of calcium phosphate apatite cements is similar to natural bone apatite, the phosphate-based cement undergoes increased biological degradation compared to calcium sulfate. Experimental studies in vivo have shown that multinucleated osteoclast-like cells surround the implanted cement. At the same time, new bone is formed by osteoblasts and progresses into the scaffold provided by the apatite cements (14,17,18). The average resorption rate of the cement depends on many factors such as the composition of cement, site of implantation, patients' metabolic rate, and general health. Comparing the experimental results of the degradations processes can often be difficult due to the variability in study protocol and design.

CALCIUM SULFATE CEMENTS

Dreesmann used calcium sulfate as early as 1892 for cavitary bone lesions and observed healing in six of nine lesions (19). Peltier did the significant early work on calcium sulfate in bone healing and first described his experience in a preliminary report in 1959 (20). Later, Peltier and Jones reported their long-term follow-up results on 26 unicameral bone cysts of which 24 healed without complications (21). Several other authors have reported their results with the use of calcium sulfate as a bone graft substitute and in general have shown positive results. Despite the early work, in recent years, calcium phosphate-based cements have superseded calcium sulfate in their usage as injectable cement.

Calcium sulfate as a bone graft substitute is available in two chemical forms—calcium sulfate hemihydrate (plaster of Paris) and calcium sulfate dihydrate (gypsum). Calcium sulfate dihydrate produced after hydration of the hemihydrate form is chemically stable and available in solid shapes such as pellets and blocks. Hemihydrate when mixed with a diluent (water, saline, or other liquids) undergoes a hydration reaction to form a putty/paste and is converted into the dihydrate form. In this putty form, the calcium sulfate is injectable until it sets in as solid calcium dihydrate. Special care in the processing of calcium sulfate needs to be maintained in order to produce surgical grade calcium sulfate with a predictable resorption rate and optimal crystalline structure to provide an osteoconductive medium for new bone ingrowth.

The mechanism of calcium sulfate resorption is not well understood but calcium sulfate appears to resorb by dissolution into surrounding body fluids rather than by being actively degraded by cellular mechanisms (22,23). Recent literature has suggested that calcium sulfate may not be osteoconductive and that new bone formation occurs as the cement dissolves, possibly acting as a bone void filler (24). The resorption of calcium sulfate in vivo is rapid and thus not suitable for clinical situations where cement is required to provide structural support. Therefore, calcium sulfate used alone is useful for contained nonstructural defects or as an adjunct to fixation devices to improve their holding strength in bone. Calcium sulfate can also be used as a carrier for growth factors in the appropriate clinical applications (24–26).

INDICATIONS

The indications are still evolving for uses of calcium phosphate and calcium sulfate cements. Clinical experience with these bioactive cements in distal radius fractures and bone lesions (such as simple bone cysts, aneurysmal bone cysts, or enchondromas) is increasing. In the distal radius, these cements are especially useful in fractures with severe comminution, bone loss at the fracture site, or fractures involving osteoporotic bone which are difficult to stabilize. Injectable bone cements, by providing additional mechanical stability, can reduce the immobilization time, allow earlier range of motion exercise and thereby facilitate rapid recovery (27–29).

Bone lesions often require bone graft to fill the defect which may be the result of the primary pathology or from curettage. Use of calcium-based bone graft substitutes in this setting obviates the need to obtain autologus bone graft. Additionally, because the material can be injected into the defect, only a small cortical window is required; thereby, minimizing further compromises to the integrity of the native bone.

A reported complication is extrusion of the cement into the joint. Metaphyseal fractures frequently have subtle intra-articular extensions and the cement when injected under pressure may permeate through these intra-articular extensions. Once in the intra-articular space, the cement can cause persistent pain and wound drainage/infection. Lobenhoffer et al. reported a patient who developed sterile wound drainage with use of injectable cement for a tibial plateau fracture (30). The wound was revised but no cause was found. Due to persistent drainage, a second revision was done and this time on opening the suprapatellar recess, two small pieces of cement was found which were not visible in the postoperative radiographs. After removal of these loose bodies, healing progressed normally.

Cement remaining in the soft tissue can also be a cause of persistent postoperative pain. Kopylov et al. in their study on

the use of injectable calcium phosphate cement in distal radius fractures had two patients who appeared to have more postoperative pain in the wrist. In both the cases, cement was found in the soft tissue (28). Although both calcium phosphate and calcium sulfate have good biocompatibility, several reports of inflammation with their use exist (31,32). Calcium sulfate appears to induce an inflammatory reaction to a lesser degree than calcium phosphate.

SURGICAL TECHNIQUES

Whether the calcium cement is to be used to augment a distal radius fracture or fill a bone lesion, the general technique is the same. Preparation of the cement should be done according to the manufacturers' specific recommendations. Different formulations of the ceramic cements have different mixing and injection times; therefore, it is important that the scrub nurse/-technician is familiar with the system.

The surgical setup, equipments, instruments, implants, and initial portion of the surgical procedure are done as they would be normally. Distal radius fractures are reduced and stabilized, and bone lesions are curettaged, as needed. The bony defect can then be accessed through the surgical incision or percutaneously with a delivery needle. An image intensifier can be used to confirm that the needle is within the void. Saline is irrigated through the needle to evacuate any hematoma. Injection is begun by docking the syringe onto the preplaced needle and backfilling the defect. The needle is slowly withdrawn as fill is achieved. Image intensification is used to ensure that the void is completely filled. Excess material outside of the defect is removed, after which the injected material is allowed to solidify without disturbance. After the material has harden, light irrigation is performed and closure is done per routine.

CASE EXAMPLE

A 43-year-old right-hand dominant male sustained an intra-articular left wrist fracture (Fig. 1). Notable in the history was that he receives hemodialysis (HD) through an arteriovenous shunt in the ipsilateral arm (Fig. 2). Operative stabilization was recommended because of the articular depression and the fact that immobilization of the wrist would preclude use of the shunt for HD. A minimally invasive technique was chosen to minimize postoperative swelling and avoid tourniquet use in that arm. The articular step-off was reduced by use of an elevator through the cortical window in the radial styloid (Fig. 3). After placement of the MICRONAIL (Fig. 4), percutaneous injection of calcium phosphate cement (Norian SRS; Synthes, Paoli, Pennsylvania, U.S.A.) into the metaphyseal bony defect was performed to provide addition support of the articular surface (Fig. 5). Postoperatively, the patient was able to get HD through the arm on the following day because no immobilization was required (Fig. 6).

OUTCOMES

Distal Radius Fracture

Few clinical studies exist regarding the role of calcium cements in the treatment of acute distal radius fractures and those that displaced after conservative management. Cassidy et al.

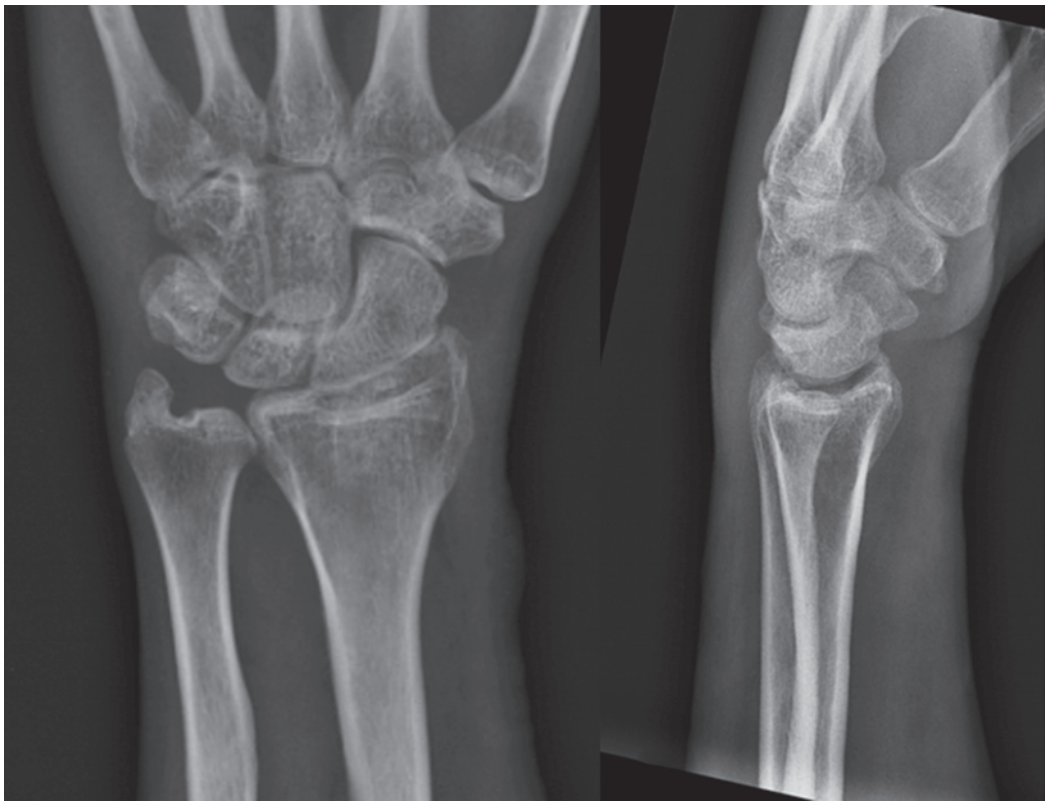

FIGURE 1 Posterior–anterior and lateral radiographs of the intra-articular distal radius fracture of the patient. *Source*: Courtesy of Virak Tan, MD.

FIGURE 2 Clinical photograph of a hemodialysis patient who sustained a distal radius fracture in the ispilateral wrist. *Source*: Courtesy of Virak Tan, MD.

performed a prospective, randomized multicenter study to evaluate closed reduction and immobilization with and without calcium phosphate cement (Norian SRS) in the management of distal radial fractures (33). A total of 323 patients with a distal radial fracture were randomized to a treatment group consisting of a closed reduction and Norian SRS, and a control group consisting of a closed reduction and application of a cast or external fixator. In the treatment group, wrist motion was encouraged beginning two weeks postoperatively while in the control group, the fixator or cast was continued for six to eight weeks. Significant clinical differences were seen at six and eight weeks postoperatively resulting in better grip strength, wrist range of motion, digital motion, use of the hand, and social and emotional function, with less swelling in the patients treated with Norian SRS than in the control group. By three months, there were no significant differences except for digital motion, which remained significantly better in the group treated with Norian SRS. At one year, no clinical differences were detected. Radiographically at six to eight weeks, both groups were equivalent with the exception of the change in ulnar variance, which was higher in the treatment group (2.2 mm compared with 1.5 mm) (33). Similar results were reported by Kopylov et al. in a randomized study on failed conservative treatment of distal radius fractures or redisplaced distal radius fractures (34). The study compared calcium phosphate cement followed by cast immobilization with external fixator alone.

FIGURE 3 Reduction of the articular depression with an elevator placed through the cortical window at the radial styloid. *Source*: Courtesy of Virak Tan, MD.

Sanchez-Sotelo et al. performed a prospective, randomized study on 110 patients older than 50 years with distal radius fractures to compare the outcome of conservative treatment to implantation of moldable bone cement and immobilization in a cast for two weeks (35). The authors reported that patients treated with Norian SRS had less pain and earlier restoration of movement and grip strength. Satisfactory results were demonstrated in 82% of the Norian SRS patients and 55% of the control group. The rates of malunion were 18% and 42%, respectively. Soft-tissue extrusion was present initially in 69% of the Norian SRS patients decreasing to 33% at one year.

Zimmermann et al. performed a prospective study on 52 menopausal, osteoporotic women with unstable intra-articular distal radius fractures to compare the outcome of percutaneous pinning and immobilization in a cast for six weeks to the use of injectable calcium phosphate bone cement (Norian SRS) to supplement pin and screw fixation with immobilization in a cast for three weeks (36). All patients were reviewed on average two years (range 21–29 months) after surgery. The authors reported that patients treated with Norian SRS had better functional outcome, restoration of movement, and grip strength. In the treatment group, there was a 1-mm loss of radial length, a 3° loss of radial inclination and a 7° loss of palmar tilt. In the control group, the radial length decreased by 3 mm, radial inclination decreased by 11°, and palmar tilts by 12°. Loss of reduction was significantly higher in the control group compared with the treatment group.

In a preliminary report, Jupiter et al. reported their results on the percutaneous use of injectable calcium phosphate cement (Norian SRS) in five patients with distal radius fracture (29). The purpose of the study was to evaluate the feasibility of Norian SRS bone cement injected percutaneously into a distal radius following reduction in preventing loss of reduction as well as safety. All fractures were reduced under regional or general anesthesia and the cement was introduced via a catheter system into the metaphyseal defect of the fracture. A short arm cast was applied and remained in place for six weeks. Prospective follow-up at 12 months showed an average loss of <1 mm; radial angle maintained at an average of 25.4°; and volar angle was within the normal range (0–21°) in four patients while one patient had a dorsal angle of 7°. Wrist motion improved 50% between six weeks and three months and improved further by 12 months when grip strength reached a

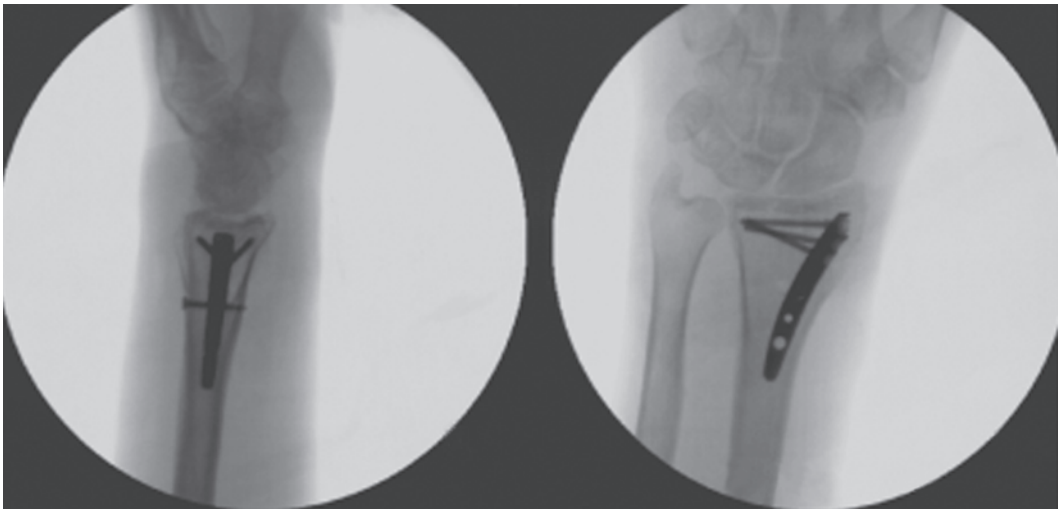

FIGURE 4 MICRONAIL fixation. *Source*: Courtesy of Virak Tan, MD.

mean of 88% of the contralateral side. Dorsal and volar extrusion of injected cement in four patients resorbed over time. There were no clinically significant adverse effects or complications. The authors concluded that cement proved to be clinically safe and effective as a cancellous bone cement to maintain fracture reduction of unstable extra-articular distal radius fractures.

In an unpublished series, Paige (37) augmented 15 patients who underwent internal fixation of unstable distal radial fractures with injectable calcium sulfate bone graft due to dorsal fragmentation and an associated metaphyseal bone void. All patients had prospective evaluation using the patient-rated wrist evaluation (PRWE) form at a minimum of 3 months and again at 6 and 12 months after fixation. The fractures united within 6 to 12 weeks with restoration of anatomical position in a high percentage. The return to functional activities was highlighted by improvement in the PRWE Scores. In summary, the author concluded that volar locking plate fixation may benefit for bone graft substitute augmentation for the more complex, unstable fracture patterns.

Bone Lesions

Injectable ceramic bone cements provide a suitable bone-filling material for cystic lesions since it can be used with minimal trauma to the thin cortical shell around the lesions and also provides immediate structural support.

Few clinical studies exist regarding the use of injectable calcium phosphate bone cements in the management of bone lesions. Joosten et al. reported a one-year prospective study of eight patients with enchondroma who were treated with calcium phosphate cement (BoneSource, Howmedica, Rutherford, New Jersey, U.S.A.) without fixation (38). All patients had a full functional recovery without any complications. In another study, Yasuda et al. reported 10 patients with digital enchondroma (six proximal phalanges, two middle phalanges, and two

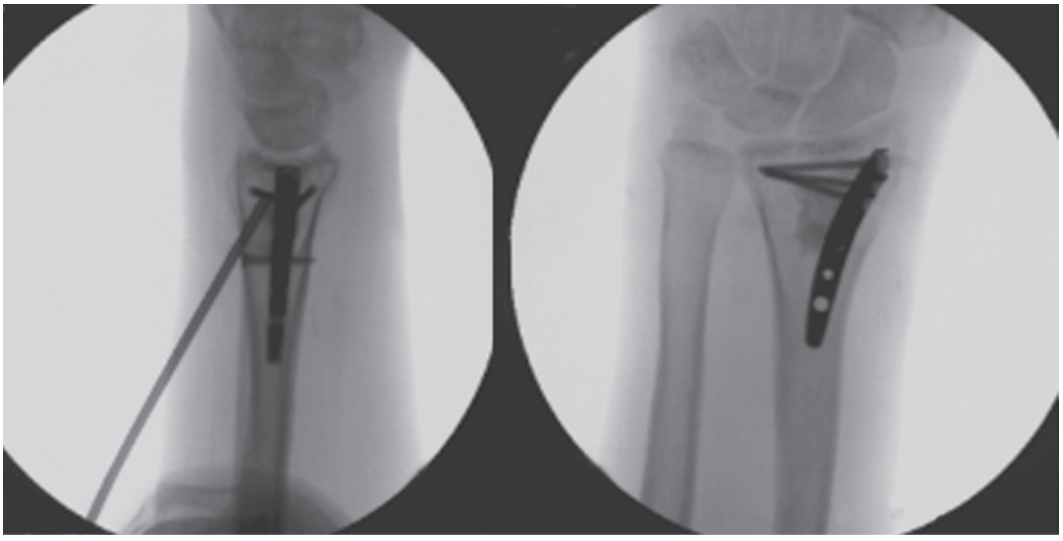

FIGURE 5 Calcium phosphate bone graft substitute cement was injected percutaneously into the metaphyseal defect. The cement appears as a radiodense material on fluoroscopic images. *Source*: Courtesy of Virak Tan, MD.

FIGURE 6 A postoperative clinical photograph showing the incisions for the minimally invasive techniques of distal radius fracture fixation and bone substitute cement placement. There is minimal swelling in the wrist even in this early postoperative time. *Source*: Courtesy of Virak Tan, MD.

metacarpal bones) treated with an injectable calcium phosphate bone cement after curettage of the lesions through a small cortical window (39). No postoperative splint was used and only a bulky dressing was applied. One week after surgery, range of motion exercises were started. Serial radiographs were used to evaluate bony incorporation and absorption of cement. Incorporation of cement (defined by authors as a seamless change of radiographic appearance and no gap between cancellous bone and cement) occurred at an average of 4.5 months (range 3–6.1 months) after surgery. All patients had full range of motion after surgery. All but one patient returned to their ordinary daily activities within four weeks of surgery (39).

In another study, Gaasbeek et al. reported their results with use of plaster of Paris in 19 enchondromas of foot and hand in 19 patients. After thorough curettage of enchondroma lesions, sterile plaster of Paris tablets were used to fill the cavities. After a mean follow-up of 53 months (range 15–139 months), the mean functional Musculoskeletal Tumor Society Score was reported as 29.1 points (97%; range 28–30) and no local recurrence was seen. The authors concluded that plaster of Paris appears safe and effective as a bone-filling substance after curettage of enchondroma (40).

SUMMARY

Ceramic-based synthetic bone graft substitutes, which include calcium phosphate and calcium sulfate, have undergone significant development in the past decade. These bone graft substitutes offer several distinct advantages over autograft and other groups of bone graft substitutes. Though autograft is still the gold standard in bone grafting, significant number of disadvantages exists. The ceramic cements fulfill many of the requirements of an ideal bone graft yet overcome several disadvantages of autograft as well. Because autologous bone does not need to be harvested, by definition these bioceramic substitutes are "minimally invasive."

In recent years, minimally invasive technologies and techniques have revolutionized many types of surgeries. The injectable calcium phosphate and calcium sulfate-based ceramic bone graft substitutes are one more addition to the armamentarium of minimally invasive orthopedic surgery. Injectable cements are generally used as an adjunct to internal fixation for the treatment of fractures or as bone void fillers. The cements harden endothermically which limits tissue damage while developing a compressive strength intermediate between cortical and cancellous bone.

A number of studies have been done to evaluate injectable cements in clinical situations including trauma such as distal radius fractures, tibial plateau fractures, calcaneous fractures, and vertebroplasty, and benign bone lesions such as enchondromas. However, further studies need to be conducted to evaluate the role of injectable calcium sulfate and calcium phosphate cements in the management of bone cysts in the hand and forearm. As new data from preclinical and clinical studies accumulate, the clinical uses of these bone graft substitutes will be expanded and enhanced.

Most studies in general have shown positive results with the use of these substitutes. However, disadvantages do exist for these bone graft substitutes. The cements are known to lack osteogenic or osteoinductive potential and exhibit poor strength under sheer stress. Inflammatory reactions to loose bodies in the joints can complicate their use in a small percentage of patients. Besides these clinical limitations, one practical pitfall which prevents their widespread use is the high cost of injectable cements.

SUMMATION POINTS

Indications

- Distal radius fractures with metaphyseal comminution
- Simple bone cysts
- Aneurysmal bone cysts
- Enchondromas

Outcomes

- Less pain
- Earlier restoration of movement and grip strength

Disadvantages

- Lack osteogenic or osteoinductive potential
- Poor strength under sheer stress
- Extrusion into soft_tissue and joint space may cause inflammatory reactions in a small percentage of patients
- High cost

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4

Bioabsorbable Implants in Hand and Wrist Surgery

Mark L. Kavanagh, Regis L. Renard, and John T. Capo
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Metal implant devices have a long, reliable clinical history, are relatively cheap, and easy to produce and shape. These implants used in hand and wrist surgery also have their disadvantages. Large differences between Young's moduli of the implants and bone often lead to stress shielding resulting in osteopenia which may result in pathologic fractures (1). In addition, elevated stress concentration at the junction of the implants and the host bone may result in periprosthetic fractures. Implantation of metallic devices often requires significant soft tissue stripping which reduces the local blood supply about the implant. This effect is constant during the entire time the implant is in place. Metallic devices also have the potential for corrosion and wear and debris formation with subsequent metallosis (2). Prominent or protruding metallic hardware may interfere with surrounding tissues that disturb joint movement, tendon gliding, or even cause tendon ruptures resulting in pain and loss of function. This effect is particularly important around the hand and wrist. Often times these implants need to be removed. Stern et al. (3) and Berman et al. (2) have reported a need for plate removal in 25% of cases of metacarpal and proximal phalangeal fractures.

An ideal implant would ensure adequate bone fixation, transfer increasing load to bone, not affect skeletal growth, and need not be removed. Bioresorbable implants can avoid problems associated with metal implants, such as stress shielding, corrosion, wear and debris formation, and the need for implant removal (4).

EVOLUTION OF IMPLANTS

During the last few decades, the interest in safe, reliable resorbable implants has steadily increased. The first application of this technology came with the use of bioresorbable polymers in sutures, such as Dexon (US Surgical, Norwalk, Connecticut, U.S.A.) and Vicryl (Ethicon, Somerville, New Jersey, U.S.A.). There are now resorbable implants designed for trauma surgery, including pins, screws, plates, dowels, anchors, and membranes. Bioresorbable implants must meet several biological and technical requirements (4). They must not induce adverse inflammatory or foreign body reactions. The implants must not be carcinogenic, mutagenic, or teratogenic, must not cause allergic, hypersensitive, or toxic responses, and must not activate the complement system (5). Resorbable implants need to maintain adequate mechanical properties in vivo for the desired time and degrade at an effective rate required for bone healing. Mechanical properties are determined by the conditions of polymer synthesis, the processing of materials into implants, and by the sterilization process of implants.

IMPLANT PROPERTIES

Degradation of implants manifest as implant fragmentation, strength loss, and reduction of polymer molecular weight (6–9). Degradation of these implants in vivo proceeds via a bulk hydrolysis of ester bonds that are present in the polymer chain. These materials degrade to monomeric acids and eventually to carbon dioxide and water that are removed from the body via respiratory routes and kidneys during Krebs cycle. Physical factors that affect tissue response to implants include implant shape, physical structure, mass of the implant, stress at the implantation site, and micromotion at the implant–tissue interface (4). Clinically large bulky implants with fast degrading polymers can cause a larger inflammatory reaction when compared with smaller implants with slowly degrading polymers.

The earliest resorbable implants were made from polyglycolic acid (PGA), but this material is relatively hydrophilic and highly crystalline and will degrade and lose its strength very rapidly in the body. It may also give rise to fluid accumulation and sterile sinus formation. This material is no longer used in orthopedic fixation devices.

Today, copolymerization can be used to create implants with different ratios of monomers (D and L monomers) to alter the chemical and physical properties (4,10). The L isomer of polylactide (PLLA) is the material found in most orthopedic implants used today. This isomer has a high degree of crystallinity and is more resistant to hydrolysis. A pure PLLA remains detectable for between 18 months and 4 years in vivo. The D isomer (PDLLA) is amorphous and provides less tensile strength. It promotes resorption of the implants over a longer period of time. Currently, bioabsorbable implants are available in a variety of plates, screws, and smooth pins (Figs. 1–3).

PROCESSING AND STERILIZATION

Self-reinforcing (SR) manufacturing technique enables the processing of bioabsorbable polymers into high strength, high-modulus implants (9,11–13). A high degree of molecular orientation makes the self-reinforced implants stiff and strong in the direction of their long axis, which increases the mechanical strength, modulus, and toughness of the implants. The bending modulus of SR devices is close to that of cortical bone (10–17 GPa), which is important for bone healing (12,14,15). The high bending modulus of metallic implants (100–250 GPa) leads to stress shielding in the bone in loaded areas (13). SR implants also have better handling properties. SR plates can be bent with pliers to conform to the bone at room temperature without significant loss of strength.

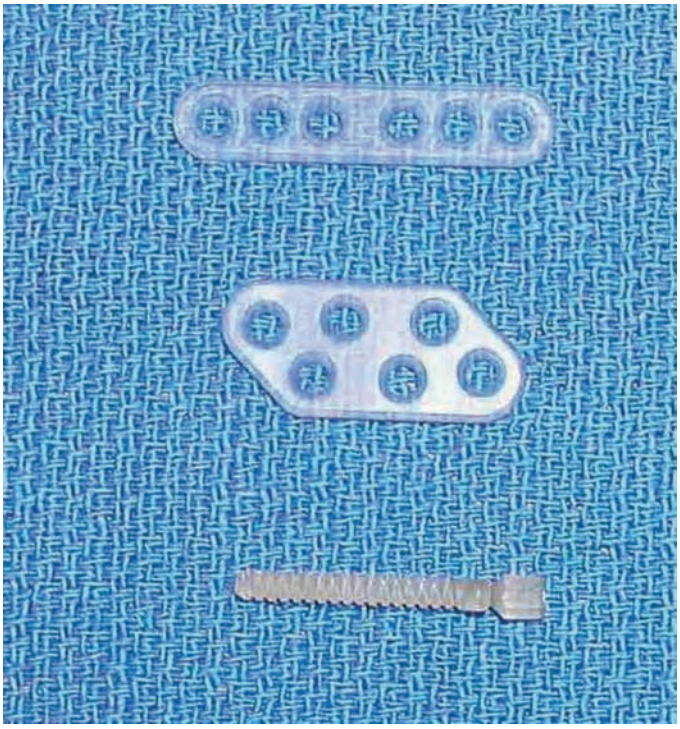

FIGURE 1 Two different sized plates and a bioresorbable screw from the ReUnite™ set (EBI, Parisippany, New Jersey, U.S.A.). These implants are manufactured from a copolymer of 82% L-lactic acid and 18% glycolic acid. *Source*: Courtesy of John T. Capo, MD.

Problems can occur with sterilization of these implants (16,17). High-energy irradiation causes extensive degradation and loss of mechanical properties. Ethylene oxide sterilization does not practically affect mechanical and molecular properties of the implants but there are concerns about residues and environmental problems (17). Newer sterilization techniques now include the use of gamma irradiation due to the potential risks of toxic residues remaining after ethylene oxide sterilization (16).

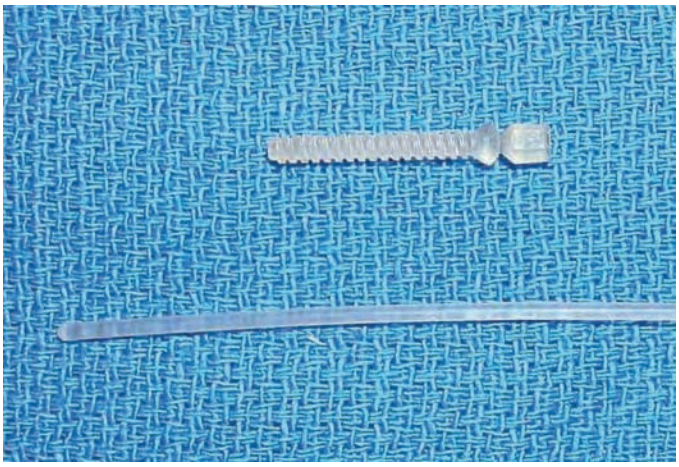

FIGURE 2 A ReUnite screw and smooth pin. The screw head attachment is seen. This hex-shaped end fits into the screwdriver and is sheared off when the screw is fully seated. *Source*: Courtesy of John T. Capo, MD.

FIGURE 3 The ReUnite set contains a variety of metal drill bits, taps, implant insertion instruments, and depth gauges.

EXPERIMENTAL STUDIES

Animal Investigations

Viljanen et al. (14) studied the changes that occur in bones after experimental osteotomies were fixed with absorbable 4.5-mm SR-PLLA screws and 4.5-mm metallic screws the distal femur in rabbits. They found that at 36 weeks, there was a significantly increased amount of external callus with the metallic fixation group when compared with the SR-PLLA group. However, cortical bone mineral density was decreased in the metallic fixation group at both 6 and 36 weeks. Magnetic resonance imagings showed edema surrounding the screws in both groups, however, the size of the edematous zones was significantly decreased in the SR-PLLA group. The authors felt that the SR-PLLA fixation method resulted in more rapid and improved healing due to the physiologic elasticity of these implants when compared with the metal screws. The resorbable implants appeared to prevent stress protection atrophy and weakening of the fixed bone secondary to osteoporosis.

Joukainen et al. (11) studied the strength retention of 2.0-mm SR-PLA 70/30 rods and fixation properties of these implants in rat distal femur osteotomies. In addition, 70 absorbable rods were implanted into the dorsal subcutaneous tissue of 16 rats and three point bending and shear tests were performed after these animals were killed. At 52 weeks, the shear strength and flexural modulus was 41% of their initial value and the flexural strength was 43% of its initial value. Osteotomies in the distal femur were fixed with rods in 39 rats. Macroscopic and X-ray analysis showed that 23 out of 32 subjects (72%) have solid union at the osteotomy site. These authors felt that the mechanical strength and fixation properties of the resorbable rods were adequate for fixation of osteotomies in cancellous bone in rats.

Human Investigations

Pihlajamaki et al. (18) examined the use of SR-PLLA absorbable pins in the fixation of fractures and osteotomies in humans. They reviewed 27 patients with fractures or osteotomies that were treated with internal fixation using bioabsorbable pins. Patients had small fragment fractures and osteotomies of the hand, foot, elbow, and patella. The authors used 1.5- or 2.0-mm cylindrical rods composed of SR-PLLA. There were no wound infections or inflammatory foreign body reactions noted. No redisplacement occurred in any of the patients and the materials were absorbed within two years. Computed tomography scans were obtained in three patients at 15 and 37 months and showed that the pins were no longer visible but no new bone had formed within the drilled channels.

INDICATIONS

Although the literature has yet to clearly elucidate definitive indications for the use of bioabsorbable implants, there are specific times when the use of these implants can be beneficial. In the hand and wrist, there is little soft tissue coverage and the use of a bulky metal implant can be problematic. Using resorbable implants in these cases could be advantageous to minimize final hardware prominence and to avoid a second operation to remove these implants (1,3,19–26). When metal implants are removed, unfilled holes can provide a stress riser for a fracture. As bioabsorbable implants slowly degrade, the surrounding bone is able to fill in such defects.

The use of metal implants around the tendons and joints in the hands and wrist can also pose potential problems. Bioresorbable implants pose less of a problem with encroachment on a tendon or the joint capsule. If a small portion of the implant is within the joint or impinging on a tendon, this difficulty will be alleviated as the implant resorbs.

There are also other times in which a bioabsorbable implant is not an appropriate choice. If the patient has an active infection, the use of any type of implant should be avoided as this would provide a nidus for persistent infection. At this point in time, complex articular fractures that need rigid fixation in order to prevent displacement and to ensure anatomic articular alignment, should be fixed with the more traditional metal implants (5).

SPECIFIC IMPLANTS USED IN FIXATION OF FRACTURES

Metacarpal Shaft Fractures

Surgical Technique

The typical injury is usually a displaced index or middle finger metacarpal fracture in a slender and young individual (Fig. 4). Anesthesia can be performed locally, via regional blockade, or general anesthesia as per surgeon preference. The hand is prepped and draped in standard fashion. A longitudinal dorsal incision should be made over the metacarpal fracture site. The extensor tendon is protected and retracted and the juncturae tendinae are divided if necessary. The overlying periosteum and interosseus muscle are elevated as a flap. The fracture surfaces are identified and fracture ends prepared in standard fashion (Fig. 5A). To improve fracture stability while still keeping the hardware low-profile, we often prefer to place a metal interfragmentary screw first (Fig. 5B). This also makes placement of the plate much easier. A bioabsorbable plate is applied dorsally to the tension side of the metacarpal. The ReUnite™ (EBI, Parisippany, New Jersey, U.S.A.) set has malleable templates available to size and assess the contour of the necessary plate (Fig. 6). The screw holes are drilled and the threads are tapped with metal instruments. The bioabsorbable screws are individually wrapped sterile and come attached to an insertion rod fixed to the head. They are inserted with the appropriate screw driver and the insertion rod is sheared off

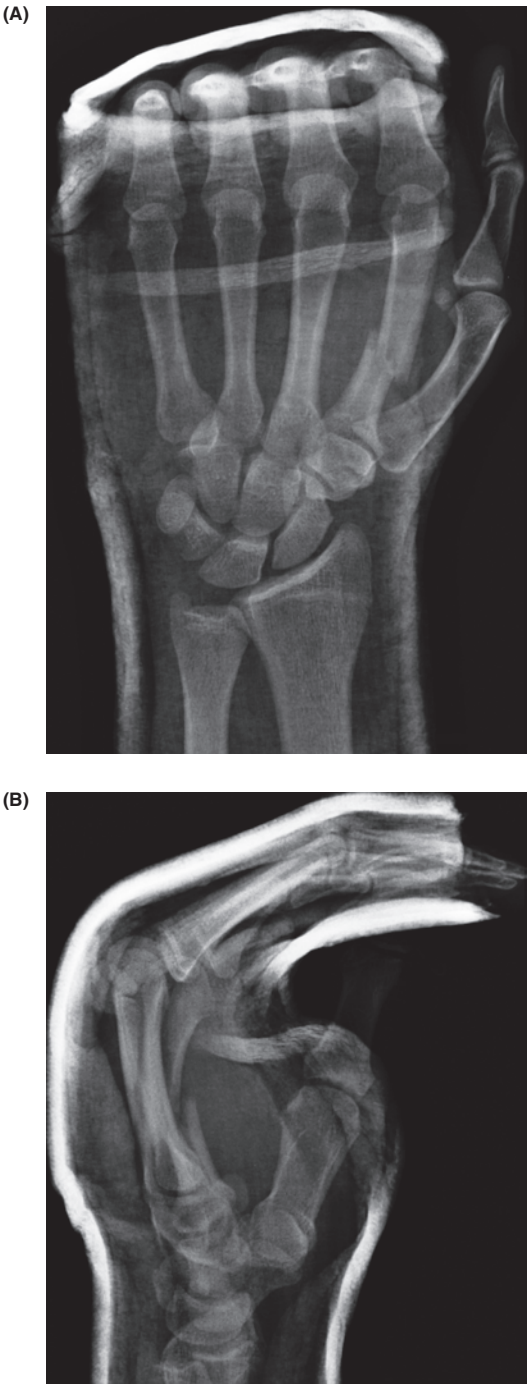

FIGURE 4 (**A**) Anterior–posterior radiograph demonstrating a second metacarpal shaft fracture with shortening and displacement. (**B**) Lateral view shows unacceptable angulation of the fracture. *Source:* Courtesy of John T. Capo, MD.

FIGURE 5 (**A**) Exposure of a mid-shaft second metacarpal fracture through a longitudinal incision. The periosteum and muscle fascia are elevated as a flap. The patient is a 17-year-old boy and this is his dominant hand. (**B**) The fracture is first stabilized with a tenaculum and then provisionally fixed with 1.3-mm titanium screw in a lag fashion. *Source*: Courtesy of John T. Capo, MD.

as the screw is seated (Fig. 7). The final few turns typically achieve a solid bite, but care must be taken not to overtighten the screws as the head can be sheared off. The heads may be flattened somewhat with an electrocaughtery instrument included in the set that melts the material. The periosteum and muscle fascia are closed over the plates to avoid any early tendon impingement (Fig. 8).

Outcomes

Waris et al. (22) compared bioabsorbable miniplating versus metallic fixation for metacarpal fractures, using fresh frozen second metacarpals from cadavers. He tested three point bending and torsional loading after transverse osteotomies were fixed with a variety of methods, including SR-PLLA-PGA 80/20 plating, SR-poly-L/DL-lactide 70/30 plating,

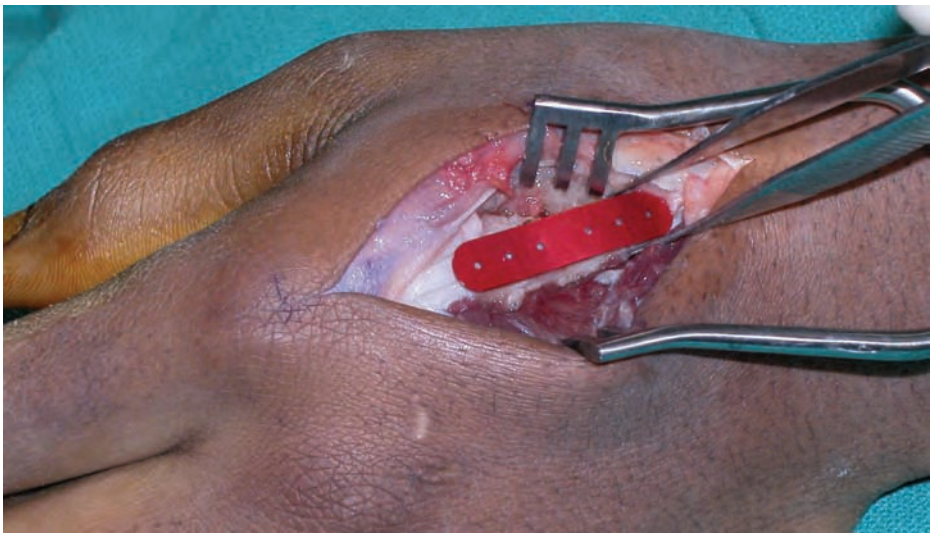

FIGURE 6 A trialing template is placed over the dorsum of the metacarpal to approximate the length of the plate required. *Source*: Courtesy of John T. Capo, MD.

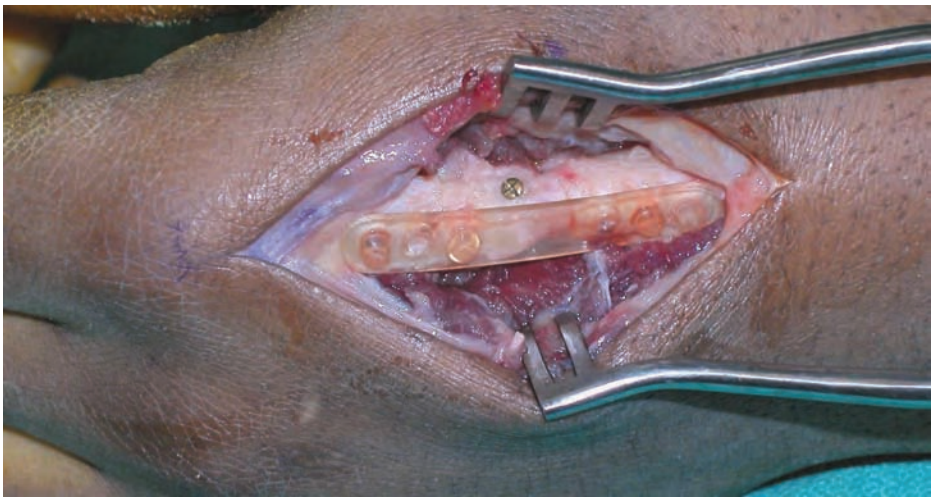

FIGURE 7 The resorbable implant is placed dorsally and fixed proximally and distally with two screws. *Source*: Courtesy of John T. Capo, MD.

titanium plating, and Kirschner (K)-wire fixation. In apex dorsal and palmar bending, dorsal SR-PLLA-PGA 80/20 plating, and SR-poly-L/DL-lactide 70/30 plating provided stability comparable with dorsal titanium 1.7-mm plating. The rigidity and maximum bending moment of 2.0-mm dorsal bioabsorbable plates were higher than those of K-wires. Overall, he found that low profile SR-PLLA-PGA and SR-poly-L/DL-lactide miniplates provide satisfactory biomechanical stability for metacarpal fixation.

PHALANGEAL FRACTURES AND INTERPHALANGEAL JOINT ARTHRODESIS

Surgical Technique

Fracture Fixation

The phalangeal fractures are reduced in a standard fashion and percutaneous pinning is typically performed. With most bioabsorbable pins, a hole needs to be first drilled with a metallic pin. The resorbable rod is then placed into this tract with an insertion device. The insertion device pushes the rod along the hole drilled by the K-wire. This requires rigid stability of the fracture fragments to avoid malalignment of the K-wire path. This at times can be difficult. Recently a new resorbable pin, Trim-It Drill Pin™ (Acumed, Beaverton, Oregon, U.S.A.) has been introduced that avoids this. The pin has an attached metal tip that allows it to be drilled directly into the bone. The metal tip can be cut off on the far side of the bone when possible or can be left on the inner side of the medullary canal to avoid migration.

Arthrodesis

The distal interphalangeal joint is approached through a dorsal Y- or H-type incision. The extensor tendon is divided and the collateral ligaments are elevated. The articular surfaces are removed with a rongeur. Next, the intramedullary canals of the distal and proximal phalanxes are drilled utilizing a drill-bit that is 0.5-mm larger in diameter than the bioabsorbable rod. This is followed by reaming the canals to the size of the implant. The bioabsorbable rod is inserted anterograde into the distal phalanx medullary space. The distal phalanx and intramedullary placed rod is then reduced to the middle phalanx in a retrograde fashion. The extensor tendon, collateral ligaments, and skin are then sutured in standard fashion and the finger is splinted.

Outcomes

Jensen and Jensen (26) investigated poly-*p*-dioxanone (PPD) pins in phalangeal fracture fixation, arthodesis, and osteotomies versus standard K-wires. Their case series compared 11 patients with biodegradable pin devices [four open reduction and internal fixation (ORIF), five arthrodeses, and two osteotomies] to 12 patients (three ORIF and nine arthrodeses) instrumented with K-wires followed over six months. In the fracture-fixation group, the authors reported an earlier return to normal range of motion using the resorbable implants. One out of the four patients with PPD pins required reoperation secondary to loss of fixation. All of the K-wire fracture fixations required additional procedures for hardware removal.

Patients treated with PPD arthodeses had two failures of fusion (40%) and one required re-fusion while the second received an amputation. This is greater than the frequency of failed fusions noted in the K-wire group (22%). One pin tract infection was noted in the PPD arthodesis group versus two pin tract infections in the K-wire group. Thirteen additional procedures were needed to remove the K-wires. This study is promising, but it contains small patient numbers and had a follow-up time of only six months.

Interphalangeal joint arthrodesis utilizing PLLA rods was investigated by Arata and colleagues (27). This case series of 15 distal interphalangeal joints and one interphalangeal joint of the thumb had a follow up of two to 25 months. Successful fusion was noted in all joints by eight weeks. Two patients developed painless localized swelling. No cases of infection, nonunion, or deformity were noted. The authors concluded that PLLA rods can be safely used for interphalangeal fusions.

SCAPHOID FRACTURES AND NONUNIONS

Surgical Technique

The following surgical technique will focus on percutaneous fixation of scaphoid fractures from a volar approach. For more comminuted or displaced fractures, an open technique is more appropriate. The patient is positioned supine and the upper extremity is placed on a standard hand table and a mini-fluoroscopy machine is used to visualize the scaphoid. The wrist is placed over a small towel bump to induce wrist extension. The volar retrograde approach is our preferred entry site for percutaneous fixation of scaphoid fractures.

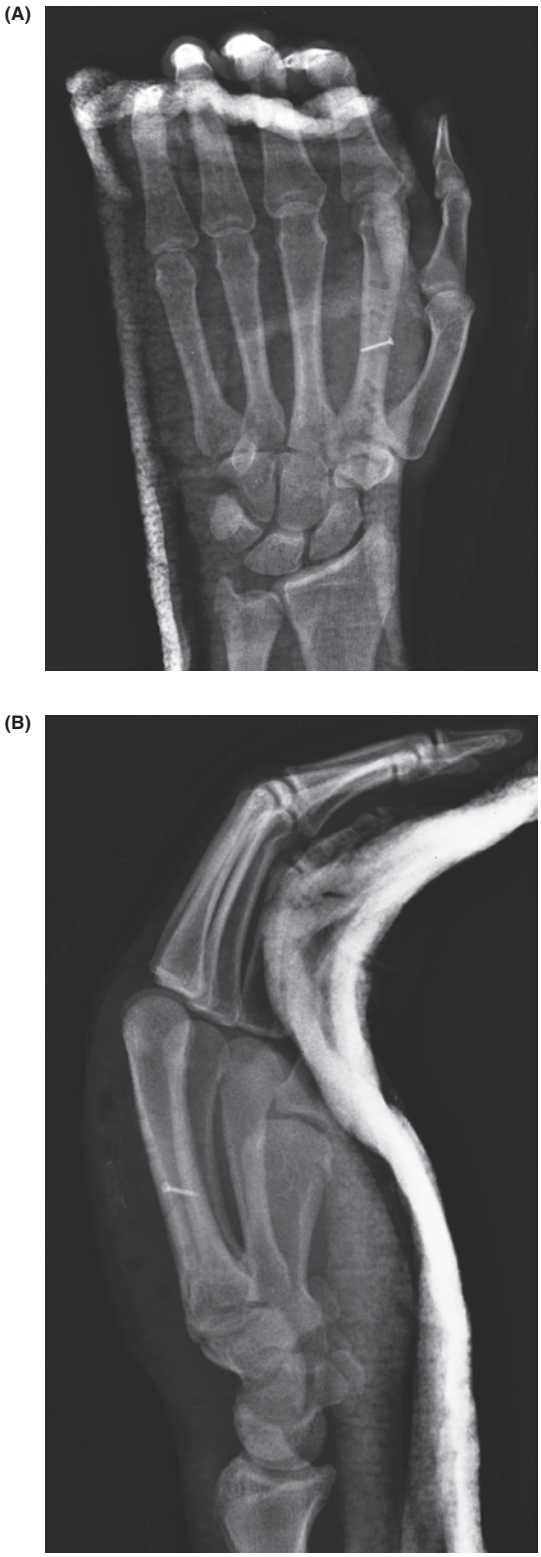

FIGURE 8 Postoperative X-rays show near anatomic alignment of the metacarpal fracture in the (**A**) anterior–posterior and (**B**) lateral views. *Source*: Courtesy of John T. Capo, MD.

The position of the guidewire and final screw is crucial to the success of the procedure. For retrograde insertion, we have found that drilling through the volar corner of the trapezium usually gives the appropriate starting point. The angle is ulnar and dorsal approximately 45° and follows the line of the thumb ray. The guide pin must be in the center of the scaphoid in all views.

Provisional fixation can be obtained with a K-wire, however, it should not interfere with the desired screw location. A small 3 to 4 mm incision should be made at the screw starting point. The drill is then inserted and driven by hand or power. Care should be taken not to overdrill the proximal fragment. If the fragments are unstable or the drill is inducing rotation, a second pin can be placed outside the center of the scaphoid to stabilize the bone. Next, the screw is placed to the exact depth desired. Length should be accurate to ensure that the screw is buried at least 2 mm on both the proximal and distal ends. The goal is to keep the alignment, induce bone healing, and stabilize the entire scaphoid. Typically, one nylon stitch is all that is needed and a thumb spica splint is placed on the extremity.

Currently Available Implants

There are currently two bioabsorbable screws for scaphoid fixation available on the market. Biocomposites, Inc. (Staffordshire, U.K.) makes a product called the Little Grafter and is available for the fixation of scaphoid and various other small bone fractures. It is a 4-mm screw available in a size range of 17 to 27 mm. It can be inserted in a percutaneous method or through an open approach. It is osteoconductive and provides a bioactive scaffold for new bone growth. Arthrex, Inc. (Naples, Florida, U.S.A.) makes a biocompression screw that is also available for fixation of scaphoid fractures. The screw is headless, absorbable and can be inserted either through an open or percutaneous technique (Figs. 9–11). The company recommends inserting the screw from a dorsal approach in an antegrade fashion. The screw is only available in one length with 3.7-mm proximal diameter and 2.7-mm distal diameter. It is composed of a PLLA polymer.

■ OUTCOMES

Bailey et al. (28) studied the biomechanical properties of a new composite bioresorbable screw in a bone model produced from rigid polyurethane. These authors used a bioresorbable cannulated screw composed of PLLA and hydroxyapatite. The study evaluated interfragmentary compression generated by this screw compared with four conventional metal screws. The mean maximum compression forces for the resorbable screw, the Asnis, and Acutrak screws were comparable and no statistical difference was found. The compression forces of the

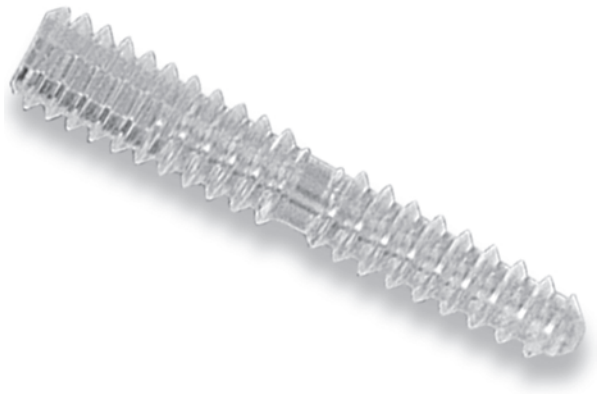

FIGURE 9 The biocompression screw from Arthrex Corporation (Naples, Florida, U.S.A.). It has a conical shape and a variable pitch screw thread. *Source*: Photo courtesy of Arthrex Corporation.

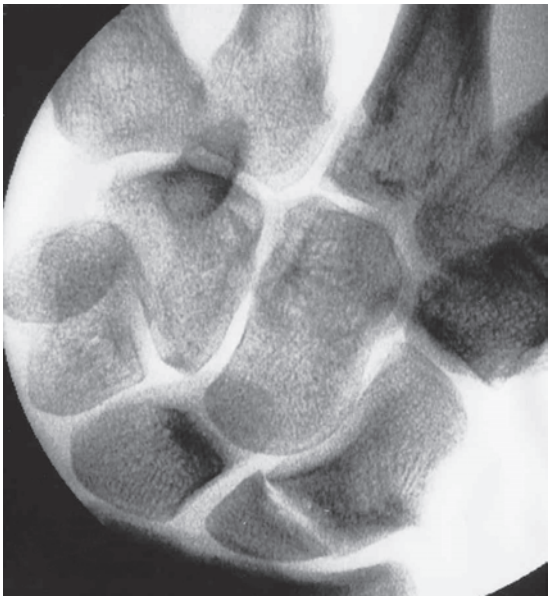

FIGURE 10 Anterior–posterior view of a proximal third scaphoid fracture with unacceptable displacement. *Source*: Photo courtesy of Arthrex Corporation.

Herbert and Herbert-Whipple screws were significantly lower (Herbert 21.8 and Herbert-Whipple 19.9N, Zimmer, Warsaw, Indiana, U.S.A.). The study showed that these bioresorbable screws have good compressive fixation when compared with commonly used small fragment metallic screws.

Kujala et al. (29) examined the treatment of scaphoid fractures and nonunions using bioabsorbable screws. In his study, there were a total of six patients with scaphoid waist fractures (3) or nonunions (3) that were all treated using bioabsorbable SR-PLLA screws.

Interposition of a bone graft from the iliac crest was used in four cases. A solid union was achieved in five cases. The single nonunion was in a previously operated wrist. No infections developed in any of the patients. Using the Mayo-modified Green-O'Brien wrist score, results were graded as excellent in one case, good in four cases, and poor in the single case of nonunion.

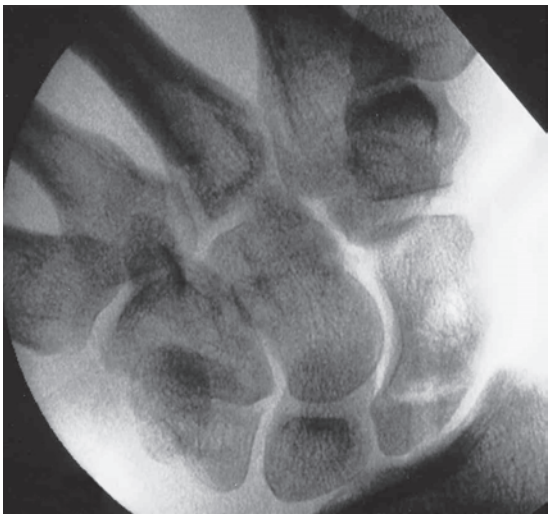

FIGURE 11 Postoperative radiograph of scaphoid fracture stabilized with a resorbable biocompression screw. *Source*: Photo courtesy of Arthrex Corporation.

REPAIR OF ULNAR COLLATERAL LIGAMENT TEARS

Surgical Technique

A lazy S-shaped incision is typically used over the dorsal ulnar aspect of the thumb metacarpophalangeal (MCP) joint. Care should be taken to protect the terminal branches of the superficial radial nerve. The adductor aponeurosis should be incised sharply and the ulnar collateral ligament (UCL) should be identified on or beneath it. Often a Stener lesion is present and the ligament rests superficial to the aponeurosis. Most UCL ruptures occur distally. If the ligament is ruptured distally, a tunnel should be drilled in the proximal phalanx that is perpendicular to the axis of the finger. This tunnel should be approximately 3 to 4 mm from the MCP joint and should be appropriately sized for the tack being used for repair.

Once the tunnel is drilled a 1.1-mm diameter K-wire is used to create a hole in the ligament approximately 3 to 4 mm from its torn end. Next, a bioabsorbable tack should be placed through the ruptured ligament. Once this tack is in place and through the ligament, it should be introduced into the tunnel created in the proximal phalanx. The top of the tack should be pressed tightly against the ligament and cortex. Alternatively, a suture may be attached to the ligament end and then attached to the anchor which is inserted into the drill hole (Figs. 12 and 13). If the ruptured occurred proximally, the previous steps would

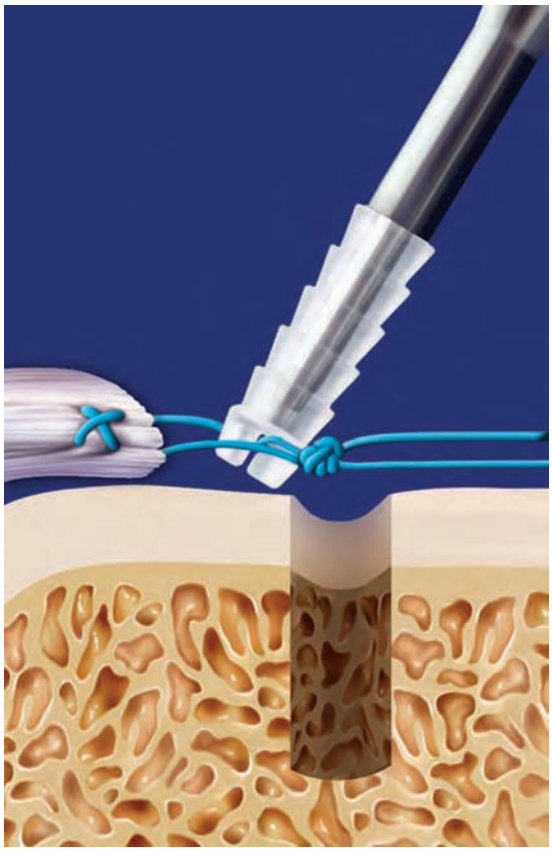

FIGURE 12 A nonabsorbable suture is used to hold the ligament end with a grasping technique. The suture is placed through the anchor approximately 3 mm from the ligament end.

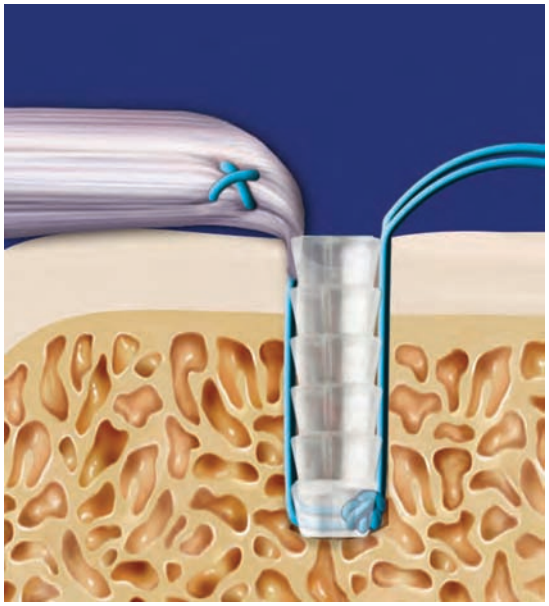

FIGURE 13 The anchor is then inserted into the drill hole bringing the ligament in opposition to the bone surface. The free ends of the sutures may be used to reinforce the repair.

be reversed and a tunnel would be drilled in the metacarpal head approximately 3 to 4 mm from the joint and the ligament would be secured with a tack into the metacarpal head.

Currently Available Implants

Arthrex, Inc. has a system of bioabsorbable anchors (V-Tak™ and Mini V-Tak™, Arthrex, Naples, Florida, U.S.A.) for small joint ligamentous repair. The anchors are available with 2–0 sized nonresorbable sutures and range in sizes of 2.2 mm × 4 mm or 2.2 mm × 7 mm. The anchors are made from proprietarily prepared poly(L-lactide-*co*-D,L-lactide) acid.

Outcomes

Vihtonen et al. (24) examined the use of an absorbable SR-PLLA tack for the repair of ruptured UCLs in first MCP joints. This study has a total of 70 patients with total avulsion of UCL. The authors were able to achieve good or satisfactory results in 66 of the patients. One patient developed a local infection at nine months postoperatively and the tack was removed, and one patient had persistent pain in the scar and required an additional surgery. After reoperation, this patient had normal function without pain.

COMPLICATIONS

Adverse Reactions to Self-Absorbable Implants

There are reports in the literature of infrequent occurrences of fluid accumulation and/or sinus formation associated with local pain, redness, and swelling (8,27,30–32). These are mainly related to older generation of implants made of polyglycolide. Pelto-Vasenius et al. (31) described osteolytic changes that occurred after PGA fixation in chevron osteotomies in metatarsal heads. Postoperative osteolytic changes occurred in 22% (21 out of 94) of patients. At final follow-up, 16 out of 21 patients with osteolysis had complete resolution and 4 had partial resolution. In one patient, the osteolytic changes remained visible at six years. Avascular necrosis with signs of collapse in the subchondral bone occurred in one patient and minor redisplacement (1–2 mm) occurred in another patient. Foreign body reactions occurred in 6.3% of patients. None of these reactions were associated with an infection. Superficial wound infections occurred in 3.2% of patients. These infections healed completely after treatment with antibiotics and none occurred in patients with osteolytic lesions. There was no correlation found between transient osteolysis and foreign body reaction or infection.

Bostman (32) reported on adverse tissue reactions to bioabsorbable fixation devices in 2528 patients operated on using pins, rods, bolts, and screws made of PGA or PLA. A clinically significant local inflammatory, sterile soft tissue reaction was seen in 108 (4.3%) of the cases. In 107 patients, the reaction was due to a PGA implant (5.3% of 2037 patients) occurring at an average of 11 weeks postimplantation. In four patients, a severe reaction, which caused extensive osteolytic lesions in the implant tracks, occurred with subsequent arthrodesis of the wrist or ankle due to severe osteoarthritis. Only one patient had a reaction due to a PLA implant (0.2% of 491 patients) 4.3 years after surgery.

SUMMARY

Using bioabsorbable implants to treat fractures of the hand is of special interest because the applied mechanical stresses are relatively low and subsequent surgical removal of traditional metallic hardware can be avoided. Modern SR manufacturing techniques allow bioabsorbable devices for osteofixation that possess high strength, formability with controlled degradation, and offer a useful option to treat small bone fractures of the hand. Resorbable pins and screws are being increasingly used in the treatment of fractures and osteotomies of the extremities, including metacarpal, phalangeal, and scaphoid bones. Early data suggest that bioabsorbable implants have similar clinical success as metal implants, and can be used effectively to treat fractures in the hand and wrist.

Bioresorbable implants are ideal as they ensure adequate bone fixation, transfer increasing load to bone, do not affect skeletal growth, and do not need to be removed. These implants also avoid problems associated with metal devices, such as stress shielding, corrosion, wear and debris formation. Reported complication rates are low, but include sterile sinus tract formation, osteolysis, synovitis, and hypertropic fibrous encapsulation. Currently, further clinical studies are needed in order to determine in which specific situations these implants have the best indications.

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5

Use of Cannulated Screws in Hand and Wrist Surgery

Drew Engles
Summit Hand Center, Crystal Clinic, Inc., Akron, Ohio, U.S.A.

INTRODUCTION

Recent advances in instrument and imaging technology have revolutionized how hand surgeons treat the entire spectrum of upper extremity ailments and injuries. Many of these previously daunting conditions are now amenable to minimally invasive techniques.

Minimally invasive surgery has long been the purview of orthopedic surgeons. Arthroscopic procedures predated most endoscopic advances in the other surgical disciplines. Additionally, the use of cannulated screws has been prevalent for decades (1). More recently upper extremity surgeons have applied these techniques, either alone or in combination to address injuries and disorders specific to the hand and carpus.

This chapter deals specifically with concepts critical to the appropriate application of cannulated screw technology in upper extremity surgery. Obviously, any technique has specific indications as well as limitations. At times these limitations are a function of the human anatomy and the biological properties of its components. For instance there are obvious biomechanical differences between cancellous bone and cortical bone. There also exist age related constraints when injuries are adjacent to epiphyseal or physeal structures. Finally the implant or its delivery system may preclude its utilization in certain situations.

Advances in imaging technology have coincided with these breakthroughs in upper extremity care. Specifically, small scale low-intensity fluoroscopy systems, with direct digital conversion capability can provide excellent osseous imaging. The availability of this high resolution fluoroscopy has helped support the wide spread implementation of these orthopedic advances.

BASICS OF SCREW CONFIGURATION

To optimally utilize cannulated screws in hand and wrist surgery, one should have a working knowledge of screw design and geometry. Many of the variables in screw geometry affect their biomechanical properties and influence their clinical performance and their application. The basic terminology of screw geometry and configuration are provided here for review (Fig. 1).

Major Diameter

The diameter of the crests of an external straight thread measured orthogonal to the screw axis.

Minor Diameter

The diameter of the roots of an external straight thread measured orthogonal to the screw axis.

Pitch

The distance between two points on adjacent thread forms measured parallel to the screw axis and on the same side of that axis.

Thread Length

The distance measured from where the thread pattern begins to where it terminates measured parallel to the axis of the screw.

Thread Depth

The distance between the crest of an external straight thread and the root of an external straight thread measured orthogonal to the axis of the screw axis and on the same side of that axis.

Shaft Length

The distance from the base of the head to the tip of the screw measured parallel to the axis of the screw.

This nomenclature becomes extremely important when comparing the mechanical properties of different screw designs.

MECHANICAL PROPERTIES OF SCREWS

The mechanical properties of screws are a direct function of both their material composition and their geometric design. Several reproducible methods are available to study these properties. Using this knowledge a design team can optimize those characteristics which will be most advantageous for the intended application of the device. The mechanical characteristics most applicable to the orthopedic clinician are pullout strength, torsion to failure, stripping torque, bending strength, and compressive force (2,3).

The first four properties are important in that they quantify under what applied loads screws fail. Pullout strength quantifies at what maximum load a screw dissociates from the material into which it has been inserted. Torsion to failure typically is performed inserting a screw into a material of greater strength and with a finite depth and then applying a torque to the screw until it fails. Typically the maximum torque achieved before failure and the site of failure are recorded for comparison (2). Stripping torque refers to the maximum torque applied prior to the screw stripping out of the material into which it was inserted (2). Bending measures the deformation of a screw as an outside load is applied. Several different types of bending studies can be performed. They include three point bending, four point bending, and cantilevered bending. The data collected yield a stress/strain curve. Information garnered from this curve includes yield point, stiffness, and ultimate strength. The yield point signifies the point at which permanent deformation of the material or implant occurs. The ultimate

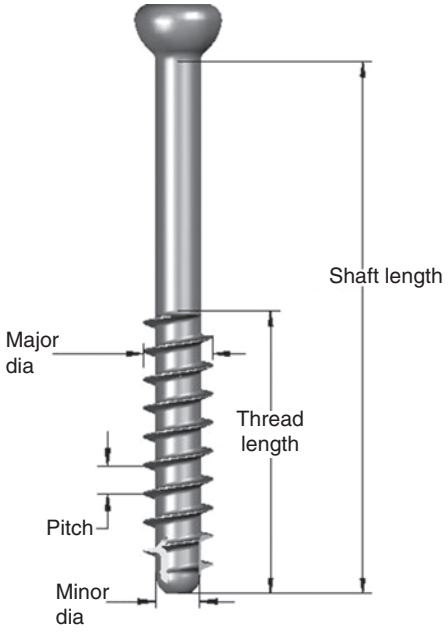

FIGURE 1 Computer Aided Design (CAD) diagram of a cannulated screw. *Source*: Courtesy of OrthoHelix Surgical Designs, Inc.

strength is the maximal load that the screw can withstand before breakage. Material fatigue can be determined by cyclically loading the implant until failure (or a predetermined degree of deformation occurs) (4). Compressive force measurements allow for analysis of compression that a screw is able to produce with in a given substance.

Some studies utilize cadaveric bone while others utilize synthetic bone substitute because of its reproducibility, lower cost, and availability. Multiple authors have shown that synthetic bone is satisfactory for simulating real bone in biomechanical experiments. In some instances, its homogeneity makes it more suitable for certain experimental designs.

BIOMECHANICAL EVALUATION OF CANNULATED SCREWS

The biomechanical evaluation of screws is of importance in that it allows the design engineer to study how permutations in screw geometry and material composition affect screw function. The following discussion provides a review of biomechanical analyses regarding various properties of cannulated screws. In 1991, Dr James Shaw studied the biomechanical properties of four different screws (5). This was actually a follow-up study to his original paper which evaluated the Herbert screw (6). In this second paper, he compared the compressive forces generated in a simulated bone model using a custom designed load cell. The four screws studied were the Herbert screw (Zimmer), the Herbert/Whipple cannulated screw, the Arbeitsgemeinschaft fiir Osteosynthesfragen/Association for the Study of Internal Fixation (AO/ASIF) 4-mm cancellous screw (Synthes), and the AO/ASIF 3.5-mm cannulated screw (Synthes). He found that the Herbert/Whipple cannulated screw and the AO/ASIF cancellous screw were able to generate comparable compression which was almost five times that of the Herbert screw. The AO/ASIF 3.5-mm cannulated screw was able to generate a compressive force nearly 2.5 times that of the Herbert screw.

In addition to these compression studies, Carter and colleagues evaluated bending properties of several screws. Specifically, they studied the bending rigidity, and the bending moment at failure, for experimental scaphoid osteotomies that were fixated with a pair of parallel placed 0.045-inch Kirschner (K) wires, a Herbert screw or an AO/ASIF 3.5-mm cannulated screw. They found that, when compared to the K-wires on a matched pair basis, both screws were statistically stronger in resisting bending forces (7).

In 1997, Toby and colleagues noted that the Herbert screw remained a popular choice for scaphoid fixation, despite the reports that it possessed less compressive force and pull-out strength than other screws. They therefore elected to study Herbert screw performance, with respect to ramped intensity cyclical bending loads, when compared to four other commercially available cannulated screws (8). These screws included the Herbert/Whipple screw, the AO/ASIF 3.5-mm cannulated screw, the Acutrak cannulated screw (Acumed), and the Universal compression screw (Howmedica). They found that the AO/ASIF, Acutrak and Herbert/Whipple screws all fared better at withstanding ramped cyclical bending forces than did the Herbert screw. The AO/ASIF and Universal compression screws provided the most stable constructs. However, the Universal compression screw did have a propensity for fracturing bone at the insertion site of the scaphoid (2 out of 6 trials). The test was then extended to evaluate the AO/ASIF screw and the Herbert screw under the same parameters but with a segment of the volar cortex removed from the scaphoid. With this alteration, both screws showed a significant decrease in ability to withstand ramped cyclical bending forces.

A subsequent study, comparing the Acutrak cannulated screw, an AO/ASIF 4-mm cancellous screw, and the Herbert screw was performed (9). This study once again showed both the Acutrak and the AO/ASIF screws to have superior characteristics than the Herbert screw with respect to fragment compression in both synthetic and cadaveric bone. When compared to the AO/ASIF screw, the Acutrak screw was able to maintain better compression after cyclical loading and it was able to maintain fragment contact at higher levels of torque.

In 2000, Brown and colleagues published a study evaluating solid and cannulated screws (3). They measured the mechanical characteristics of five screws from three separate manufacturers. Their findings supported the prior work of Chapman where thread length, major diameter, and thread shape factor were correlated to pull-out strength (10). In fact, their predicted pull-out strength correlated to observed pull-out strength with an r^2 value of 0.90. They used the equation developed by Shigley for their stripping torque calculations (11). Furthermore, they reported that, in both theoretical models and in actual mechanical testing, cannulation alone did not inherently impair 4.0-mm screw mechanical function.

The adjunctive use of a threaded washer with the AO/ASIF 3-mm cannulated screw was studied by Lo and colleagues in 2001 (12). They felt that the 3-mm cannulated screw, used in conjunction with the threaded washer, provided compression similar to that previously described by Rankin for 3.5-mm cannulated and solid screws (6).

More recently several authors have looked into the biomechanical properties of smaller diameter (2 and 3 mm) cannulated screws. Kissel and colleagues studied the pull-out strength of 2-, 2.4-, and 3-mm Osteomed cannulated and solid screws as well as 2-, 2.5-, 3-mm Vilex cannulated screws (13). In the 2-mm group, there were no statistical differences in the pull-out strength comparing cannulated and solid devices. In the 2.4/2.5-mm subset, the cannulated screws had significantly ($P < .05$) higher pull-out strengths than their noncannulated counterparts. The cannulated Osteomed screw revealed a

significantly ($P < .05$) greater pull-out strength than the other two 3-mm devices.

The most recent analysis of smaller diameter cannulated screws evaluated the AO/ASIF 3-mm cannulated cancellous screw (in conjunction with a threaded washer), the AO/ASIF 2-mm cortical screw, the Mini-Acutrak screw and the Herbert/Whipple screw (14). Compressive forces were measured in a synthetic bone model. The 3-mm AO/ASIF screw generated the most compression, nearly twice that of the 2-mm screws. The Mini-Acutrak (Acumed) and Herbert/Whipple screws were found to generate similar compression, which was approximately 70% of that of the 3-mm cancellous cannulated screw. The authors pointed out that, despite its small diameter, the Mini-Acutrak screw was equivalent in compression strength to the Herbert/Whipple and within 30% of that of the 3-mm cannulated cancellous screw and threaded washer combination.

Careful review of these studies provides sufficient scientific evidence for the use of the latest generation of cannulated screws with the confidence that they possess sufficient strength and provide adequate compression for hand surgery applications.

TECHNICAL CONSIDERATIONS IN CANNULATED SCREW PLACEMENT

The use of cannulated screws has several advantages over solid screws. First, guide pins can be inserted and then their position verified by fluoroscopic techniques before drilling (Fig. 2). This then allows for more precision in the use of the drill, typically with a single pass and thus with less chance for errant passes and potential loss of bone stock. Secondly, the screw is then placed over the guide pin and the potential for angular mismatch between the implant and the far cortex or subchondral resting site is obviated. Thirdly, screw length can be determined by measuring off of the guide wire whose length and position have already been fluoroscopically determined. Additionally, the guide pin offers a precise fit between the screwdriver and screw head even in deeper tissues where visualization may be limited.

From a physiologic stand point, cannulated screws can often be placed percutaneously or through a limited incision. This decreases tissue trauma, periosteal stripping, and potential dead space creation. One would hypothesize that this decreases the degree of scar formation, preserves blood supply to fracture fragments, and reduces the potential for hematoma formation.

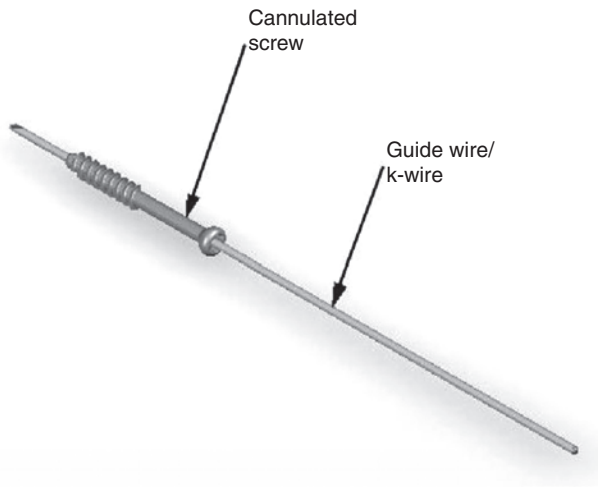

FIGURE 2 Computer Aided Design (CAD) diagram of cannulated screw and guide wire relationship. *Source*: Courtesy of OrthoHelix Surgical Designs, Inc.

With respect to fracture reduction, the guide pin itself can provide provisional fixation. Additional dissection for clamp or tenaculum placement may be avoided. With the placement of a second guide pin, rotational control can be obtained. If the fracture fragment is too small to accommodate a second screw, the guide pin can be left in place as either a temporary or potentially permanent implant. This concept is often used in the treatment of radial styloid fractures (15).

In using cannulated screws several concepts are important to maintain. It is imperative that reduction be obtained prior to guide wire placement. The addition of a second pin, even temporarily, to augment reduction and prevent rotation, is often required for optimal management of the fracture. When measuring off of the guide pin, for screw length, it is important to take into account not only counter sinking of the head, when necessary, but also anticipated compression. If the screw size selected abuts subchondral bone on the distal side of the far fragment and then significant fragment compression is achieved, the screw tip may eventually rest in either the articular cartilage or within the joint space.

It is often of benefit to advance the guide pin slightly after the screw length measurement has been taken. This will prevent drilling beyond the guide pin and accidentally extracting it upon removal of the drill. In some cannulated screw systems, a stylet is provided which is help to prevent inadvertent guide pin removal during removal of the cannulated drill bit. It is also important that the drill be passed parallel to the guide pin, if too much cantilevering occurs during drilling there is the risk of pin breakage deep within the bone. These pin fragments are often difficult to retrieve. There is also the risk of pin bending or breakage during manipulation. The potential for this is discussed by Shin and Hofmeister in their description of percutaneous scaphoid fixation via a volar approach (16). They specifically recommended the standard Acutrak screw because of its stouter guide wire.

CLINICAL APPLICATIONS

The developments in cannulated screw technology, especially those of small diameter screws, have allowed for a greater application of their use in hand and wrist surgery. While initially utilized primarily in scaphoid fixation, cannulated screws are now used at the digital, metacarpal, and carpal levels. Percutaneous and limited open techniques, often combined with arthroscopic technology, have revolutionized how many traumatic conditions are now treated (17,18).

The following discussion is an overview of techniques utilizing cannulated screws for minimally invasive surgery of the hand and wrist. As many of these techniques are described in more exhaustive detail in the following chapters, the nuances will be left for discussion by other authors, many who are experts and pioneers in these very procedures.

Interphalangeal Arthrodesis

In the distal phalanx, cannulated screws can be utilized for arthrodesis of the distal interphalangeal (DIP) joint (19). However, because of the small diameter of both the middle and distal phalanges and the relatively tight soft tissue envelope, care must be employed in both patient and implant selection. Specifically, other techniques may be better suited for patients with diminutive hands or when the small digit is being

fused. Brutus and colleagues found a 15% nonunion rate and 37% complication rate (20). All nail bed injuries were seen in the small digit. This compares to a 12% nonunion rate and 20% major complication rate published by Stern and Fulton for DIP arthrodesis using noncannulated techniques (20). With these findings in mind, careful patient and implant selection is required to optimize results. As smaller implants continue to be developed, it will be interesting to see if outcomes improve.

In larger caliber digits, this author has used the AO/ASIF 3-mm cannulated screw with good results (Fig. 3). The interphalangeal joint of the thumb is particularly amenable to this technique. The typically greater ratio of the middle phalanx to distal phalanx intramedullary diameter of the thumb makes this implant, with its increased major diameter to minor diameter ratio, well suited for this application.

A few technical considerations are worthy of discussion. First, screw fixation limits the amount of flexion that can be imparted on the distal joint. Typically, joints are fused in neutral posture and it is difficult to achieve much more than 10° to 15° of flexion due to the geometric constraints of screw diameter and length within the intramedullary cavity. Second, care must be taken not to violate the dorsal cortex of the distal phalanx as this may lead to nail bed injury. Finally, if a headless screw is not utilized, the head must be countersunk into the tuft to avoid symptomatic hardware.

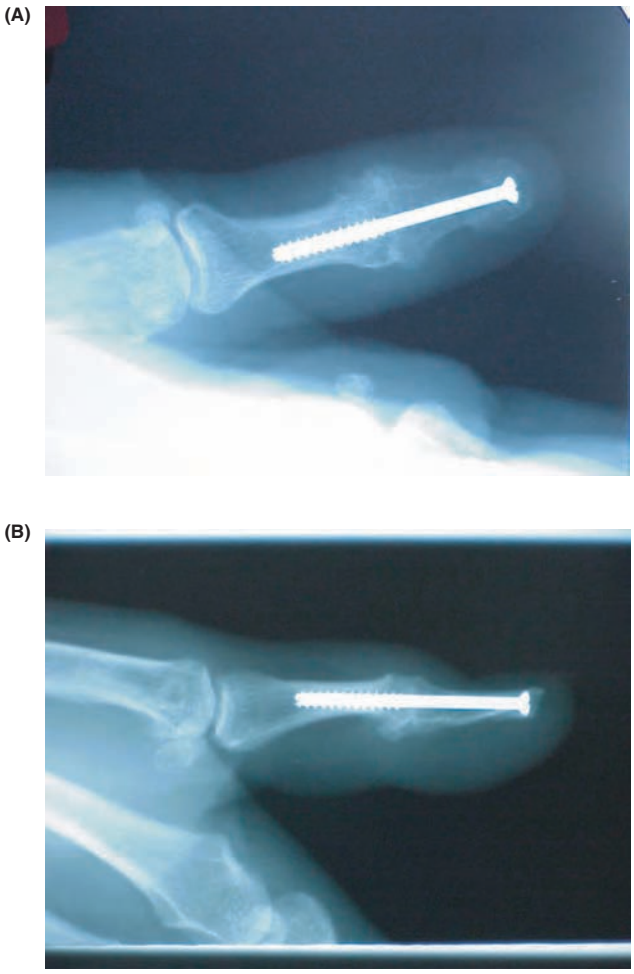

FIGURE 3 (**A**) A posteroanterior radiograph of a thumb IP joint fusion utilizing an AO/ASIF 3-mm cannulated screw. (**B**) Lateral radiographic image of a thumb IP joint fusion. *Abbreviation*: IP, interphalangeal.

To date, no authors have published their results regarding proximal interphalangeal (PIP) arthrodesis with cannulated screws. Leibovic and Strickland compared their results with Herbert screws to other fixation methods (21). They found a more favorable outcome with Herbert compression screws as opposed to K-wires or tension band techniques. It remains to be seen if cannulated screws can provide similar results.

Metacarpophalangeal Joint Arthrodesis

Several authors have published their experiences and result with cannulated screw fixation for metacarpophalangeal (MCP) joint arthrodesis. In 2002, Messer and colleagues reported their experience with thumb MCP arthrodesis using the AO/ASIF 3-mm cannulated screw (22). A total of 18 thumbs were treated with this technique. Their union rate was an impressive 100%. The also had no major complications. Two patients underwent screw removal for hardware discomfort. A later study of 26 patients utilizing the same implant in conjunction with a threaded washer revealed a 96% union rate (23). Other than the single nonunion, no other major complications were reported. Both studies found cannulated screw fixation for thumb MCP arthrodesis a satisfactory alternative to other techniques.

Scaphoid Fracture Fixation

A plethora of studies exist detailing cannulated screw fixation of scaphoid fractures. One study of particular interest is that of Trumble and colleagues (24). In this report Herbert/Whipple screws were compared to AO/ASIF 3-mm cannulated screws in the treatment of acute displaced fractures. They found no statistical difference in clinical and radiographic results between the two groups. Additionally, scaphoid alignment was improved and carpal collapse was decreased by either technique. They also evaluated screw placement with computerized tomography scans in both the sagittal and coronal planes. They noted that both techniques allowed for placement of the implant into the proximal fragment with satisfactory accuracy.

More recent studies have evaluated percutaneous screw fixation of scaphoid fractures either alone or in conjunction with arthroscopic assistance (17,18,25). This can be performed either via a dorsal or volar approach (Fig. 4). While the personality of the fracture may dictate the approach chosen, the bulk of these injuries are mid-waist fractures and are amenable to either anterograde or retrograde insertion. Thus often physician preference determines the technique employed.

In a groundbreaking study, Bond and colleagues evaluated percutaneous screw fixation as an alternative to cast immobilization for nondisplaced scaphoid fractures (26). Their prospective, randomized study of twenty-five active military patients evaluated with a minimum of two years follow-up found that the surgically treated group achieved radiographic union in a shorter period of time and a more rapid return to military duty. The average time to fracture union was seven weeks in those patients treated with cannulated screw fixation as opposed to 12 weeks in the cast immobilization cohort. At the two-year follow up, there was no statistically significant difference in range of motion or grip strength.

Slade and Moore have extended the use of percutaneous cannulated screw fixation for scaphoid fractures to now include unstable fractures, displaced fractures and fibrous unions (25). They reported a 100% union rate, confirmed by computerized tomography, in 50 scaphoid fractures. No complications were reported. Capo and Tan have also reported percutaneous

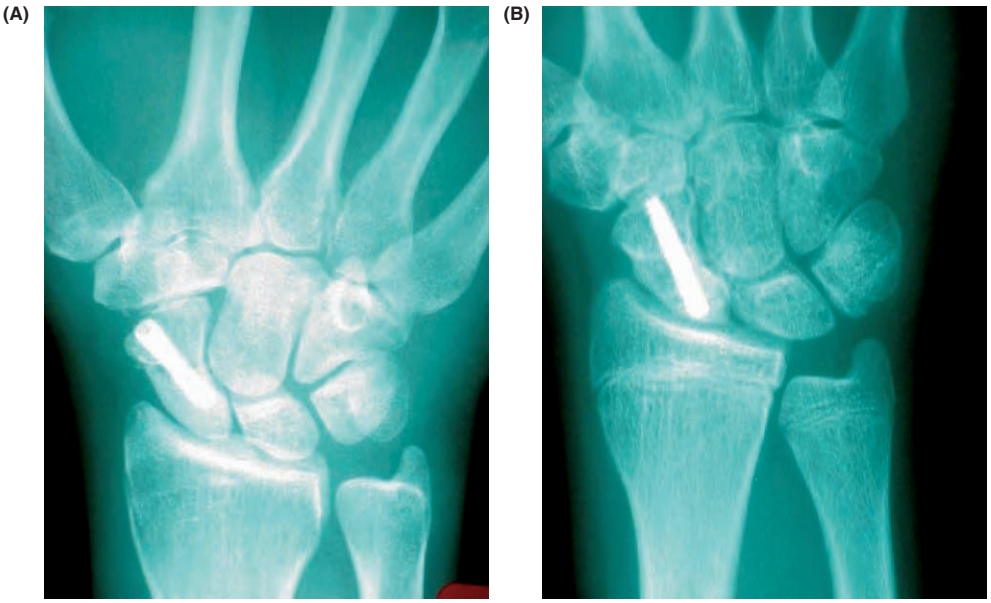

FIGURE 4 (**A**) Scaphoid fixation utilizing a volar percutaneous retrograde fixation technique. (**B**) A similar fracture treated via a dorsal approach and anterograde screw placement.

cannulated screw fixation of selected scaphoid nonunions (27). This author has had similar experience utilizing the Acutrak screw for scaphoid fractures with delayed union or nonunion. Healing times are, however, typically longer than those of acute injuries.

Carpal Injuries

In addition to isolated scaphoid injuries, Slade has championed the percutaneous treatment of transscaphoid, transcapitate perilunate fracture dislocations (28). The rationale behind this approach is the desire to stabilize the carpal fractures with minimally invasive technology thus limiting soft tissue stripping, preserving carpal blood flow, and allowing for a more rapid initiation of postoperative motion. In his technique, the scaphoid fracture is addressed with a dorsally placed headless compression screw and then the capitate is repaired with an identical implant using a percutaneous approach procedure from either the second or third web space. Anterograde placement of a cannulated screw in the scaphoid can be utilized in conjunction with lunotriquetral ligament repair or dorsal capsulodesis in transscaphoid perilunate fracture dislocations (Fig. 5).

Intercarpal Arthrodesis

Several authors have described the use of cannulated screws in intercarpal arthrodesis. Both percutaneous and open approaches have been utilized. Calandruccio and colleagues performed capitolunate arthrodesis in combination with scaphoid and triquetrum excision as treatment for scapholunate advanced collapse (SLAC) arthritis. Both cannulated and noncannulated screws were employed for fixation of the capitolunate interface (29). These included Herbert, Herbert/Whipple and AO/ASIF 3-mm cannulated screws. They did not specify which implant was used in each patient. They found their results similar to other procedures described for SLAC wrist arthritis but utilizing a technique necessitating fusion at only one site. Slade and Bomback have described percutaneous capitolunate arthrodesis using either an arthroscopic or limited open approach (30). He reported the use of a headless compression screw (Acutrak) across the lunocapitate interval for fixation. In his study, ten patients were treated via this technique; Five had an arthroscopic resection while the remainder had a limited open incision. At a minimum of 38-months follow up, all patients had satisfactory fusion based on computerized tomography scans. Nine patients were reported to be pain free and one had mild pain. All returned to their prior work and avocations.

This author has utilized AO/ASIF 3-mm cannulated screws in conjunction with a corticocancellous bone graft for lunotriquetral fusion with satisfactory results. The screw can be placed percutaneously via an ulnar approach in combination with a limited open dorsal exposure.

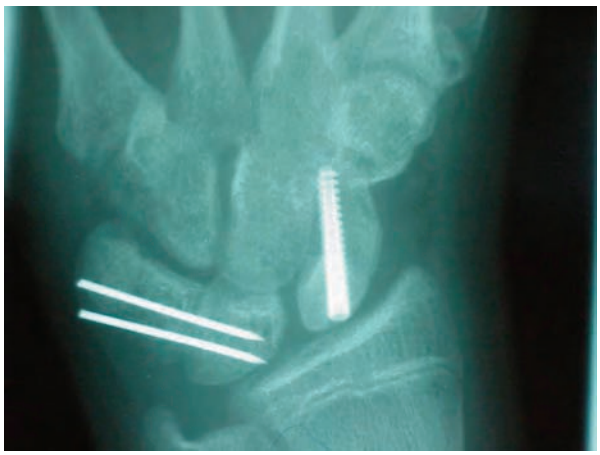

FIGURE 5 A posteroanterior radiograph of a transscaphoid perilunate fracture dislocation repaired utilizing an anterograde cannulated screw for scaphoid fixation and supplemental Kirschner (K) wire fixation of the lunotriquetral ligament repair.

Distal Radius Fractures

Cannulated screw technology is also applicable to distal radius fractures, particularly radial styloid fractures (Fig. 6). In these instances either limited open or arthroscopic techniques can be utilized (16). For Colles' and Barton's fractures plate fixation is typically employed. However, if there is a concomitant radial styloid fracture this can be reinforced with a lag screw using either cannulated or noncannulated technology. If a cannulated system is employed in conjunction with plating one must be careful to insure that there is not a mismatch between the biomaterials.

Arthroscopically assisted reduction allows for the precise reduction of the intra-articular components of the distal radius fracture. It also provides the additional benefit of evaluation of the intercarpal ligaments. The surgeon must always have a high index of suspicion for additional carpal or ligamentous injuries in the face of a radial styloid fracture (31).

Technical Alternatives

Other options for skeletal fixation in the hand and wrist include K-wires, small external fixators, cerclage, intraosseous or tension band wiring, solid screws (with or without the use of plates), and bioabsorbable implants. With the exception of bioabsorbable implants, all of these methods are used routinely and successfully in the surgery of the hand and wrist. It is up to the individual surgeon to determine what combination of surgical technique and implant choice best fits the fracture, the patient, and his or her level of experience.

With respect to the use of solid screws, Motley and colleagues have described a technique in which solid screws are used with precision similar to that of cannulated screws (32). This is done by using a hybrid system in which components of the Synthes 4.5-mm cannulated screw, 7.3-mm cannulated screw, and 6.5-mm solid screw systems are utilized. They achieve their precision by first placing a 1.6-mm threaded guide wire followed by a 4.5 mm measuring device. An 8.5-mm tissue protector is then used for the remaining steps in which the guide pin is first over drilled by a 3.2-mm cannulated drill bit. This is then followed by a 4.5-mm cannulated drill bit. The guide wire is then removed and a 6.5-mm solid screw is then placed via the guidance of the 8.5-mm tissue protector. They cited concern over cannulated screw strength as their main impetus for developing a system that could accurately deliver solid screws with the precision of a cannulated system.

Bioabsorbable screws are also an alternative to cannulated metallic screws. Kujala and colleagues published their results using bioabsorbable screws in the treatment of scaphoid fractures and nonunions (33). They reported solid union in five out of six patients. They felt that this was a reasonable alternative to metallic screw fixation. They did, however, point out that the screws once implanted were difficult to see and that cannulated system would allow for more accurate screw placement under fluoroscopic guidance.

POTENTIAL COMPLICATIONS OF CANNULATED SCREW PLACEMENT

As with the implantation of any device for surgery of the hand or upper extremity, there exist risks and potential complications. These include infection, nonunion, implant failure, implant migration, and damage to surrounding structures during surgical intervention. Additional complications associated with cannulated screw systems are often related to the guide wire. Schwend and colleagues reported a series of five instances where surgery was complicated by instrument breakage (34). In four instances, the guide pin was sheared off by the cannulated drill. In the remaining case the cannulated tap broke. In each case a 3.5-mm-diameter system was being utilized. Breakage of a cannulated screw at the head–neck interface, as can happen with solid screws, was reported by Mechan and Galindo (35). In another report,

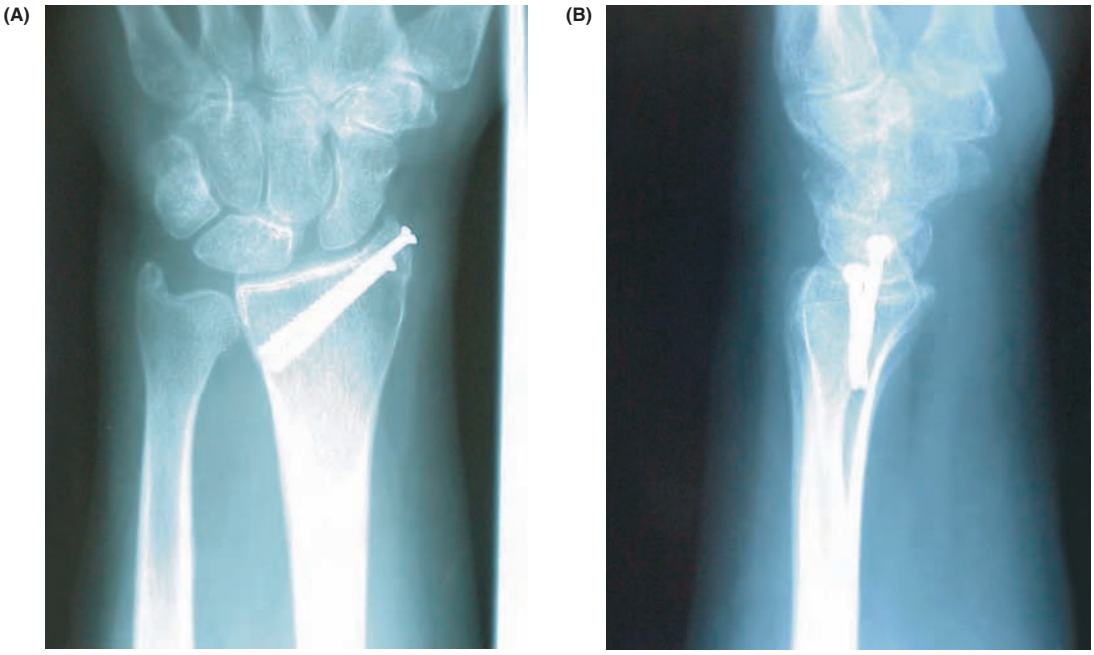

FIGURE 6 (**A**) A posteroanterior radiograph of a radial styloid fracture repaired with cannulated screw technology. The fragment was large enough for placement of two screws thus insuring rotational stability. (**B**) Lateral radiographic view of the same fracture showing screw placement within the metaphysis.

Mooney and Simmons detailed a more unique failure of the cannulated screw (36). In three separate instances, during initial placement of a cannulated screw in the metaphyseal bone of adolescent patients, the threads dissociated from the shaft of the screw. In each case, the threads literally unraveled during insertion. In all three instances there was no appreciable tactile change to alert the surgeon to the compromise of the device.

SUMMARY

Cannulated screws are an effective tool in minimally invasive surgery of the hand and wrist. They often allow for stable fixation while requiring only minimal surgical exposure and thus greater preservation of the soft tissue envelope. Biomechanical studies have shown them to be at least equivalent if not better than solid screws in many respects. Additionally, the ability to use these screws via percutaneous techniques has revolutionized the treatment of several injuries and disorders of the hand and carpus. The now widespread use of percutaneous cannulated screw fixation for the treatment of scaphoid fractures is a testimony to this.

Ensuing chapters in this book highlight the use of cannulated screws in specific instances and in much greater detail. The reader is directed to the accompanying list of references for a more in depth analysis of this topic.

ACKNOWLEDGMENTS

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6

Percutaneous Pinning of Phalangeal and Metacarpal Fractures

Yi-Meng Yen
Steadman-Hawkins Clinic Vail, Vail, Colorado, U.S.A.

Roy A. Meals
Department of Orthopedic Surgery, David Geffen School of Medicine at UCLA, Los Angeles, California, U.S.A.

INTRODUCTION

Fractures of the metacarpals and phalanges are some of the most common injuries that are presented to the hand surgeon (1,2). Ten percent of all fractures occur in the metacarpals or phalanges and 80% of all hand fractures involve these bones (3,4). Until the early part of the twentieth century, these fractures were treated nonoperatively. Albin Lambotte in 1928 pioneered the work of operative fixation for metacarpal fractures (5). Even today the majority of metacarpal and phalangeal fractures are treated conservatively. Those fractures that are nondisplaced or minimally displaced are inherently stable and require only nonsurgical management. Other fractures can be reduced in a closed manner and held in a cast or splint.

The unstable fracture or dislocation, such as a transverse or oblique metacarpal or phalangeal shaft fracture, requires surgical fixation to maintain alignment. Percutaneous pin fixation of small bone fractures was first pioneered by Tennant in 1924 using a phonograph needle. Kirschner described the use of small traction wires made from piano wire in 1927 (6,7). Bosworth reported using closed reduction and percutaneous pinning of fifth metacarpal neck fractures with Kirschner (K) wires in 1937 (8). World War II created a vast opportunity for fracture stabilization. Bunnell and others used K-wires for various percutaneous fixations in the hand (6). Vom Saal in 1953 reported his results after closed reduction and percutaneous fixation of a variety of metacarpal and phalangeal fractures (9). Twenty years later, Green and Anderson described crossed K-wire fixation of phalangeal fractures (10).

Percutaneous fixation can be applied to fractures of the hand because most bones have subcutaneous access for insertion of K-wires. Percutaneous techniques minimize the swelling and stiffness that may result from using plates or screws. Although percutaneous fixation is not as rigid as plate or screw fixation, increased rigidity may not be necessary when the hand is immobilized. Percutaneous pinning can be used with both closed and open reduction; however, this chapter will focus on the technique of closed reduction and percutaneous pinning of metacarpal and phalangeal fractures.

INDICATIONS

Operative indications for metacarpal or phalangeal fractures are for those fractures with instability after closed reduction, malrotation, intra-articular fragments, bone loss, open injury and severe contamination, adjacent fractures, and also those with major soft tissue injury requiring reconstructive surgery. The choice of open reduction and fixation with a screw or plate versus percutaneous fixation depends upon the injury pattern and soft tissue coverage. Patients who have concomitant tendon injuries or those who require immediate motion generally benefit from rigid internal fixation, which allows early motion and gives better tendon gliding. Patients with fractures that have segmental bone loss or that are extensively comminuted also benefit from rigid internal fixation, although percutaneous external fixation can be used. Inadequate closed reduction is a contraindication for percutaneous pin fixation.

Metacarpal Fractures

Metacarpal head fractures are rare and generally involve the articular surface. They usually require open reduction, and K-wire fixation may delay mobilization of the joint. Metacarpal neck fractures are quite common and consideration for closed reduction and percutaneous pinning depends upon the degree of angulation and which metacarpal neck is fractured. If the index and middle fingers are fractured, residual angulation and volar prominence of the metacarpal head may adversely alter grip patterns, so near anatomic reduction is preferred. Although there is lack of consensus for small and ring finger metacarpal neck fractures, it is generally agreed that up to 40° of apex-dorsal angulation is acceptable.

Metacarpal shaft fractures are generally transverse, oblique, or spiral and can be simple or comminuted. Indications for closed reduction and percutaneous pinning are angulation greater than 30° for the small finger, 20° for the ring finger, and any angulation in the middle or index finger. Any visible malrotation of the ray or shortening of 5 mm are also indications for surgery. Metacarpal base fractures are rare in the second through fourth metacarpals but can be treated by percutaneous pinning. The so-called baby Bennett's (fifth metacarpal base) fracture tends to be unstable and closed reduction and percutaneous pinning can be considered. Additionally, the Bennett's fracture (first metacarpal base) can be treated with closed reduction and percutaneous pinning.

Phalangeal Fractures

Indications for percutaneous pinning of phalangeal fractures are similar to metacarpal fractures. Shaft and condylar fractures that are unstable with closed reduction are amenable to percutaneous pinning. Long oblique and spiral oblique fractures that are initially in an acceptable position are relative indications for percutaneous pinning since these fractures can displace despite immobilization.

PREOPERATIVE PLANNING

A thorough history is taken paying particular attention to the mechanism of injury. The preoperative examination should include a complete assessment of the injured extremity noting the dominant hand. Open wounds should be noted. Examination of all finger extensors and flexors should be conducted and compared with the contralateral side. Threshold sensation should be thoroughly documented. The patient should be asked to make a fist or the examiner should passively flex the fingers at the metacarpophalangeal (MP) and proximal interphalangeal (PIP) joints in order to identify any rotational malalignment. Range of motion (ROM) should be assessed at each joint.

Standard lateral and posteroanterior or anteroposterior (AP) X-rays are required. If the fracture pattern is not clearly seen, semisupinated and semipronated views are helpful. The hand must be placed on the X-ray cassette in incomplete supination to obtain a true AP view of the fifth ray and in a hypersupinated position for the second ray. For all views, the X-ray beam should be centered proximally/distally over the area of concern rather than capturing a generic view of the entire hand or digit. Specialized X-ray views (e.g., Brewerton for proximal phalanx base fractures) or computed tomography scans are sometimes needed to elucidate subtle fracture patterns, but such fractures are generally not candidates for percutaneous K-wire fixation.

SURGICAL TECHNIQUE

Operating room setup should include the standard radiolucent hand table, with the operating table positioned to facilitate access for the C-arm. An experienced surgical assistant is helpful to hold the fracture reduction while the K-wires are inserted. The C-arm should be positioned to allow easy access for the surgeon to reduce the fracture. General anesthesia, Bier block, wrist block, digital block, or brachial plexus block can all be used. The choice depends on the desires of the patient, the specific injury, and preference of the surgeon and anesthesiologist. A tourniquet is generally applied to the upper arm or forearm but is usually not inflated. The fracture is manipulated and checked under fluoroscopy for reduction. Fracture reduction can sometimes be achieved and held with the use of fracture reduction forceps or even towel clips applied over the intact skin. If the fracture cannot be reduced, open reduction is appropriate.

K-wires are available in different diameters and lengths and can have one or both ends ground to a point. For metacarpals and proximal phalanges, a 0.045- or 0.035-inch K-wire is generally used for large or average-sized adults. A 0.035- or 0.028-inch K-wire can be used for smaller phalanges or children. The selection of K-wires is determined by bone size and surgeon preference. The high-rake angle trochar tips are preferred since they can be introduced at an oblique angle to the bone surface. K-wire tips that are cut in the operating room will not penetrate the bone easily; they cut a large diameter hole and cannot be expected to sustain an appropriate interference fit. Likewise, slow insertion speed and avoidance of repeat passes also improve the security of the K-wire fit in the bone (11–13).

Metacarpal Neck (Boxer's Fracture)

Reduction of the fracture is most commonly done with the Jahss maneuver (Fig. 1A) (14). The MP and interphalangeal (IP) joints are flexed to 90°, and the proximal phalanx can then be used to push the metacarpal head out of its volarly angulated position.

One method of fixation is to stabilize the fractured metacarpal head to the next closest intact metacarpal head. One or two K-wires are inserted transversely from the fractured metacarpal head into the next metacarpal head (Fig. 1B). Another K-wire is inserted between the diaphysis of these metacarpals for final stabilization. An alternative method is to use a crossed pin technique with two K-wires inserted across the fracture from opposite sides of the metacarpal head in a retrograde fashion (Fig. 1C). Other methods are noted in Table 1. The hand is then placed in an ulnar gutter splint for 7 to 10 days. If satisfactory alignment is maintained, protected active ROM can then be initiated. Pin removal is at three to four weeks.

Metacarpal Shaft Fractures

The fracture is reduced by flexing the MP joint to 90° to tighten the collateral ligaments and use the proximal phalanx to control the distal fragment. A towel clamp can be used to assist with rotational reduction. Fractures are then fixed with crossed pins introduced laterally at the retrocondylar fossa of the metacarpal head and drilled obliquely to the opposite cortex. Alternatively, K-wires can be placed transversely from the fractured metacarpal into an adjacent intact metacarpal using the intact metacarpal as a plate of sorts. A combination of the methods can also be used (Fig. 2). The hand is then splinted in the safety position. K-wires are removed at three to four weeks.

Fifth Metacarpal Base Fracture (Baby Bennett's)

Reduction is obtained by longitudinal traction and medially and volarly directed pressure on the base of the fifth metacarpal. The fifth metacarpal shaft is pinned to the fourth metacarpal shaft (Fig. 3). An obliquely oriented pin can be used to fix the fifth metacarpal base to the hamate (15). An ulnar gutter splint is used for 7 to 10 days. Pins are either cut and buried under the skin or left percutaneous and removed at three to four weeks.

Second to Fourth Metacarpal Base Fractures

The middle ray is the key to reduction and should be reduced first. Following longitudinal traction, palmar translation is applied to reduce the joint. One pin is driven obliquely at 45° from the dorsoulnar surface of the metacarpal crossing the carpometacarpal joint without interfering with the extensor tendons (16,17). Alternatively, a longitudinal wire can be driven down the metacarpal through the MP into the distal carpal row (18).

Bennett's Fracture

Reduction of the fracture is typically obtained by applying longitudinal traction, palmar abduction, and pronation of the thumb while exerting pressure over the dorsoradial aspect of the metacarpal base. Fixation requires one or two K-wires to maintain alignment of the shaft and joint surface (19).

A nearly longitudinal K-wire can secure the metacarpal base to the trapezium (1). Another K-wire is then placed

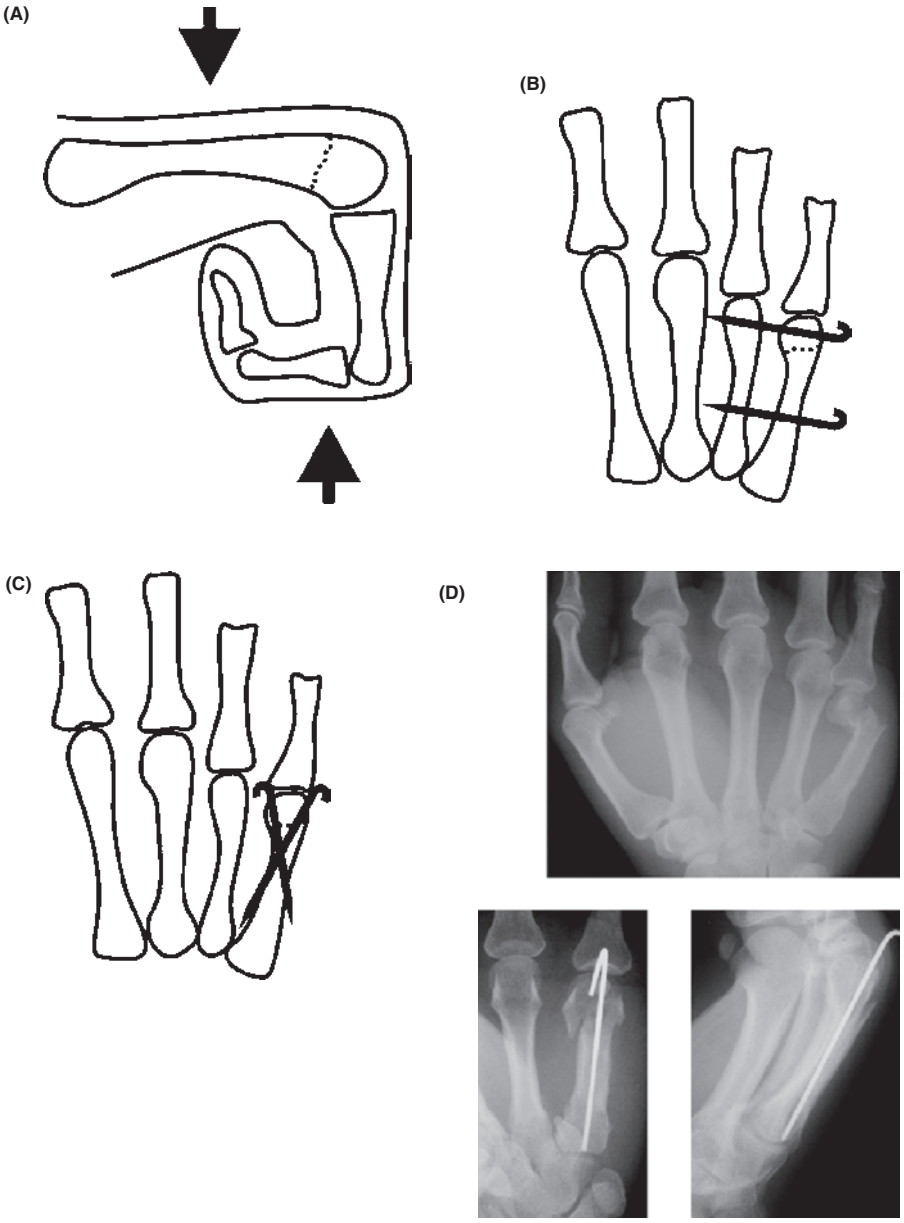

FIGURE 1 (**A**) Jahss maneuver for a fifth metacarpal neck fracture. MP and IP joints flexed to 90°; the proximal phalanx can be used to push the metacarpal head back into position. (**B**) Fixation of the fractured metacarpal head into the adjacent metacarpal with an additional pin in the diaphysis for stabilization. (**C**) Crossed pin stabilization. (**D**) Pre and post-operative fixation of a fifth metacarpal neck fracture with a single pin. *Abbreviations*: IP, interphalangeal; MP, metacarpophalangeal.

transversely from the first metacarpal base distal to the fracture into the second metacarpal base (Fig. 4A) (20). Alternatively, intermetacarpal pinning can be used alone (Fig. 4B) (21,22). A short-arm thumb spica is then applied. The K-wires are removed at four to six weeks.

Phalangeal Fractures

Several methods of percutaneous pinning can be used for phalangeal fractures (Fig. 5). An oblique or spiral fracture can be reduced by longitudinal traction applied manually or with finger traps. The fracture is held in place with a towel clamp or cannulated clamp. Rotation is verified by checking for abnormal crossing of the fingers with flexion of the MP and IP joints. Multiple mid-lateral pins, placed to avoid the lateral bands and perpendicular to the fracture, are used to hold the fracture (Fig. 5D). The reduction and pin placement are verified under fluoroscopy and the finger is taken through an ROM. If extension is limited, the pins may have transfixed the extensor mechanism and should be repositioned.

Transverse fractures can be stabilized by a variety of pin placements. The fracture can be reduced with the MP and PIP joints in full flexion and a K-wire inserted retrograde into the retrocondylar fossa of the proximal phalanx with a slight dorsal angulation. A single pin or crossed pins can be used. Alternatively, K-wires can be inserted from proximal to distal starting

TABLE 1 Alternative Methods of Fixation for Fifth Metacarpal Neck Fractures

Fixation	Method
Intramedullary	Retrograde through metacarpal head with MP flexed
Bouquet osteosynthesis	Multiple intramedullary K-wires pre-bent and inserted from proximal metaphysis
External fixation	Span fracture with K-wires and attach pins with polymethylmethacrylate

Abbreviations: K-wires, Kirschner wires; MP, metacarpophalangeal.

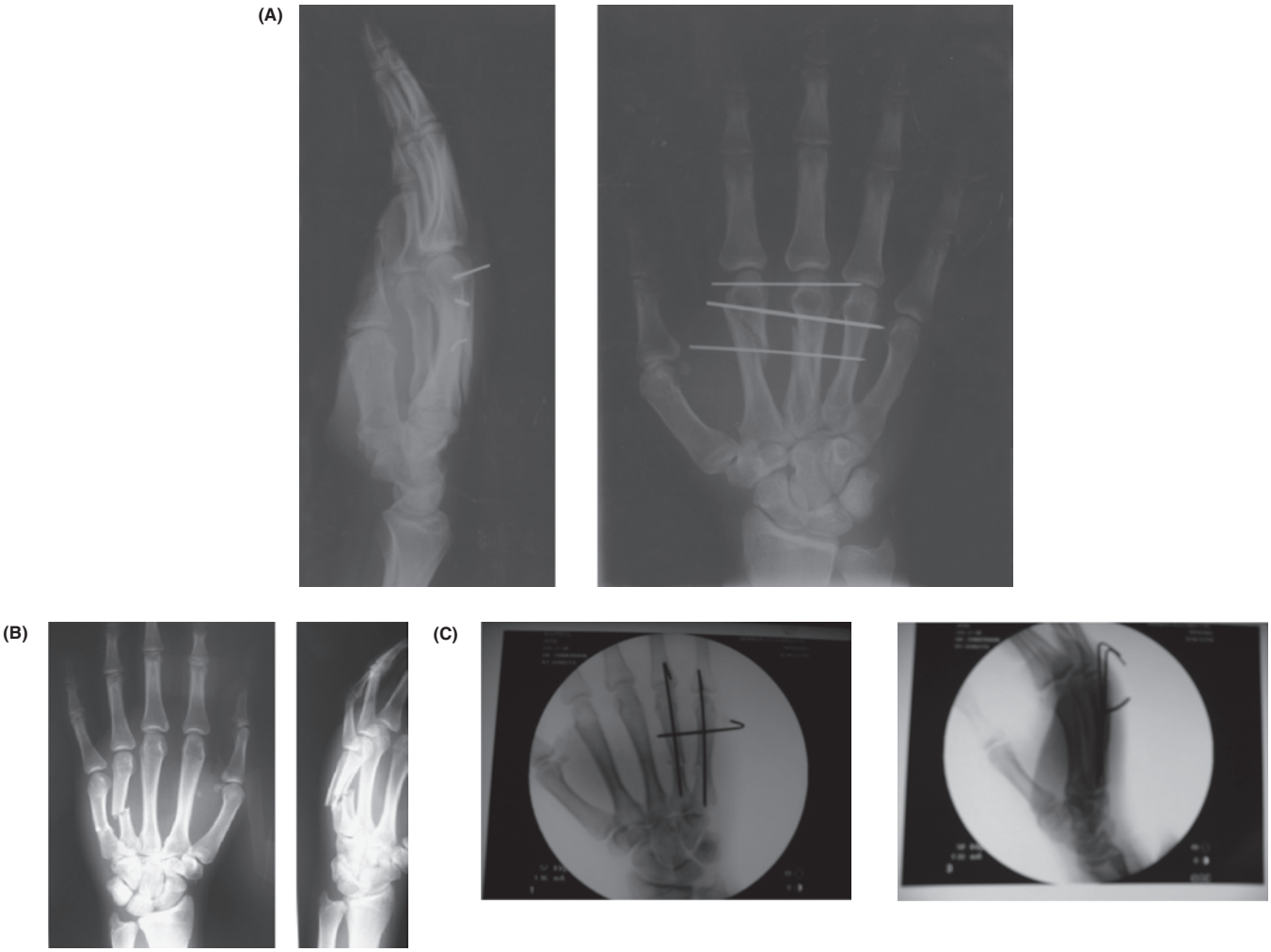

FIGURE 2 (**A**) Percutaneous pinning of second and third metacarpal fractures to the adjacent metacarpal. (**B**) Preoperative fourth and fifth metacarpal fractures. (**C**) Longitudinal single pin fixation with a stabilizing cross pin for rotational control.

adjacent to the MP joint articular surface (Fig. 5B). This allows some motion at the MP joint, while permitting splinting in the safe position. For comminuted or unstable basilar fractures, a K-wire can also be inserted through the metacarpal head into the proximal phalanx (Fig. 5C). The K-wire is introduced lateral to the extensor tendon of the MP joint and advanced longitudinally across the fracture site. This violates a normal MP joint but does ensure that the MP joint remains in the favorable, fully flexed position while the digit is immobilized.

K-wires can be cut off just beneath the skin or left protruding and bent 90° to minimize inward migration. A sterile dressing is applied, and the finger and adjacent neighboring finger are splinted and placed in the safety position. Pins are removed at three weeks and then the finger is protected with buddy taping for another three weeks before allowing full ROM. A clinical example of an oblique distal third proximal phalanx fracture stabilized with parallel mid-lateral pins is seen in Figure 6.

■ COMPLICATIONS

Percutaneous pin fixation can be technically demanding. The most common error when placing pins is to enter at an incorrect angle levering the fracture site open as the pin is advanced. Holding the fracture compressed and placing the pin at the correct angle prevent fracture distraction. If percutaneous pinning does not hold the fracture reduced, conversion to an open technique is mandated. Superficial pin track infection ranges from 0% to 10% (23–25). To a great extent, pin track infections can be avoided by sharply releasing tethered skin immediately after confirmation of satisfactory pin placement. Oral antibiotics with or without pin removal is usually curative. Nonunion, malunion, or delayed union may be the result from malpositioned K-wires. Loss of motion of the MP or IP joints results in poor outcomes. ROM can be maximized by ensuring an adequate reduction, ensuring excursion of the tendons perioperatively, and early active ROM. Careful pin placement and prevention of plunging through the far cortex during surgery are necessary to avoid neurovascular compromise.

■ OUTCOMES

Outcome following fixation of phalangeal and metacarpal fractures is variable but is generally favorable for percutaneous pinning with K-wires (10,26,27). Green and Anderson reported that 18 of 26 unstable phalangeal fractures regained full ROM within eight weeks after percutaneous fixation (10). Belsky et al. reported that 61 of 100 phalangeal fractures regained full ROM (26). More recently, Hornbach and Cohen have reported on 12 unstable proximal phalanx fractures, with an average total

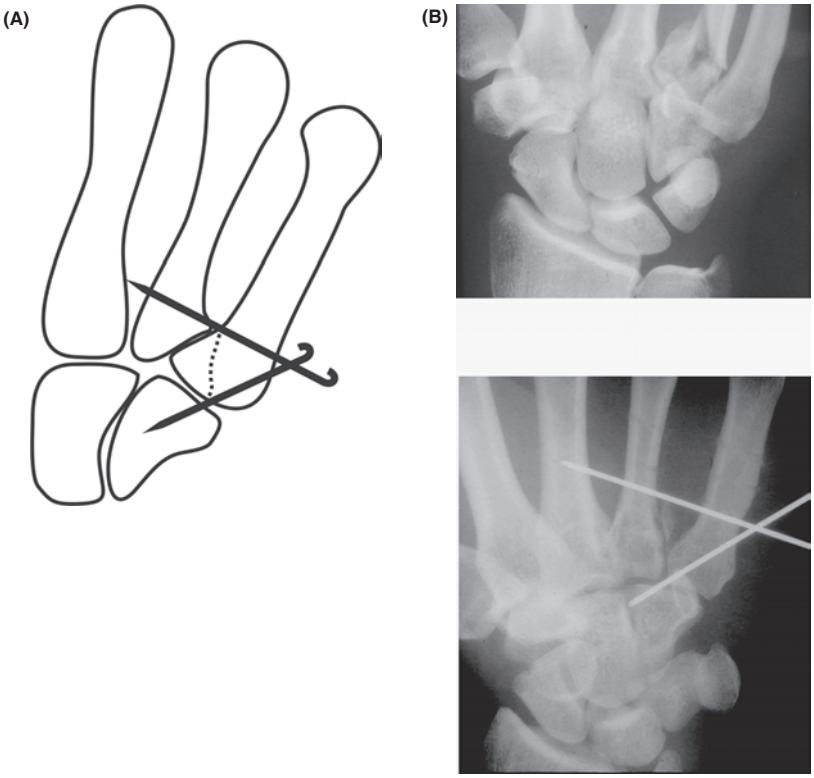

FIGURE 3 (**A**) Fracture fixation of a "baby Bennett's" fracture. Obliquely orientated pin to fix the fifth metacarpal base into the hamate and an additional pin stabilizing the fourth and fifth metacarpal. (**B**) Pre and post-operative radiographs of a fourth metacarpal fracture with a dislocation of the fifth metacarpal.

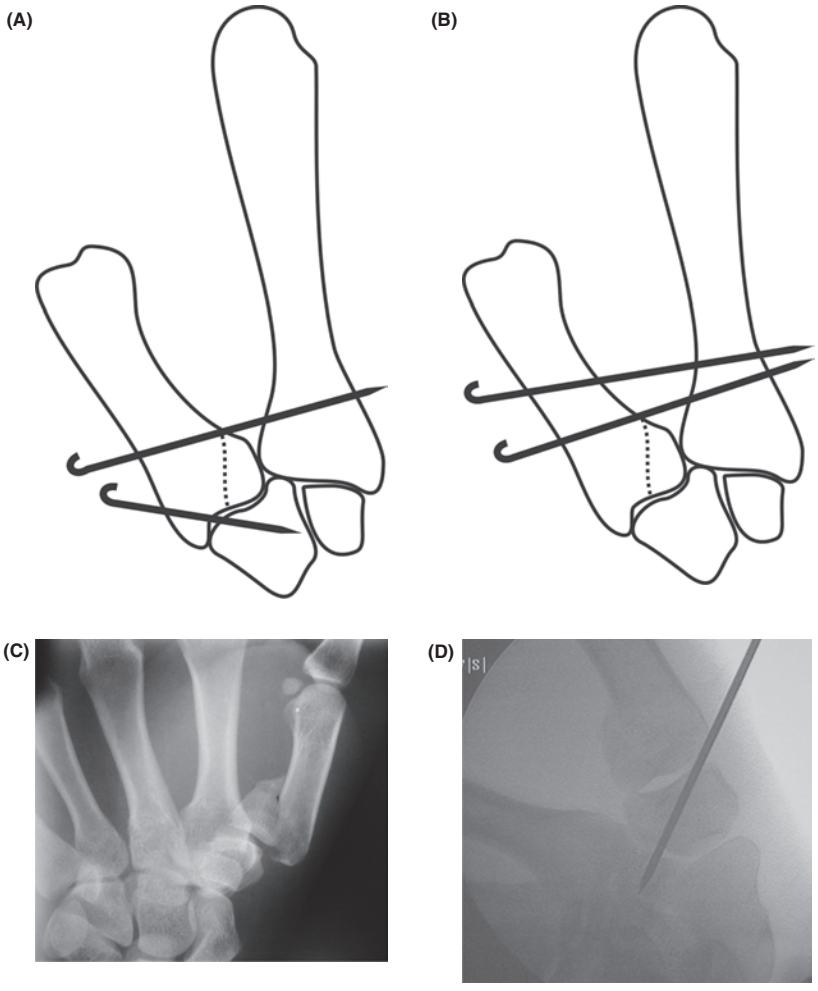

FIGURE 4 (**A**) Longitudinal K-wire securing metacarpal base to trapezium. An additional K-wire is used to secure the first metacarpal to the second metacarpal base. (**B**) Intermetacarpal pinning of a Bennett's fracture. (**C**) Pre-operative radiographs of a Bennett's fracture. (**D**) After closed reduction and pinning with a single pin. Fracture was stable under fluoroscopy. *Abbreviation*: K-wire, Kirschner wire.

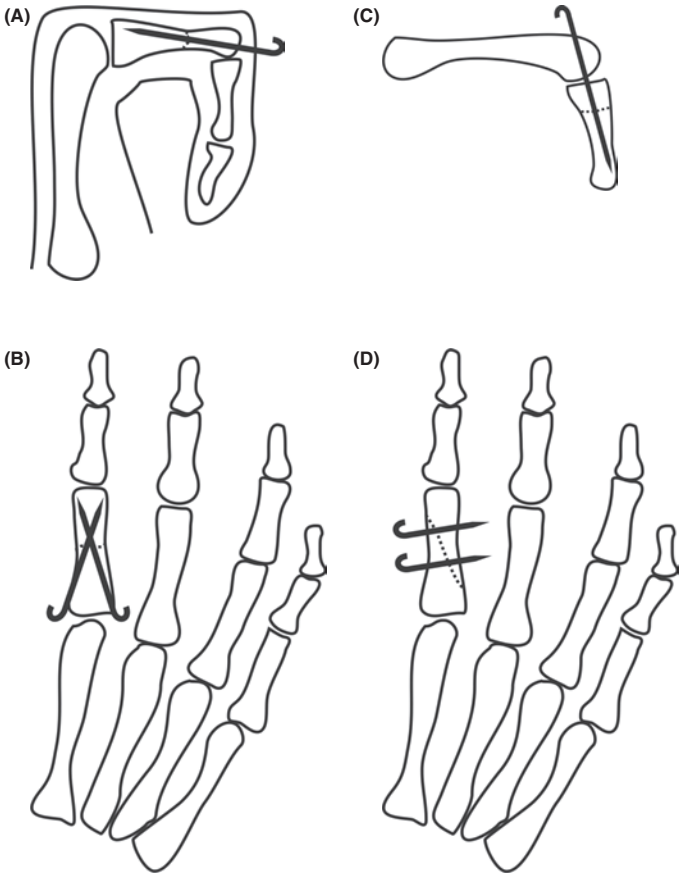

FIGURE 5 (**A**) Fixation of a transverse phalangeal fracture, first, with reduction of the MP and IP joints in full flexion. A K-wire is then inserted into the retrocondylar fossa with a slight dorsal angulation. (**B**) Crossed K-wire fixation from proximal to distal starting adjacent to the MP articular surface. (**C**) Fixation through the metacarpal head into the proximal phalanx. (**D**) Oblique or spiral fracture is reduced and multiple mid-lateral pins placed perpendicular to the fracture avoiding the lateral bands and extensor mechanism. *Abbreviations*: IP, interphalangeal; K-wire, Kirschner wire; MP, metacarpophalangeal.

ROM of 265°. There was one flexion contracture, one tendon adhesion, and one rotational deformity, but 10 of 12 patients obtained excellent results (24).

Metacarpal fracture fixation in 24 patients yielded an average of 0° to 3° of dorsal angulation having no metacarpal shortening with complete healing by six weeks (28). A nonrandomized comparison of transverse and intramedullary percutaneous pinning of the fifth metacarpal neck showed excellent results with both methods and no difference in grip strength, ROM, pain, and angulation (29).

Dartee et al. achieved full motion and complete pain relief in 32 of 33 patients with Bennett's fractures treated with intermetacarpal pinning (21). In a comparison of open versus percutaneous pinning of the Bennett's fracture by Lutz et al., the type of treatment did not influence the clinical outcome or the prevalence of radiological posttraumatic arthritis. But the percutaneous group had a higher incidence of adduction deformity of the first metacarpal (30).

SUMMARY

Percutaneous pinning of metacarpal and phalangeal fractures is a useful technique for injuries that are unsuitable for closed reduction and cast immobilization and that do not demand open reduction. Soft tissue dissection and swelling is minimized with percutaneous pinning. One limitation is that motion exercises are often delayed due to immobilization and sometimes cannot be started until the K-wires are removed. However, for many patients, percutaneous pinning can minimize complications and provide excellent results.

SUMMATION POINTS

Indications

- Unstable fractures of the metacarpals and phalanges

Outcomes

- Good to excellent outcomes in >90% of cases

Complications

- Limited ROM, pin track infections, malunion, nonunion, and delayed union

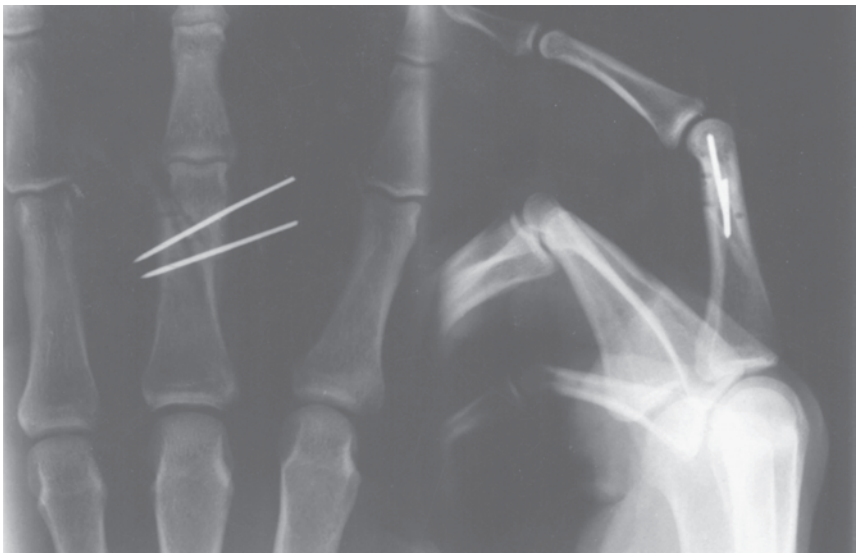

FIGURE 6 Post-operative radiograph of oblique distal third phalangeal fracture fixed with two K-wires. *Abbreviation*: K-wires, Kirschner wires.

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7

Percutaneous Mini Screw Fixation of Phalangeal and Metacarpal Fractures

Alan E. Freeland and William B. Geissler
Department of Orthopedic Surgery and Rehabilitation, University of Mississippi Medical Center, Jackson, Mississippi, U.S.A.

INTRODUCTION

The principles of unstable hand fracture management include anatomic restoration, sufficient stability to prevent displacement until callus seals the fracture and allows early progressive functional recovery, and the avoidance of unnecessary additional operative trauma (1). A fracture is considered unstable when reduction cannot be achieved and maintained without fixation or when motion cannot be initiated without the loss of reduction. Large (involving >25% of the articular surface) articular and oblique diaphyseal hand fractures are typically inherently unstable.

Hand surgeons have long recognized the consequences of fibroplasia, scar generation, and digital stiffness that may result from the open surgical treatment of closed hand fractures, especially those of the proximal phalanges and proximal interphalangeal joints (PIPJs) of the fingers (2–7). Subperiosteal dissection may also devascularize fracture fragments. Consequently, hand surgeons have been among the early advocates of minimally invasive surgery (MIS) and have admonished against injudicious open surgical procedures.

"Atraumatic" or MIS with closed reduction and internal fixation (CRIF) allows "biological (minimally undisturbed) fracture healing" (8). CRIF with percutaneous wires or mini screws is relatively atraumatic when compared with open operative procedures. CRIF preserves periosteal integrity and circulation at the fracture site and minimizes expansion of the zone of injury. Intraoperative fluoroscopic X-ray capability facilitates CRIF.

Wires splint without compressing fractures. By purchasing the bone cortices and having the option for compression, mini screw fixation provides greater fracture stability than do Kirschner (K)-wires, with little more soft tissue damage (1,9,10). Percutaneous mini screw fixation may require a higher level of technical proficiency than that in K-wire fixation. While K-wires must typically be removed four to six weeks after insertion, mini screws have the additional advantage of remaining in place for the duration of fracture healing. Mini screws are usually removed only if they become symptomatic, a rare occurrence. The pace and intensity of rehabilitation may be accelerated and morbidity decreased owing to the increased stability of mini screw fixation.

INDICATIONS

CRIF using percutaneous K-wires has established benchmark clinical outcomes for the management of unstable simple (two-part) long oblique extraarticular phalangeal fractures, articular fractures of the phalanges, and Bennett's fractures of the thumb (1–6,11–13). The length of a long oblique fracture is equal to or greater than twice the diameter of the adjacent bone. The length of a short oblique fracture is less than twice the length of the adjacent bone diameter (1).

Open K-wire or mini screw fixation is typically reserved for irreducible closed isolated simple fractures or as a contingency for failure of percutaneous technique. Open treatment may also be appropriate for open, pathologic, or multiple hand fractures; hand fractures accompanied by ipsilateral extremity injuries; and polytraumatized or unreliable patients (1–4,14). Percutaneous mini screw fixation alone is usually not suitable for comminuted fractures. Although there may be exceptions, fractures of the metacarpals are usually not sufficiently accessible for percutaneous mini screw fixation.

PREOPERATIVE PLANNING

Hand fractures are evaluated for local signs, deformity, stability, wounding, complexity, sensation, and tissue viability. Digital block with local anesthesia may relieve pain sufficiently to allow the digital motion necessary to define a deformity. The patient should be assessed for any anesthetic or surgical risk factors.

Good quality routine posteroanterior (PA), lateral, and at least one oblique X-ray views are sufficient to evaluate most hand fractures. Additional oblique or special views may be taken at the physician's discretion. Gedda has described a special view to profile the thumb trapeziometacarpal joint for Bennett's fractures (12,13). Computerized tomograms or magnetic resonance imaging is rarely necessary.

SURGICAL TECHNIQUE

An extremity tourniquet, hand table, mini or conventional C-arm fluoroscopic X-ray machine, a conventional X-ray machine, a cannulated power drill, K-wire set, and the appropriate mini screw set and instruments must be available. A "time out" should be taken to avoid "wrong site surgery." The procedure may be performed with general anesthesia or an appropriate regional or digital block. The use of a tourniquet insures good visibility at the operative site throughout the procedure and minimizes operative time, which may be significant should difficulties arise that require conversion to an open procedure.

Mini Screws

Conventional mini screws may be conceptualized as small straight K-wires with a head and threads (1). The proximal cortex of the pilot hole may be enlarged to the thread diameter of the intended mini screw to produce a "gliding hole."

The screw head buttresses the adjacent cortex while the distal threads purchase the distal cortex, compressing the fracture as the screw is tightened. Lag screws have the greatest compressive force when inserted perpendicularly to a fracture. Mini screws inserted perpendicularly to the bone axis provide maximum resistance to shear forces and provide sufficient stability for hand fractures (1).

Closed anatomic fracture reduction and provisional K-wire fixation are critical to successful percutaneous mini screw management, especially in articular fractures. Once fracture reduction is assured, the K-wires can be exchanged for mini screws, thus enhancing stability. The exchange is facilitated owing to collinear K-wire and mini screw core diameters allowing K-wire removal and immediate insertion of a self-tapping bicortical mini screw ("fixation mini screw") or mini lag screw (Table 1). Roth and Auerbach have reported that bicortical fixation is as reliable as lag screw fixation in treating well-reduced oblique phalangeal shaft fractures (9).

Although single mini screw fixation is typically sufficient for securing articular fragments owing to interlocking of the cancellous interstices, two or more mini screws are required for reliable fixation of oblique shaft fractures of the hand. Two or more mini screws in the shaft of a hand fracture serve to protect each other from shear, rotational, and bending forces during rehabilitation. Larger articular fragments may allow the insertion of two mini screws spaced with equal distance between the screws and between each mini screw and the proximal or distal edge of the fracture.

Cannulated headless mini screws are also available. Their conical shape and differential thread pitch (the screw pitch increases as the cone expands) allow them to compress the fracture. Percutaneous headless cannulated mini screw fixation is an excellent option for oblique articular and diaphyseal fracture fixation in the hand (10). Headless mini screws typically fit entirely within the bone fragments, minimizing interference with adjacent soft tissues. Mini screw cannulation allows precise placement over a guide wire and may simplify insertion.

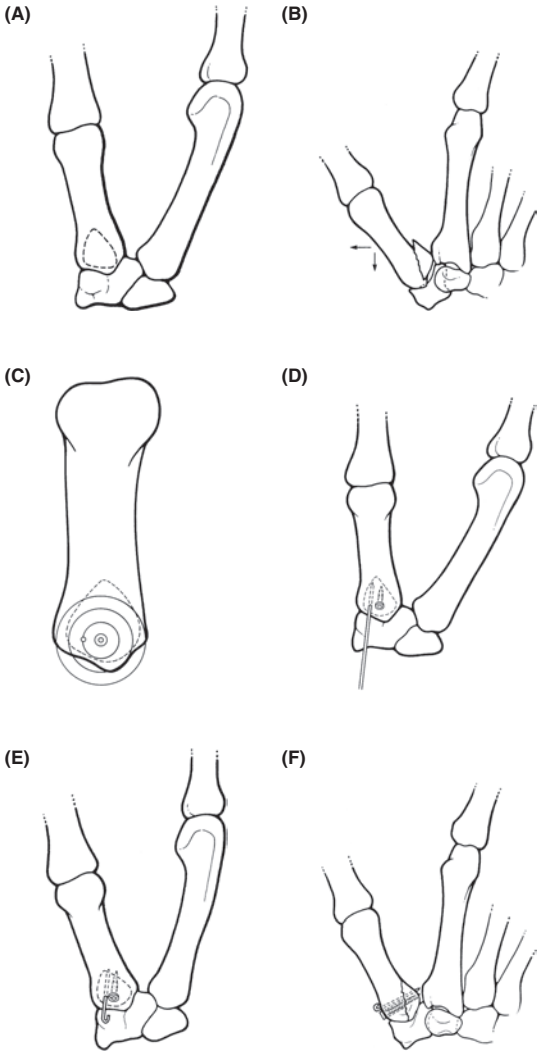

FIGURE 1 (**A**) PA illustration of a Bennett's fracture. (**B**) Lateral illustration of a Bennett's fracture. (**C**) The concept of centering a "target" on the articular fragment is illustrated. A screw head is located in the center of the target. A cross-section of a Kirschner wire is located on an inner peripheral ring to the left of center. (**D**) Fracture stabilization with a central mini screw and a peripheral K-wire. (**E**) PA illustration after the K-wire is cut and bent at its proximal end. (**F**) Lateral illustration after the K-wire is cut and bent at its proximal end. *Abbreviations*: K-wire, Kirschner wire; PA, posteroanterior.

Bennett's Fracture

Technique

The articular fragment at the base of the thumb metacarpal is secured in anatomic position by the anterior ulnar oblique ligament while the remaining metacarpal base is subluxed radially, proximally, and dorsally (Fig. 1A,B). A closed reduction is performed under fluoroscopic X-ray control using traction and manipulation. A pointed dental pic may be useful in applying pressure at the base of the thumb metacarpal. A 1 to 2 cm dorsal "buttonhole" or "portal-sized" incision is centered between the abductor pollicis longus and the extensor pollicis longus approximately 1 cm from the proximal border of the thumb metacarpal. A fine hemostat is used to spread the subcutaneous tissue away from the bone. A drill guide, tap sleeve, or 14-gauge hypodermic needle is always used with K-wires or drill bits to protect the adjacent soft tissues. The concept of "targeting" is used to determine wire placement (Fig. 1C). The fracture is secured with one K-wire directed through the dorsal base of the main metacarpal fragment into the center of the palmar ulnar fragment ("target"). A second peripheral K-wire maintains the reduction and prevents rotation of the fragment during mini screw insertion. The central K-wire is removed. Screw length may be determined using a depth gauge.

A self-tapping mini screw is inserted (Fig. 1D). The peripheral K-wire may removed or left undisturbed for two to four weeks at the discretion of the surgeon, depending upon the stability of the fracture (Fig. 1E,F).

TABLE 1 Inches to Millimeter Conversion Tables

K-wire diameter (inches)	Core diameter (mm)	Corresponding mini screw core diameter
0.028	0.7	1.1
0.035	1.1	1.5
0.045	1.5	2.0
0.62	2.0	2.7

K-wires are named by their diameter. Mini screws are designated by their thread diameter. *Abbreviations*: K-wire, Kirschner wire.

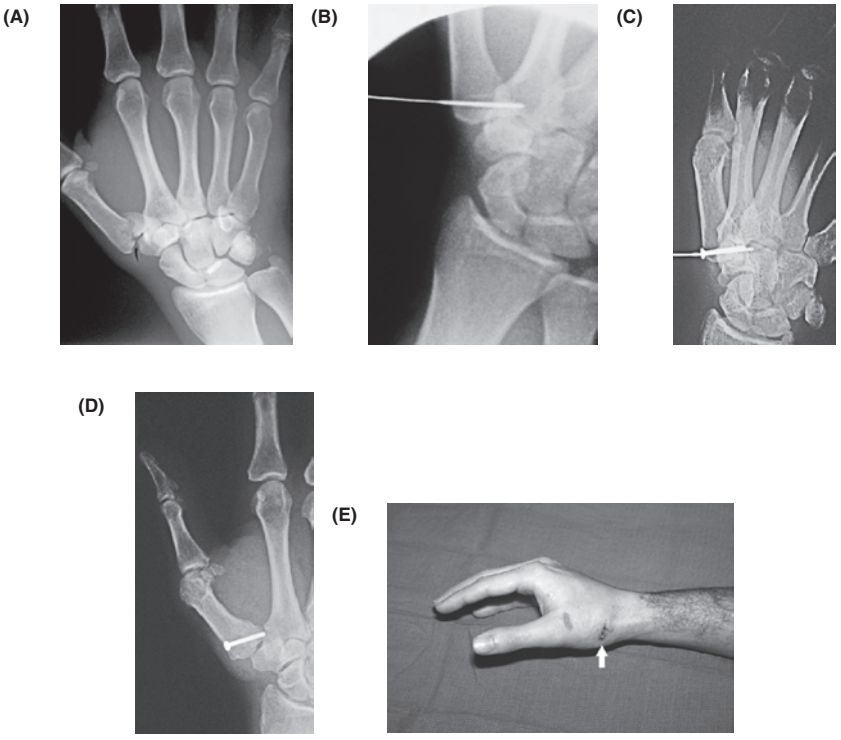

FIGURE 2 (**A**) Displaced Bennett's fracture. (**B**) Bennett's fracture, reduced and stabilized with a single central K-wire. (**C**) A peripheral K-wire has been added. A mini screw has been inserted in place of the central K-wire. (**D**) The small, minimally invasive incision is demonstrated one week after surgery. (**E**) The K-wire has been removed. The central mini screw remains in position. *Abbreviation*: K-wire, Kirschner wire.

Case Example

A 31-year-old patient fell while playing tennis and sustained a Bennett's fracture of his dominant hand (Fig. 2A). Surgery was performed on the day of injury. The fracture was reduced and provisionally fixed with a 1.5 mm central K-wire (Fig. 2B). After inserting a peripheral 1.5 mm K-wire, the central wire was removed and a self-tapping bicortical 2.0 mm mini screw was inserted (Fig. 2C). The K-wire was removed two weeks after surgery (Fig. 2D,E). The patient resumed administrative duties within one week. The fracture healed and the patient resumed full occupational responsibilities six weeks after surgery. Five years after injury, the patient was asymptomatic and had full function.

Condylar Fracture of the Proximal Phalanx

Technique

Condylar fractures typically displace proximally (Figs. 3 and 4). A "bicondylar sign" may be present on lateral X ray owing to rotation of the condylar fragment. A closed reduction is performed under fluoroscopic X-ray control using traction and a fine-pointed reduction forceps (Fig. 3B,C and Fig. 4B) (17). The condyles should align concentrically on lateral X ray following reduction. A 1 to 2 cm "buttonhole" or "portal-sized" midlateral incision is centered over the condylar fragment ("target"). (Fig. 4C,D) A fine hemostat is used to spread the subcutaneous tissue away from the collateral ligament overlying the condylar fragment. A drill guide or tap sleeve is always used with K-wires or drill bits to protect the adjacent soft tissues. A K-wire is inserted into the distal periphery of the subchondral bone of the condylar fragment just beneath and parallel to the articular surface of the proximal phalanx at the PIPJ and advanced through the opposing cortex (Fig. 3D). The peripheral K-wire maintains the reduction and prevents rotation of the fragment during the remainder of the procedure.

The proximal origin of the collateral ligament may be reflected distally or a cruciate incision made at the mid-origin of the conjoint collateral and accessory collateral ligaments adjacent to the center of the fragment (Fig. 4E,F). A K-wire or drill bit is directed through the center of the condylar fragment and into the opposing condylar cortex. The central K-wire is exchanged for a mini screw (Fig. 3E). The peripheral K-wire may be removed or left undisturbed for two to four weeks at the discretion of the surgeon, depending upon the stability of the fracture.

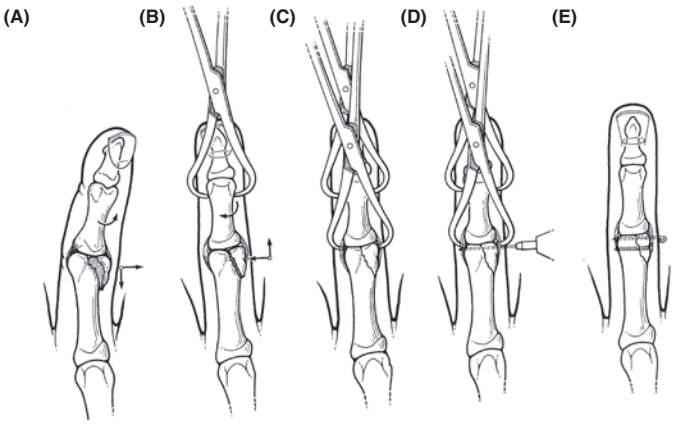

FIGURE 3 (**A**) Displaced unicondylar fracture, PA view. (**B**) Digital traction restores finger length. (**C**) The fracture reduction is completed by direct application of a pointed reduction forceps. (**D**) A K-wire is inserted parallel to and just beneath the articular surface. (**E**) A mini screw is inserted through the central portion of the condylar fragment. *Abbreviations*: K-wire, Kirschner wire; PA, posteroanterior. *Source*: From Ref. 15; (Fig. 1).

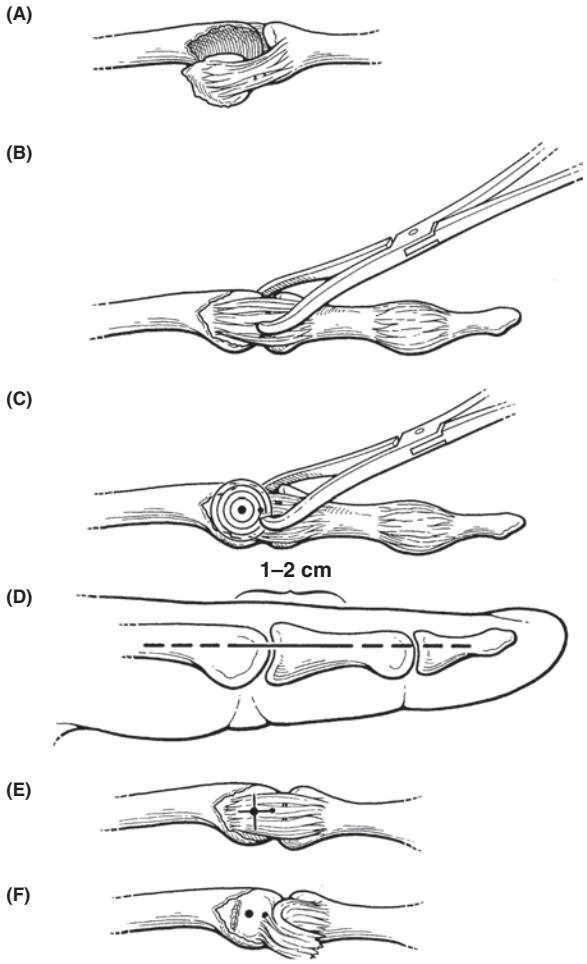

FIGURE 4 (**A**) Displaced unicondylar fracture, lateral view. (**B**) The fracture reduction is completed by direct application of a pointed reduction forceps. (**C**) The concept of centering a "target" on the articular fragment is illustrated. A screw head is located in the center of the target. A cross-section of a Kirschner wire is located on an inner peripheral ring to the right of center. (**D**) The midlateral line is illustrated for placement of the mini incision. (**E**) A cruciate incision is illustrated at the center of rotation of the PIPJ. (**F**) Partial reflection of the origin of the collateral ligament is illustrated. *Abbreviations*: PIPJ, proximal interphalangeal joint. *Source*: From Ref. 15; (Fig. 1).

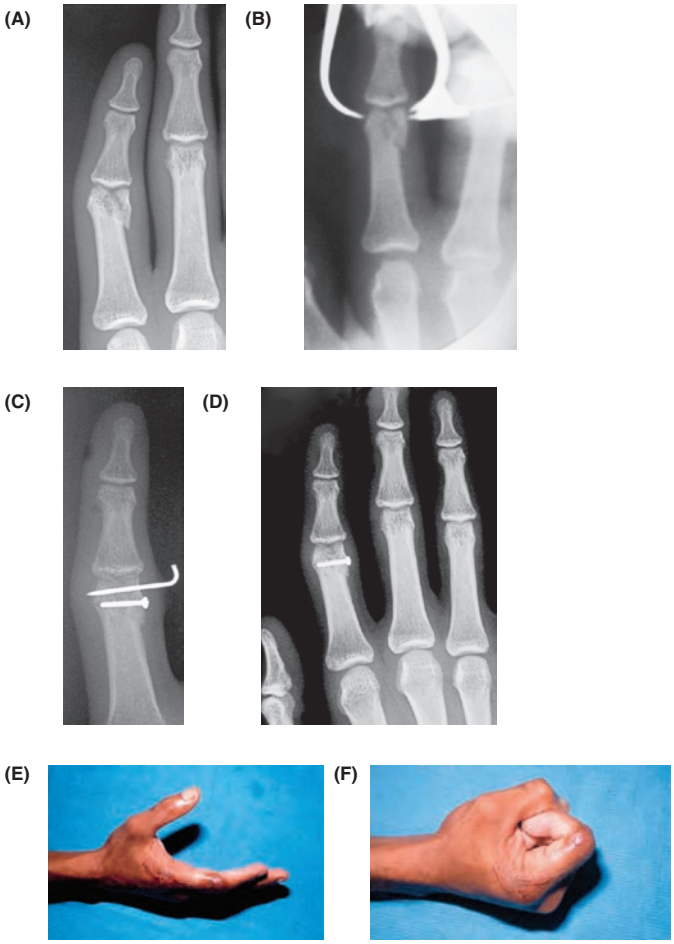

FIGURE 5 (**A**) Displaced unicondylar fracture, PA view. (**B**) The fracture reduction is completed by direct application of a cannulated pointed reduction forceps. (**C**) A K-wire has been inserted parallel to and just beneath the articular surface. A mini screw has been inserted through the central portion of the condylar fragment. (**D**) The K-wire has been removed. The fracture remains stabilized by the central mini screw. (**E**) Finger extension at six weeks. (**F**) Finger flexion at six weeks. *Abbreviations*: K-wire, Kirschner wire; PA, posteroanterior. *Source*: From Ref. 16; (Fig. 2).

Case Example

A 19-year-old patient jammed the index finger of his dominant hand while playing basketball. He sustained a displaced fracture of the ulnar condyle of the proximal phalanx (Fig. 5A). A closed reduction was performed and temporarily secured with a cannulated pointed reduction forceps (Fig. 5B). A peripheral 1.5 mm K-wire and a central 1.5 mm mini screw were inserted (Fig. 5C). The wire was removed two weeks after surgery. The mini screw was left in place (Fig. 5D). The fracture healed and the patient had 17° to 85° of PIPJ flexion six weeks after surgery (Fig. 5E,F).

■ Long Oblique Fractures of the Phalangeal Shaft

Technique

Oblique proximal phalangeal shaft fractures tend to shorten and rotate (Fig. 6A). A closed reduction is performed under fluoroscopic X-ray control using traction and one or two fine-pointed reduction forceps (Fig. 6B,C). Approximately 1 to 2 cm midlateral incisions are centered over the junctures of the proximal third and middle third and the middle and distal third of a sagittal uniplanar fracture. Uniplanar oblique fractures may vary slightly from the true sagittal plane, but are rarely found in the coronal plane. Wire and mini screw application are easier in uniplanar oblique than in spiral fractures which require adjustments in the position selected for mini screw insertion in relation to the rotating plane of the fracture for each wire or screw that is inserted.

A fine hemostat is used to spread the subcutaneous tissue away from the lateral band or oblique fibers of the metacarpophalangeal joint dorsal expansion proximally or the lateral surface of the proximal phalanx distally. The lateral band may be retracted, divided, or excised to approach the proximal mini screw insertion site (19–21). Cortical bone surfaces of metacarpals and phalanges are hard and round, and the medullary canal is narrow. A drill guide, tap sleeve, or 14-gauge hypodermic needle is always used with K-wires or drill bits to control the wire or drill, prevent slippage, and protect the soft tissues at the insertion site. Instrument compression of the

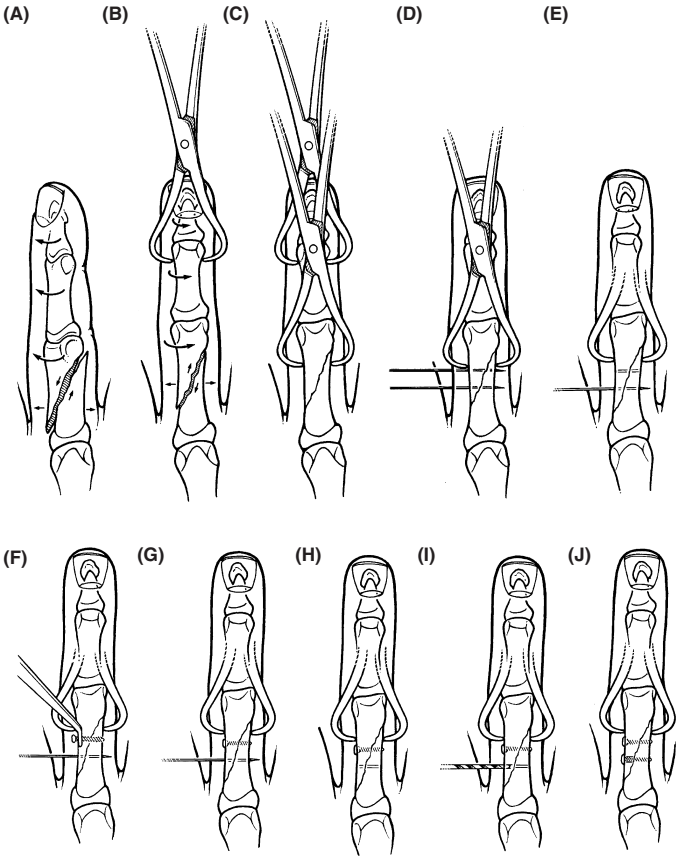

FIGURE 6 (**A**) A closed long oblique fracture of a proximal phalanx is shortened and rotated. (**B**) Length is restored and alignment improved with traction and manipulation. (**C**) Reduction is completed by the direct application of a pointed reduction forceps. (**D**) The reduced fracture is secured with two K-wires that divide the fracture into thirds. (**E**) The distal K-wire is removed. (**F**) Mini screw length is measured indirectly. (**G**) A bicortical "fixation" mini screw is inserted distally. (**H**) The proximal K-wire is removed. (**I**) The proximal cortex is drilled to correspond to the mini screw thread diameter. (**J**) A mini lag screw is inserted proximally. *Abbreviations*: K-wire, Kirschner wire. *Source*: From Ref. 18; (Fig. 3).

fracture with a fine-pointed small bone reduction forceps prevents distraction at the fracture site during wire insertion and the mini screw for K-wire exchange. Long oblique diaphyseal phalangeal fractures may be stabilized by two or more mini screws spaced with equal distance between the screws and between each mini screw and the proximal or distal edge of the fracture.

The fracture is secured with two K-wires directed through both cortices of the reduced fracture at the selected sites that divide the fracture into thirds (Fig. 6D). One K-wire is removed (Fig. 6E). Screw length may be measured directly by depth gauge or indirectly determined by holding the mini screw over the fracture and imaging with the fluoroscope (Fig. 6F). Indirect measurement by imaging avoids the small but real risk of displacing the fracture that accompanies the depth gauge measurement maneuver. A self-tapping bicortical "fixation" mini screw is inserted distally (Fig. 6G). The proximal K-wire is removed (Fig. 6H). The proximal cortex is enlarged to correspond to the thread diameter of the selected mini screw (Fig. 6I). A self-tapping mini lag screw is inserted (Fig. 6J). A third mini screw may be inserted at the discretion of the surgeon. Three mini screws may be inserted, dividing the fracture into quarters, when the fracture length is three times the bone diameter (1).

Headless mini screws are inserted so that the widest parts of the screws are frequently positioned opposite each other to allow maximum bone purchase. Headless screws are usually not placed in the middle third of the phalangeal shaft owing to the risk of fragmenting the hard cortical surfaces in the narrow area of the isthmus of the phalanx. Supplementary K-wire fixation may be used in the midshaft area, if necessary.

Case Example

A 38-year-old patient fell and sustained a closed oblique fracture of the shaft of the proximal phalanx of her nondominant small finger (Fig. 7A,B). Small "stab" skin incisions were made to facilitate K-wire and mini screw insertion (Fig. 7C). Two 1.1 mm K-wires were inserted, dividing the fracture into thirds. Indirect screw measurement was performed (Fig. 7D). Two 1.5 mm mini screws were inserted (Fig. 7E,F). The fracture healed. Six weeks after surgery, the patient had recovered flexion of 12° to 80° of PIPJ and returned to work (Fig. 7G,H).

Articular Fracture—Phalangeal Base

Technique and Case Example

A 34-year-old patient jammed his finger at work. He sustained a closed articular fracture of the base of the middle phalanx (Fig. 8A). A closed reduction was performed under fluoroscopic X-ray control using traction and a fine-pointed cannulated reduction forceps (Fig. 8B). One guide wire was placed centrally into the condylar fragment parallel to the articular surface and just distal to the insertion of the collateral ligament (Fig. 8B,C). This site should be selected so as to assure that the mini screw threads do not penetrate the adjacent joint surface. The guide wire is advanced through the reduced fracture fragments and through the skin on the opposite side of the digit so that it can be removed easily should it break. A second guide wire is inserted eccentrically into the condylar and major phalangeal fragments to prevent fragment rotation during reaming and mini screw insertion (Fig. 8D,E). A 1 to 2 cm midlateral incision is centered over the condylar fragment ("target") (Fig. 8F). Blunt dissection is continued with a hemostat to the level of the bone surface. A cannulated reamer slides over the central guide wire (Fig. 8G). The bone is then reamed across both bone cortices. Recently, a self-drilling headless cannulated mini screw (variable pitch mini Acutrak screw, Acumed, Hillsboro, Oregon, U.S.A.) has been introduced. With this new self-drilling cannulated headless mini screw, only the near cortex has to be reamed, and the self-drilling screw is then inserted over the guide wire (Fig. 8H). The screw is inserted over the guide wire so that it fits entirely inside the bone on both the PA and lateral X-ray views. The final mini screw position is fluoroscopically confirmed by both PA and lateral views. The guide wires are then removed (Fig. 8I,J). A single mini screw may provide adequate stability. The fracture healed and the patient had recovered full finger motion six weeks after surgery (Fig. 8K,L).

A second headless cannulated screw may be inserted into larger condylar fragments at the discretion of the surgeon. The second mini screw is usually inserted in the opposite direction of the first screw, owing to the obliquity of the fracture line. This allows the smaller diameter lead portion of the screw to cross the fracture site and engage the smaller remaining cortical area of the condylar fragment, thus decreasing the risk of fragmentation.

FIGURE 7 (**A**) A closed long oblique fracture of a proximal phalanx is shortened and rotated. The amount of rotation corresponds to the size of the gap between the fragments. (**B**) A lateral x-ray demonstrates that the tip of the proximal fragment will block PIPJ flexion unless it is reduced. (**C**) The incision site is guided by fluoroscopic x-ray. (**D**) Two K-wires stabilize the fracture. Mini screw length is measured indirectly. (**E**) Mini screw fixation, PA view. (**F**) Mini screw fixation, lateral view. (**G**) Finger extension six weeks after surgery. (**H**) Finger flexion six weeks after surgery. *Abbreviations*: PIPJ, proximal interphalangeal joint; K-wire, Kirschner wire; PA, posteroanterior.

Postoperative Care and Rehabilitation

Functional recovery is the fundamental goal of rehabilitation (22,23). Early digital motion and differential superficialis and profundus tendon gliding exercises are prioritized. Elevation augments digital motion by diminishing and resolving restrictive swelling and edema. Progress is guided by soft tissue response, fracture stability, and the patient's pain tolerance. Rehabilitation must be stopped short of generating additional inflammatory or fibroblastic response, signaled by increased pain, swelling, tenderness, redness, or heat at the fracture site. Fracture stability limits pain and allows more rapid implementation of exercises. There may be less morbidity if exercises can be started early (within 21 days), although final outcome is usually not adversely affected in patients who require as much as four weeks of continuous static splinting provided motion is initiated at that time (24,25).

Protective splints may be worn between exercise sessions until pain, swelling, and tenderness subside. Splints that hold the wrist in slight flexion and all four finger metacarpophalangeal joints in full flexion allow the extrinsic extensors to supplement the intrinsic extensors in recovering interphalangeal joint (IPJ) extension without impeding the recovery of finger flexion, especially in patients with proximal phalangeal fractures. An attachment to hold the PIPJ's fully extended may be added to the splint at night to decrease the risks of PIPJ extensor lag and contracture.

The recovery of 4 to 5 mm of flexor tendon excursion during the first four weeks following flexor tendon repair in

FIGURE 8 (**A**) Displaced large articular fracture of the condylar base of a middle phalanx. (**B**) A K-wire has been inserted through a cannulated pointed reduction forceps. (**C**) The K-wire is parallel and distal to the proximal joint surface. (**D**) A second K-wire is being inserted through the fracture distal to the first K-wire. (**E**) The reduction and K-wire fixation have been completed. (**F**) A small incision is made in the skin at the insertion site of the proximal K-wire. (**G**) The cannulated drill has been inserted over the proximal K-wire. (**H**) The cannulated headless mini screw is ready to be inserted over the proximal K-wire. (**I**) The reduced fracture has been secured with the headless mini screw. The headless mini screw is entirely contained within the bone. (**J**) The reduced fracture has been secured with the headless mini screw, lateral view. The patient has regained full finger extension (**K**) and full finger flexion (**L**) six weeks after surgery. *Abbreviations*: K-wire, Kirschner wire.

zone 2 reliably prevents the formation of permanent adhesions between bone and tendon, and correlates with good to excellent final digital motion in most patients (26). A more modest recovery during the four weeks following surgery predicts less favorable results. Extrapolation of these findings to proximal phalangeal fractures and allowance for 4 to 5 mm of both adjacent flexor and extensor tendon excursion would require a 40° to 50° partial arc of PIPJ or total active integrated finger motion (27).

Metacarpal and phalangeal fractures are usually clinically stable at four weeks after injury even in the absence of the appearance of callus on X ray (1). Fracture fragments may be considered "locked" when they are joined by callus that is visualized on X ray, usually at five to six weeks after fixation. At four to six weeks after injury, patients may be weaned from their splints as fracture stability and healing, pain, and tenderness allow. When adequate fracture healing is assured, movement may be intensified, and static joint blocking and strengthening and conditioning exercises may be initiated with minimal risk of fracture disruption. Passive stretching and dynamic splints designed to overcome tendon and joint adhesions may usually be initiated safely at five to six weeks after injury (22,23).

Patients are instructed and checked out so that they can perform daily therapy at home. If monitoring demonstrates that progress is unsatisfactory, outpatient therapy is initiated. Work hardening may be added if needed. Therapy is continued until the patient reaches a point of maximum recovery. Patients may continue to regain PIPJ motion for as long as one year following injury (7).

COMPLICATIONS AND THEIR MANAGEMENT

Intraoperative Complications

Percutaneous fixation sacrifices direct visual confirmation of fracture reduction. The fracture may be opened if direct visualization becomes necessary during the procedure in order to

assure proper fracture reduction. Unambiguously, irreducible fractures require open reduction. Percutaneous or open K-wire or open mini screw fixation may be used as a contingency when technical difficulties necessitate abandonment of percutaneous mini screw fixation. Physicians and patients should be prepared for conversion of a percutaneous to an open procedure. Mini screw breakage, loosening, or pull-out is a rare occurrence.

Long-Term Complications

Residual stiffness is the most common complication following articular and phalangeal fractures of the hand (2–4,7). Patients with residual finger stiffness typically adapt well and rarely desire remedial surgery (7,28,29). Approximately 25% of patients with articular fractures suffer long-term cold intolerance and aching pain, typically managed nonoperatively (7,28–30). Symptomatic arthritis is more frequent in poorly reduced articular fractures, emphasizing the importance of accurate reduction and reliable stabilization. Occasional joint reconstruction may be necessary. Malunion and nonunion are rare occurrences. Fambrough and Green reported a flexor tendon rupture owing to attrition from a protruding mini screw tip (31).

OUTCOMES

Initial efforts at mini screw fixation of hand fractures in 1958 were discouraging (32). However, in 1976, Crawford reported typically successful results and no complications following mini screw fixation in 21 various articular fractures with large fragments and oblique phalangeal shaft fractures, reviving interest in the technique (33).

Bennett's Fracture

CRIF with percutaneous K-wires has previously been acknowledged as the treatment of choice for Bennett's fracture (3,4,11–13). K-wire or screw fixation has been successfully used for those Bennett's fractures requiring open reduction (34–37). Lutz et al. reported no difference in outcome or posttraumatic arthritis between patients treated with percutaneous Kirschner wire fixation or open mini screw fixation followed for a mean of seven years (37). Meyer et al. reported uniform fracture healing, 13 good to excellent results, one fair result, and two poor results in 16 Bennett's fractures treated with cannulated screw osteosynthesis and followed for an average of 17 weeks (38).

Unicondylar Fractures

Weiss and Hastings reported their results in 38 consecutive patients with unicondylar fractures of the proximal phalanx followed for an average of 3 years (39). PIPJ motion in their series averaged from 13° (range: 0–35°) to 85° (range: 60–115°) of flexion. Clinical outcomes measured by total active PIP joint motion were slightly better when two or more K-wires were used ($89° \pm 18°$) than with open mini screw fixation ($79° \pm 8°$) (30,40). No differences were detected between percutaneous and open wiring techniques. None of the fractures stabilized with multiple K-wires or mini screws lost reduction for the duration of treatment. Five out of seven undisplaced fractures and four out of ten fractures treated with a single K-wire lost reduction during the course of treatment, required secondary fixation, and had greater PIP joint stiffness than those managed with multiple K-wire or mini screw fixation. These investigators did not use percutaneous mini screws. Irreducible condylar fractures were approached in the capsular interval between the central slip and the ipsilateral lateral band. Full recovery of PIP joint motion was the exception rather than the rule, typically owing to some residual extensor lag or flexion contracture or some loss of flexion. They concluded that all unicondylar phalangeal fractures require initial fixation with two or more K-wires, one or more mini screws, or a wire and a mini screw.

Ford, et al. detailed their results treating ten condylar fractures of the proximal phalanges and four of the middle phalanges with open mini screw fixation (30). No excellent results were reported. Four patients with unicondylar proximal phalangeal fractures had good results and six had poor outcomes. There was an average residual loss of 20° to 30° of extension. PIPJ flexion was more reliably restored. Dynamic splints seldom improved results. Two patients with condylar fractures of the middle phalanx had good results and two had poor results.

Geissler and Freeland reported on 12 patients with intra-articular fractures of the digits (10). Ten patients had unicondylar fractures of the fingers and two patients had intra-articular thumb fractures. The average age was 22 years (range: 16–35 years). Nine patients were males and three were females. Nine patients underwent stabilization with a single headless cannulated mini screw and three patients had two headless mini screws inserted. All patients healed clinically and radiographically within six weeks following surgery. There was no loss of reduction in any of the patients. Out of the 10 patients with unicondylar fractures of the phalanges, the average loss of PIPJ extension was 3° (range: 0–7°) and the average PIPJ flexion was 85° (range: 80–95°). Two patients with intra-articular thumb fractures averaged 16° of IPJ hyperextension (range: 12–20°) and 60° of IPJ flexion (range: 55–65°). There was no fracture displacement or malunion. No patients required mini screw removal. Although this series is small, the results were uniform and suggest that headless mini screw fixation may be superior to open mini screw fixation and at least equivalent to multiple wire fixations. More data and replication of these results are needed.

Long Oblique Proximal Phalangeal Shaft Fractures

Green and Anderson reported that 18 out of 21 (87%) oblique proximal phalangeal shaft fractures treated with two or more transfixing K-wires healed and achieved a full range of motion at eight weeks after injury (6). Belsky et al. reported fracture healing and 29 good [total active motion (TAM) 180–220°] and 61 excellent (TAM $>220°$) motion in 90 out of 100 consecutive closed simple phalangeal shaft fractures treated with percutaneous K-wire CRIF (5). Out of the total, 55 fractures were oblique.

Using open K-wire fixation on a variety of closed phalangeal fracture configurations, Widgerow, et al. reported results nearly equivalent to those of Green and Anderson and Belski, et al. (5,6,40) Dabezies and Schutte reported excellent results (TAM $>220°$) in all 29 proximal phalangeal fractures stabilized with mini screws alone, or with mini plates placed on the dorsolateral side of the phalanx (19). They advocated a midlateral approach dividing the lateral band, if necessary, and avoiding the gliding tissue between the periosteum and the extensor apparatus. Ford, et al. reported 13 excellent results, four good results, and one poor result in 18 proximal phalangeal fractures treated by open reduction and internal fixation using 1.5 and 2 mm AO mini screws (30).

Diwaker and Stothard reported better results with open mini screw fixation than with percutaneous K-wires in their retrospective review of metacarpal and phalangeal fractures (41). Horton et al. conducted a randomized prospective study of 22 patients with oblique extraarticular proximal phalangeal

fractures treated with percutaneous K-wire or open mini screw fixation (21). Fractures were approached through a midlateral incision and, if necessary, the lateral band was excised. There were no differences between the two groups in outcomes for fracture union, functional recovery, or residual deformity. All fractures united and the patients returned to their previous jobs. Case reports of fracture union with excellent functional recovery using percutaneous or limited open incision of 1 to 2 cm and internal mini screw fixation of oblique phalangeal shaft fractures have been published (42,43). More data and report replications are needed to determine the efficacy of percutaneous mini screw application as compared to percutaneous K-wire or open K-wire or mini screw fixation.

Articular Fractures—Phalangeal Base

CRIF with percutaneous K-wires are widely used to stabilize articular fractures of the phalangeal base. Larger fractures involving greater than 25% of the articular surface are typically quite accessible for percutaneous mini screw insertion, but few specific data are available for this specific fracture.

SUMMARY

General Conclusions

Clinical results for oblique phalangeal fractures treated with open mini screw fixation compare favorably with those using percutaneous Kirchner wires (5,6,16,18,30,41). A midlateral approach avoiding incision of the dorsal apparatus, sparing of the gliding tissue between the periosteum and the extensor mechanism, increased stability, and earlier and more intensive therapy are among the factors that may explain these somewhat paradoxical equivalencies between percutaneous K-wire and open mini screw fixation. Two case reports of percutaneous mini screw fixation yielded excellent digital motion.

Reports suggest that percutaneous mini screw fixation may have an advantage over percutaneous K-wire or open K-wire or mini screw fixation for treatment of undisplaced or adequately reduced closed simple oblique Bennett's, phalangeal unicondylar, and articular phalangeal base articular fractures with large fragments (>25% of the articular surface), but those reports are not conclusive (44,45). Spiral fractures or smaller (<25% of the articular surface) articular fragments may be more challenging than uniplanar fractures or fractures with larger fragments. Cannulated headless mini screws may provide an advantage over conventional mini screw application. The surgeon should not hesitate to convert to an open procedure to assure an adequate fracture reduction or if technical difficulties arise with fixation that cannot be salvaged with percutaneous K-wire fixation.

Future Direction of the Technique

The validity of conclusions based upon the material cited in this chapter are confounded by a variety of shortcomings in study design; statistical power; enrollment; randomization; effect sizes; uniformity of selection, outcome criteria, and complication categories; failure to sort specific fracture configurations; blinding; bias; confidence intervals; and replication (44–46). Greater enrollment is needed to detect beta errors (complications) reflecting minor, intermediate, and major trends (47,48). We need to know how many cases are converted to open procedures owing to failure of reduction or technical difficulties. Follow-up of a year or more is needed to attain an accurate assessment of the recovery of motion. The occurrence of arthritis is related to the accuracy of reduction and its severity may be time-related (7,28,29). Long-term follow-up is needed to assess these parameters. Subjective patient outcome and cost analyses would be helpful.

Logic would dictate that percutaneous procedures would be less likely to cause stiffness than open procedures and that fractures treated with mini screws might recover more motion and have less morbidity than those managed with K-wire fixation. What are the absolute and relative overall specific complication rates among the procedures discussed? More data, improved study design, longer follow-up, higher levels of evidence, and unconflicted replication studies are needed to support or refute the relative risks and benefits of percutaneous and open wire and mini screw techniques (44–49).

At the highest level, a prospective double-blinded, randomized, controlled trial (RCT) could be initiated between or among methods currently considered equivalent or nearly equivalent. A single research question should be addressed, e.g. "Does percutaneous mini screw fixation provide any advantage over percutaneous Kirchner wire fixation in oblique proximal phalangeal shaft fractures as determined by total active range of digital motion at one year after injury?" A pre-study power analysis should be done to assure adequate enrollment for statistical validity. A multi-center study may be necessary to assure adequate enrollment, with the caveat that multi-center studies have unique inherent deficiencies (44,45). Uniform selection and evaluation criteria and comprehensive complication reports are essential. RCTs may not be practical owing to issues of enrollment, time, and cost. Alternatively, more carefully designed prospective consecutive case series with adequate enrollment, blinded evaluation of results, and at least 1 year of follow-up would improve upon our current level of evidence.

SUMMATION POINTS

Indications

- Bennett's fractures with large fragments (>25% of the articular surface).
- Unicondylar phalangeal fractures with large fragments (>25% of the articular surface).
- Oblique phalangeal shaft fractures.
- Articular phalangeal base fractures with large fragments (>25% of the articular surface).

Outcomes

- No nonunions to date.
- No loss of reduction to date.
- Slightly less residual PIPJ and digital stiffness.

Complications: Reported to Date

(Key: None; Rare, <5%; Occasional, 5–10%, Frequent, >10%)

- Inadequate reduction: none.
- Conversion to an open procedure: none.
- Loss of reduction: none.
- Technical problems with implant insertion: none.
- Stiffness: frequent.
- Cold intolerance: none.
- Nonunion: none.
- Malunion: none.
- Dystrophy: none.
- Arthritis: none.

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8

Intramedullary Rodding of Metacarpal and Phalangeal Fractures

Jorge L. Orbay, Amel Touhami, and Igon Indriago
Miami Hand Center, Miami, Florida, U.S.A.

INTRODUCTION

Fractures of the long bones of the hand are of special interest because of their frequency and their propensity to result in functional loss. Closed treatment has been the mainstay of management for these injuries but the failure of nonoperative treatment on the more unstable fractures has prompted the utilization of surgical methods. Internal fixation provides improved final reductions but involves a trade off with iatrogenic soft tissue injury. Flexible intramedullary (IM) nailing of extra-articular metacarpal (MC) and proximal phalangeal fractures provides ample fixation while avoiding the soft tissue injury associated with plate and screw application.

Percutaneous IM Kirschner (K) wire fixation was first advocated in 1953 by Vom Saal (1) who introduced the wire in a retrograde fashion through the flexed distal joint. Clifford (2) used Vom Saal's method successfully in 36 patients with phalangeal or MC fractures. In 1976, anterograde MC K-wire fixation was reported by Foucher (3,4); it was explained as a "bouquet" osteosynthesis or as a method of "fasciculated IM pinning" for MC fractures. The fractures were to be reduced and closed, and multiple flexible pins were passed anterograde inside the medullary canal and into the MC head. It avoided both the opening of the fracture site as well as injury to the soft tissues around the metacarpophalangeal (MP) joint. Although the bouquet technique adequately controlled rotation at the fracture site, its main drawback was pin migration, shortening and the inability to support comminuted or spiral fractures. To overcome these limitations, new strategies were developed such as those suggested in 1981 by Vives et al. (5) who combined an axial pin introduced through the base of the MC with an antirotation transverse pin through the heads of the MCs. Gonzalez and Hall fixed transverse or short oblique fractures by using pre-bent flexible IM nails similar to Ender nails, instead of K-wires (6,7). To improve rotational stability and minimize shortening, Orbay et al. (8,9) enhanced fixation of flexible nails by adding a proximal locking pin. This feature broadened the indications for the procedure to include long oblique, spiral and comminuted fractures. In summary, over the past three decades, closed flexible IM nailing has evolved as an alternative to plating techniques to treat simple and complex extra-articular fractures of the long bones of the hand.

INDICATIONS

Specific Diagnoses

Phalangeal Fractures

Although simple fractures can be treated successfully with closed methods, proximal phalanx fractures can result in unacceptable deformity and loss of proximal interphalangeal (PIP) joint function. IM nail fixation is particularly beneficial for the proximal phalanx where the extensor tendon is very prone to develop post-surgical adhesions. Most extra-articular fractures are good candidates for the technique. Hyperextension injuries can produce proximal transverse fracture patterns; these are usually stable and amenable to close treatment. Transverse and short oblique fractures of the mid-proximal phalanx are optimal fracture types; these injuries are potentially unstable in rotation therefore, either two non-locked nails or a single proximally locked nail should be used. Long oblique, spiral, or comminuted proximal phalanx fractures can result in excessive shortening (more than 5 mm) and produce an extensor lag. These fractures are also satisfactory indications, but a proximal locking pin is typically necessary to provide adequate stability. Transverse fractures of the distal phalangeal shaft or neck are a distinct subtype that can be adequately treated with two nails. Those patients presenting with a chronic fracture, a nascent, or established malunion may also be treated with reconstructive surgery using flexible IM nailing, provided that the fracture is exposed through a formal incision and the callus released or excised. Open fractures with massive soft tissue damage are usually best treated by more rigid forms of fixation as the presenting wounds provide the necessary exposure, and flexible nails do not provide an advantage.

MC Fractures

Most simple extra-articular MC fractures will proceed to healing uneventfully with nonoperative treatment (10). However, some MC fractures will require fixation when an adequate reduction cannot be maintained by closed methods. Persistent angulation, after closed reduction, in excess of 45° for the small finger, 30° in the ring finger, and 20° in the middle and index fingers; projection of the MC head into the palm; clawing on extension of the fractured digit; significant loss of knuckle contour and MC shortening of more than 5 mm; all constitute good indications for operative treatment.

Most extra-articular MC fractures that can be manipulated into an acceptable reduction will be good candidates for closed flexible IM nailing. Transverse fractures of the MC shafts are usually longitudinally and rotationally stable after reduction; therefore, a single unlocked nail will provide the necessary stability (Fig. 1). Likewise, the patient with multiple transverse MC fractures is a good candidate for this procedure. Patients with MC neck fractures, if severely displaced or multiple, benefit from this form of treatment. Because of the small size of the distal fragment, proximal locking prevents nail back-out and therefore, loss of fixation. Spiral, long oblique, and comminuted fractures can be both rotationally and longitudinally

FIGURE 1 Transverse fractures of the metacarpal shafts may only require a single unlocked nail.

unstable; therefore, proximal nail locking is usually necessary (Fig. 2). Established or nascent malunions will respond to callus debridement through a small incision and IM fixation. Open fractures can be treated with this method but again the benefits of flexible IM fixation decrease with the extent of the soft-tissue defect.

Contraindications

Absolute Contraindications

Intra-articular involvement of both the proximal and distal ends of the MC, open fractures with massive soft tissue injury especially those with bone loss, local or systemic infections, previous or active osteomyelitis in the same bone, and patients who cannot cooperate are not amenable to IM nailing. Furthermore, inability to obtain closed reduction constitutes a contraindication to close IM nailing but not to open nailing.

Relative Contraindications

Patients with osteoporosis, tendon injury, and open fractures with minimal or moderate soft tissue injury are still good candidates for IM nailing provided the device is proximally locked and the associated injuries repaired. Non-locked IM nailing is not ideal for long oblique and spiral fractures, comminuted fractures, or fractures in osteoporotic bone as shortening or nail back out can occur.

Open MC fractures with massive skin, tendon, and bony loss often require plate fixation in order to provide rigid stability and apply an intercalated bone graft. In contrast, MC neck fractures are seldom plated due to the inherent surgical morbidity but can be adequately treated with closed flexible IM nailing.

PREOPERATIVE PLANNING

Preoperative Physical Examination

A number of parameters should be evaluated in the physical examination including:

- Assess active range of motion

Evaluate deformity:

- Angulation
- Shortening
- Malrotation (poorly tolerated and difficult to assess on plain radiographs, is best judged clinically by asking the patient to *simultaneously* flex all the fingers as the surgeon watches for scissoring or digital overlapping)
- A loss of knuckle contour
- *Pseudoclawing* (compensatory MP hyperextension and PIP flexion)

FIGURE 2 Spiral, long oblique, and comminuted metacarpal fractures can be both rotationally and longitudinally unstable. A locked nail is usually necessary.

- Assess integrity of soft tissue sleeve and flexor and extensor tendons
- Assess swelling and neurovascular status.

Specific Consideration for the Technique

The surgeon must assess if the fracture can be reduced by closed manipulation. This is ultimately done in the operating room (OR) under fluoroscopy and anesthesia, but a good estimate of the ease of reduction can be made during the physical examination by assessing the extent of the healing process and the acuteness of the inflammatory response.

Preoperative Imaging

Plain Films

Most MC and phalangeal fractures are readily diagnosed with standard posteroanterior and lateral radiographs. Lateral views may be difficult to interpret because of the overlying adjacent MC bones. In this case, oblique views will be helpful. Angular malalignment is radiographically apparent in either the coronal or sagittal plane. Rotational malalignment is best assessed by clinical means.

Advanced Imaging

Cross-sectional imaging, and particularly computed tomography, permits multiplanar analysis of any fracture but are rarely useful in the assessment of these fractures. In the OR, the use of a fluoroscopy unit is essential in order to perform this procedure. Portable mini-fluoroscopy units have been shown to reduce radiation exposure and operating time substantially.

SURGICAL TECHNIQUE

OR Setup and Equipment

Closed IM nailing is usually performed in a formal OR where a mini C-arm fluoroscopy unit is available and using local or regional anesthesia. The hand is draped sterile over a hand table and it is first confirmed that the fracture can be reduced by closed manipulation. If the fracture is not reducible, an open form of IM nailing must be chosen. The sterilely draped mini C-arm is brought into the field as necessary.

Pre-bent flexible IM nails have a blunt tip and come in a sterile peel pack which includes a bending and exchange tool and an implantable radiopaque nail cap to protect the soft tissues from the sharp cut end of the nail (SBFS. Hand Innovations-Depuy. Miami, Florida, U.S.A.). Nails measuring 1.1 or 1.6 mm in diameter are available in the system and come attached to a handle. Selection of nails is determined by the size of the involved phalanx or MC.

Operative Approach

MC Fractures

First, the location of the introductory portal is decided by placing, under fluoroscopy, the tip of a Mosquito forceps over the hand. A small 5 to 10 mm skin incision is made at the level of the proximal aspect of the fractured MC bone (Fig. 3). MCs 2, 3, and 4 are usually approached from the dorsal aspect; MCs 1 and 5 are usually approached from the radial and ulnar sides, respectively. Careful spreading of the soft tissues is particularly important with fractures of the third and fourth MCs because these digital extensor tendons are in, particularly, close proximity to the nail insertion site.

The medullary canal is accessed with the aid of a specially designed awl that also serves to deliver the nail. These two parts come assembled as a unit. The dorsal metaphyseal cortex is perforated with this awl and the nail is deployed into the medullary canal.

The nail is then advanced to the level of the fracture site; the fracture is manipulated and reduced under fluoroscopic guidance and the nail driven into the distal fragment (Fig. 4). If necessary, the nail can be removed and the curvature of the nail modified to achieve 3-point fixation or to better negotiate the fracture. Reduction of MC fractures is facilitated by flexing the MP joint 90° to tighten the collateral ligaments and stabilize the distal fragment. After nail insertion, rotational alignment should be checked by moving the fingers into a fist. Longitudinal traction and direct manipulation are the mainstays in correction of fracture displacement.

The nail is finally advanced into the subchondral bone of the MC head where additional rotation of the nail can assist in the final reduction. Compression is applied axially across the fracture site to prevent distraction. Once the surgeon is satisfied with reduction and nail placement, the decision to whether to lock or not to lock the nail is made. Locking the nail proximally greatly enhances rotational and longitudinal stability therefore; locking is desirable in the case of oblique, spiral or comminuted fractures. If locking is not indicated, as in the case of a transverse or short oblique MC shaft fracture, the surgeon cuts the handle off the nail, bends the proximal end to facilitate later retrieval, and cuts the remaining end off beneath the skin to prevent pin tract infection. If locking technique is used, a proximal locking sleeve is slipped over the bent end of the nail and driven transversely into the proximal metaphysis (Fig. 5). Fluoroscopic guidance is necessary for this step. When the locking pin contacts the volar cortex, resistance is encountered, indicating that the device is appropriately seated. Small teeth engage the locking pin to the nail preventing component disengagement during rehabilitation. Next, the nail and locking pin are cut below the skin and covered with the radiopaque plastic cap (Fig. 6). This step is important in order to protect the extensor tendons. For the majority of rotationally stable fractures, either a single locked or an unlocked IM nail is used. In the face of significant rotational instability, either a locked nail or multiple nails are inserted. Multiple nails are used if persistent instability of the fracture is encountered following the insertion of a single nail especially if the patient has an excessively large IM canal.

Proximal Phalanx Fractures

Reduction of fractures of the proximal phalanx is facilitated by flexing the MP joint 90°, so that the collateral ligaments stabilize the proximal fragment, the distal fragment is then reduced onto the proximal fragment. The finger can then be used to derotate the distal fragment. Proximal phalanxes are approached from either dorsal or lateral aspects and necessitate a limited splitting of the extensor expansion. Soft tissues including extensor tendons are mobilized bluntly and dissection is carried down to the bone surface. For transverse and short oblique fractures of the proximal phalanx, two nonlocked nails (Fig. 7) or a proximally locked nail should be used. If the fracture pattern is long oblique or spiral, a proximal locking pin is typically necessary to provide adequate stability (Fig. 8).

Closure and Post-Operative Management

Intraoperatively, a post-operative sterile dressing that blocks the MP joints in flexion is applied. This post-operative dressing is

FIGURE 3 A fracture of the fourth and fifth MC. First, a small 5 to 10 mm skin incision is made at the level of the proximal aspect of the fractured MC. *Abbreviation*: MC, metacarpal.

FIGURE 4 The nail is then advanced to the level of the fracture site; the fracture is reduced and the nail driven into the distal fragment.

removed at approximately one week after surgery. When a non-locking device has been used for a MC, the hand may be supported for four weeks with an MP flexion block splint or cast that allows interphalangeal (IP) motion. The use of a locking device for MC fractures allows unsupported MP and PIP joint motion, thus splinting is not required. In contrast, some form of splinting: buddy taping, PIP extension, or MP block, alone or in combination, is usually used for all proximal phalangeal fractures and also, more careful physical therapy is necessary. After radiological confirmation of bone healing (usually between four and eight weeks) all nails are routinely removed, usually in the OR, using local anesthetic and sterile technique.

■ COMPLICATIONS AND THEIR MANAGEMENT

■ Pitfalls

Inadequate Reduction

Malrotation is the most likely form of malreduction. This is a more pressing point with phalangeal fractures but can occur with spiral fractures of the MCs. Careful attention to clinical

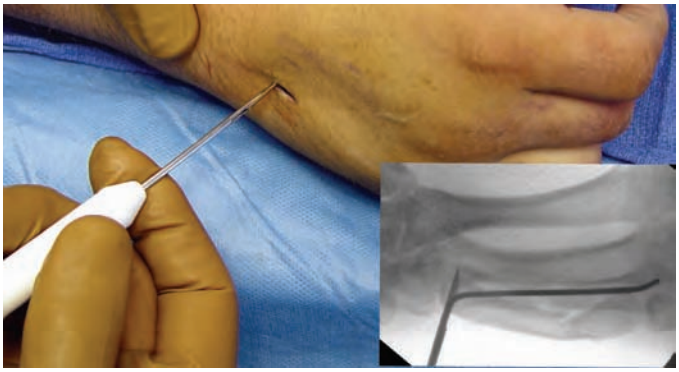

FIGURE 5 If locking technique is chosen, a proximal locking sleeve is slipped over the bent end of the nail and driven transversely into the proximal metaphysis.

rotation is imperative. The use of MP block splints corrects malrotation of the MCs and buddy splints, sometimes in combination with an MP block splint, will support the proper rotation in a phalangeal fracture. Because the rotational stability of IM nails is limited, errors of reduction can be corrected by remanipulation and supported by subsequent splinting. Angular malreduction is less likely with IM nails. Loss of length can occur for spiral or comminuted fractures. This is a particularly important issue in proximal phalanx fractures due to the resulting extensor lag. Fixation in overdistraction can also occur and result in problems with bone healing.

Poor Fixation

Fixation failure is uncommon with IM rodding of hand fractures but can occur in rotation, particularly with proximal phalanx fractures, if not supported properly. It can also involve longitudinal collapse if unstable fractures are treated with an unlocked nail and backing out occurs or if a locked nail penetrates through the MC head.

Penetration of the Nail

Through the MC head can occur in very distal fractures especially in patients with osteopenic bone. Avoiding placement of the nail tip against the subchondral bone and instead placing the bend of the nail against it or the use of multiple nails can help avoid this problem. This complication is treated by nail removal after the fracture is healed.

Excessive Distraction

Of the fracture can result in a delayed union. With either locked or unlocked technique, the surgeon must be careful to impact

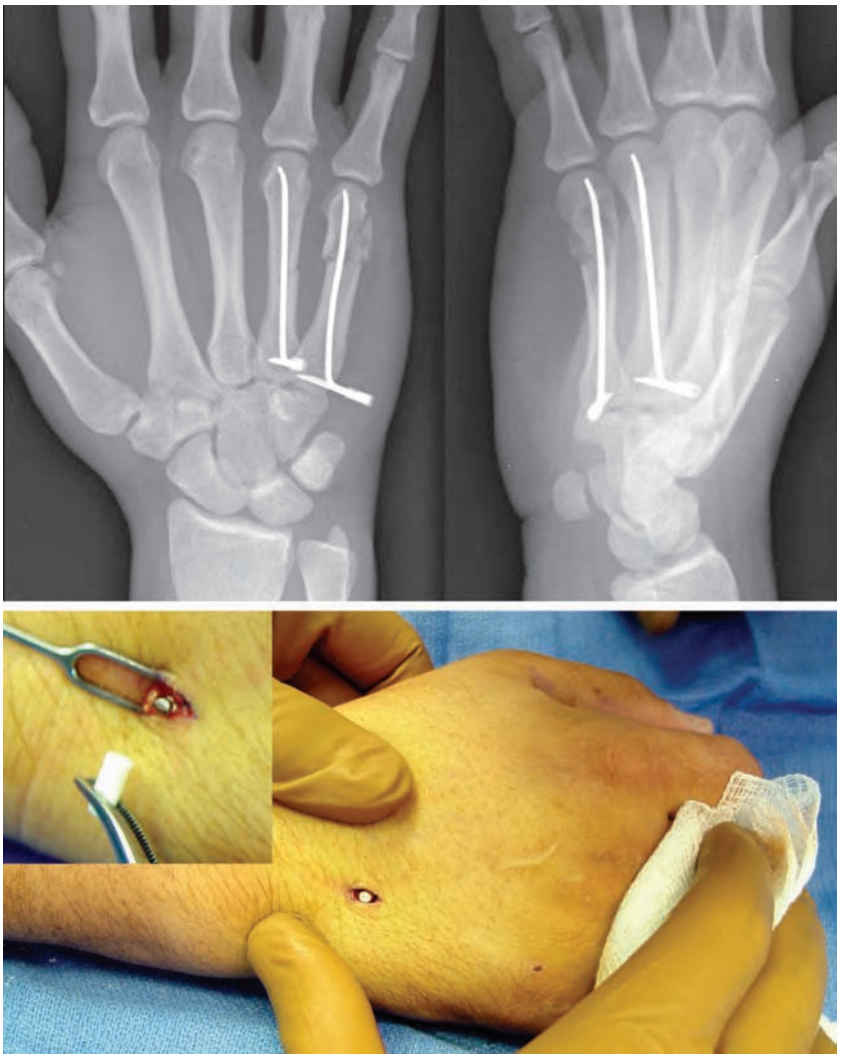

FIGURE 6 After fixation is completed, the nail and locking pin are cut below the skin and covered with the radiopaque plastic cap in order to protect the soft tissues.

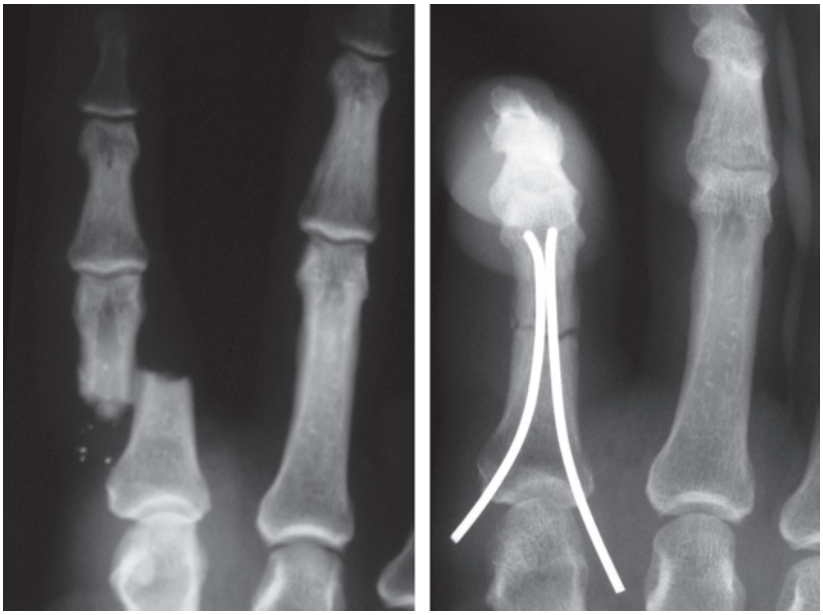

FIGURE 7 Transverse and short oblique fractures of the mid-proximal phalanx are unstable in rotation; either two non-locked nails or a proximally locked nail will provide stability.

the fragments at the fracture site to prevent this problem after inserting the nail.

Soft Tissue Injury

In the case of a fracture of the long or ring finger MC, the proximal end of the nail is located in the vicinity of the extensor tendons, raising the danger of tendon irritation or even rupture. This can occur due to mechanical attrition against the raw metal surface of the cut end of the nail. For these fractures, the use of an MP flexion block splint may minimize excursion of the extrinsic extensors and therefore the likelihood of tendon problems during rehabilitation. Tendon injury can be definitely prevented by using a protective soft tissue plastic cap that covers the cut end of the nail and provides a safe gliding surface. Cases of serious tendon irritation are best managed by early pin removal, tendon rupture will require repair. In the case of proximal phalangeal fractures, the tendon is very broad and has a very short excursion; for this reason, rupture does not occur but adhesion of the extensor expansion may limit PIP motion.

Malunion

It is the result of untreated malreduction and may require osteotomy.

■ Bailouts

Stiffness

Careful follow-up of patients will allow the surgeon to identify those patients who are at risk for this problem. Stiffness is a complex problem that includes injury and personality related factors. Much can be done to prevent and treat it. Communication with the patient and a good therapist is essential for success. The MP joints, in susceptible individuals, will tend to ankylose into extension after MC fractures; this tendency is easily corrected by placing the hand in an MP block splint that

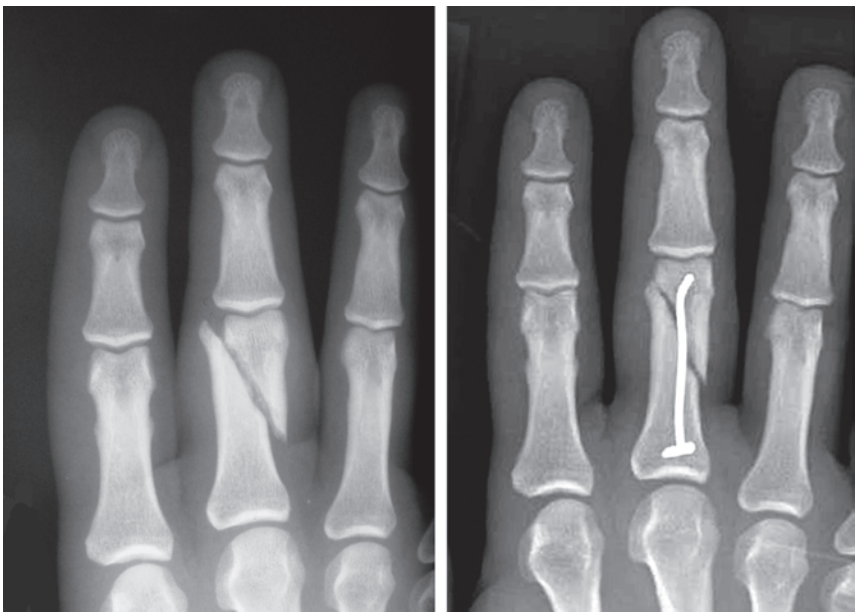

FIGURE 8 Long oblique, spiral, or comminuted proximal phalanx fractures can result in excessive shortening (more than 5 mm) and extensor lag. These fractures will require at least one proximal locked nail.

allows free IP motion. The PIP joints of most patients will tend to ankylose into flexion after proximal phalangeal fractures. This is a vexing problem with no easy solution that is aggravated by the extensor lag that results from phalangeal shortening. Encouraging active motion may be helpful in mild cases. PIP extension splinting and hands-on therapy are the mainstays of treatment. In severe cases, dynamic or progressive splints are necessary. Complex Regional Pain Syndrome is an extreme condition of the stiffness spectrum; here, referral to a pain specialist for sympathetic blocks is very effective when done early enough. Occasionally, a capsular release can be done as a salvage procedure for the long established PIP flexion contracture.

Malunion

A fracture that heals with rotational malreduction results in significant functional impairment. This problem is best avoided by paying attention in the operative theater to correct rotation and by careful patient follow up; which will not only reveal patients at risk of stiffness but also those with malreduction. Clinical inspection of the hand as the digits move from full extension into full flexion will demonstrate the presence of these two problems. Interestingly, stiffness and rotational malreduction often occur simultaneously; this occurs because full functional motion of the digits tends to correct rotational malalignment of both MC and proximal phalanx fractures. Prior to fracture healing, MP block splinting and active IP motion can correct rotational malreduction in MC fractures. Phalangeal fractures may respond to a combination of MP block splinting and buddy splinting. After fracture healing in a malrotated position, osteotomy is the only possible salvage.

PIP Joint Extensor Lag

True extensor lag as opposed to PIP flexion contracture is due to phalangeal shortening. There is no effective treatment for this condition except for prevention by accurate reduction.

Nonunion

In MC or phalangeal fractures this problem is uncommon, although delayed union is occasionally seen as a result of distraction at the fracture site. Infection and bone loss are predisposing factors to nonunion. Operative intervention is advised four months after the injury because additional immobilization is likely to cause significant stiffness. Intercalated bone grafting and plate fixation will maintain length and provide stable fixation.

Infection

Post-operative infection is uncommonly encountered after closed hand fractures are treated with internal fixation. Those observed were associated with pins that protruded through the skin. Pin removal should be done when allowed by fracture stability. Antibiotics whether oral or intravenous can be temporizing until fracture stability is achieved.

OUTCOMES

We recently reported (11) our results in 125 unstable closed fractures of the proximal phalanges and MCs. Of these fractures, 95 (76 MC and 19 proximal phalanges) were treated by a locking flexible pre-bent IM nails, 55 fractures (34 MC and 21 proximal phalanges) were treated with a non-locking flexible pre-bent IM nail. In both groups, fractures patterns were similar: transverse shaft, neck and oblique, spiral or comminuted. We evaluated total digital active motion, grip strength, residual deformity, and remaining pain using the visual analog scale (VAS). Anteroposterior and lateral radiographs were also assessed for healing and residual displacement of the fracture. Residual shortening was measured according to the method described by Manueddu and Della Santa (12). Our study was limited by being retrospective in nature and by the fact that the indications for the procedure evolved over time. The ability to lock the nails expanded the indications to fractures previously not considered suitable for IM fixation.

Our data suggested that both methods were similar, with the only statistically significant difference ($p < 0.05$) noted in our treatment groups being in the average time to recovery. The locking treatment group averaged 5.6 weeks, compared with 5.9 weeks for the non-locking treatment group. Phalangeal fractures proved to be challenging, and did necessitate an additional splinting even with the use of a locking device as opposed to the MCs. Indeed, at final follow up, loss of PIP joint extension was common averaging 20° (range 5–35°) for the non-locking treatment group and 17° (range 5–30°) for the locking treatment group, while all MC patients had regained full MP extension with no extensor lag or pseudoclawing. All patients were able to reach the palm with their fingertip in both treatment groups. Finally, both MC treatment groups were statistically comparable in terms of their average grip strength and their VAS. Although this data showed that multiple nails, proper splinting, or the use of single locked nails are all acceptable methods for maintaining adequate rotational alignment in unstable fractures, only a proximally locked nail proved to be adequate for preventing collapse in longitudinally unstable fractures.

Complications were few: a delayed union for more than eight weeks was observed in two patients in the non-locking treatment group with transverse MC shaft fractures and one patient in the locking treatment group with a spiral proximal phalanx fracture, probably subsequent to an over distraction at the fracture site. Two patients in each group experienced extensor tendon irritation after fixation of the third or fourth MC; these two cases belonged to the non-locking treatment group where the plastic protector caps had not been used. These cases were managed by early pin removal. Penetration of the wire through the MC head and into the MP joint was observed in three patients who were older than 65 years, these also required early pin removal; one in the non-locking treatment group and two in the locking treatment group. Interestingly, persistent pain, sensory dysfunction, residual rotational deformity, malalignment, clinically significant angular malunion, nonunion or infection, were not observed in either treatment groups.

SUMMARY

General Conclusions

Locked or unlocked flexible IM nailing of the MC and phalangeal fractures is a minimally invasive technique that saves OR time, minimizes soft tissue dissection, limits scarring and avoids exposure of the fracture. This procedure has a low complication rate and provides good functional results.

Future Direction of the Technique

The use of proximally locked nails may safely extend the indications to rotationally and longitudinally unstable fractures (long oblique, spiral and comminuted fracture patterns) and minimizes the need for post-operative splinting in MC fractures. The ability to lock the distal aspect of the nail will

further improve stability and hopefully enhance recovery in patients with fractures of the long bones of the hand.

SUMMATION POINTS

Indications

Most displaced/unstable extra-articular fractures of the MCs and the proximal phalanxes including those with the following patterns:

- Transverse fractures
- MC neck
- Oblique/spiral fractures
- Comminuted fractures, provided that the comminution is limited to the mid diaphyseal segment.

Outcomes

- Overall, hand function after MC fracture fixation very closely approximates that of the intact hand.
- In contrast, function after proximal phalangeal fracture fixation frequently results in at least a mild permanent deficit, typically in the form of loss of PIP extension.
- The management of proximal phalanx fractures proves a greater challenge to the surgeon than the management of MC fractures.

Complications

- Delayed union
- Extensor tendon irritation especially for the third and fourth MCs
- Penetration of the nail through the MC head and into the MP joint.

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9

Hinged Fixation and Dynamic Traction of PIP Fracture Dislocations

Kenneth R. Means, Jr., James P. Higgins, and Thomas J. Graham
The Curtis National Hand Center, Union Memorial Hospital, Baltimore, Maryland, U.S.A.

INTRODUCTION

Any surgeon who has attempted to treat complex injuries of the proximal interphalangeal joint (PIPJ) of a finger knows the difficulties inherent to the task. Perhaps in no other area of treatment in the upper extremity is the desire to achieve "minimally invasive" management more germane. This aspiration stems from the intrinsic nature of the PIPJ to become exceedingly stiff and lose function following most open, or "maximally invasive," interventions. However, specific challenges must be met for such treatment to be successful. These include establishment of a stable joint, the ability to begin active range of motion as soon as possible, and, perhaps to a lesser degree, restoration of joint congruity (1–3). Hinged fixation and dynamic traction can potentially achieve these goals through indirect joint reduction via ligamentotaxis and by providing a construct that allows immediate range of motion.

The endeavor to create minimally invasive options for PIPJ fracture dislocations is a process that has gone through several stages. Dynamic traction external fixation mechanisms began with the "homemade" use of various combinations of pins, methylmethacrylate rods, springs, or rubber bands, and included Schenk's dynamic traction device with its circular frame requiring construction by a certified hand therapist (4). Lower profile styles were later developed and have included the Agee force couple system and other hinged dynamic external fixators popularized by Slade, Suzuki, Inanami, and others (5–8). The force couple process uses three Kirschner (K) wires and a rubber band and is designed to reduce the head of the proximal phalanx dorsally and the base of the middle phalanx volarly. This and other hinged dynamic external fixators are built around the center of axis of rotation of the PIPJ, which lies within the head of the proximal phalanx. These methods are low in cost and readily available to the surgeon. However, some have found them to be difficult to create and even more challenging to establish and maintain a reliably stable PIPJ during range of motion. Some have also felt them to be cumbersome to patients (9). In addition, there are certain restrictions to their use. For example, use of the Agee force couple splint requires a stable dorsal portion of the base of the middle phalanx to resist axial and dorsal displacement of the PIPJ (1). Some of the complications and limitations encountered with these techniques led to the development of more biomechanically robust and more easily reproduced alternatives. These commercially offered systems consist of the Smith & Nephew Proximal Interphalangeal Hinge, often referred to as the Compass Hinge (Memphis, Tennessee, U.S.A.) and the Biomet BioSymMetRic PIP Fixator (Warsaw, Indiana, U.S.A.) (Fig. 1) (9).

INDICATIONS

The most common usage of hinged fixation dynamic traction is in the treatment of complex PIPJ fractures, dislocations, and fracture-dislocations. These include unstable dislocations treated in open or closed fashion to attain reduction. Also, surgeons treating fractures or fracture-dislocations involving the base of the middle phalanx and, less commonly, the distal aspect of the proximal phalanx may use dynamic traction as a sole method or in combination with open procedures and fixation as a force neutralization mechanism. Most commonly the technique is used for "pilon"-type fractures or fracture-dislocations of the base of the middle phalanx where there is extensive comminution and instability that is not amenable to other fixation options or requires supplementation for stability or force neutralization during early active range of motion. Hinged dynamic traction may also be used following release of a PIPJ contracture, volar plate arthroplasty of the PIPJ, or percutaneous fixation of the PIPJ (10). The remainder of this chapter will focus on use of hinged fixator systems for treatment of the traumatic injuries to the PIPJ mentioned above.

Further refinement of the indications for these techniques must include a caution that they should be used only for complex PIPJ injuries. Simple dislocations or fracture-dislocations that are stable once reduced may be treated in a standard manner. Furthermore, when rigid stability is attainable and desirable, other internal fixation options should be considered. Specific contraindications to the use of a hinged traction system include a relative contraindication to its use in fractures and fracture-dislocations involving the distal aspect of the proximal phalanx. This is because most of the hinged traction processes use pins as a point of reference or fixation within the head of the proximal phalanx. However, if there is a fracture or fracture-dislocation of the PIPJ that includes the head of the proximal phalanx and other treatment options are not viable, dynamic traction may be used so long as any references pins will not disrupt bony stability and the external fixation apparatus will still span the entirety of the fracture. However, this is a truly rare situation and such injuries are usually better treated with percutaneous pins or static external fixation for a short period if the articular surface is felt to be salvageable, versus joint arthroplasty or arthrodesis if the cartilage component is irrevocably damaged.

Other contraindications to the use of hinged dynamic traction include those common to other fixation options, such as infection, complex soft tissue defects, and severe bone loss. Segmental injuries to the bony architecture of the digit usually preclude the use of a PIPJ specific fixator. Also, prudence must be exercised when a multisystem injury to the digit has been incurred, such as with concomitant tendon, nerve, or vessel

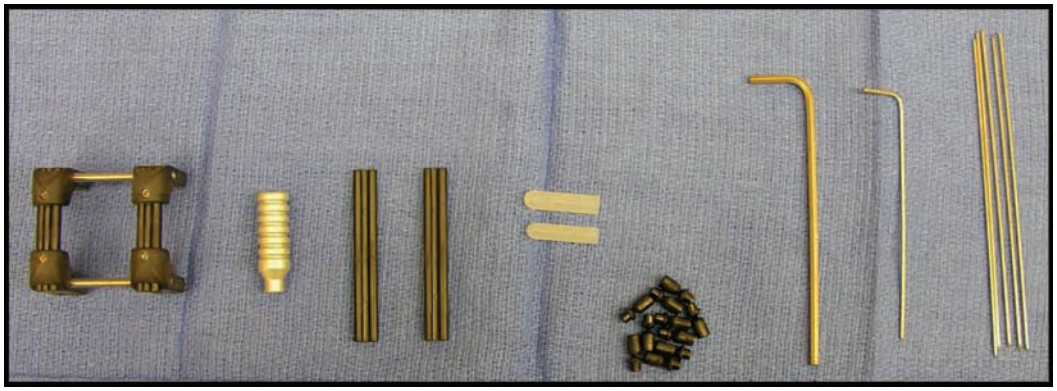


FIGURE 1 Biomet BioSymMetRic PIP Fixator set. *Source*: Photos courtesy of Kenneth R. Means, Jr.

damages requiring repairs which may be jeopardized by the placement of multiple pins for external fixation.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Preoperative physical examination of complex PIPJ fracture dislocations begins with standard inspection of the skin and soft tissue and by taking note of any gross deformity. Neurovascular status must also be determined preoperatively, both to prepare for operative interventions as necessary as well as to establish firm medicolegal documentation. Tenderness to palpation is usually easily localized to the PIPJ but there may be some difficulty in determining whether the primary injury is located within the proximal, distal, volar, or dorsal aspect of the PIPJ. Range of motion may be assessed although this is usually difficult and impractical given the patient's swelling and pain during the acute phase of the injury. Assessment with adequate anesthesia, especially at the time of definitive treatment, is likely to yield more useful information and will also provide invaluable clues as to the stability of the PIPJ throughout its range of motion.

Specific physical examination factors are relevant to the technique of hinged dynamic fixation. Significant soft tissue wounds may prevent use of external fixation, if pins cannot be safely placed outside of the zone of injury. Also, segmental digit injuries, such as associated distal interphalangeal joint (DIPJ) or metacarpal–phalangeal joint (MCPJ) pathology or phalangeal shaft fractures in the same digit, will likely prohibit use of these fixator systems.

Preoperative plain film radiography is usually the only "advanced" imaging or investigational modality necessary for these cases. However, particular radiographic considerations are pertinent to operative preparations. Evaluation must include anteroposterior, lateral, and oblique films of the PIPJ as well as images of the DIPJ and MCPJ at a minimum. Fluoroscopy at the time of definitive treatment can be very useful. It may be used to determine the point at which the PIPJ becomes stable and unstable at different degrees of flexion and extension, depending on the injury pattern. Also, close-up images can further delineate the degree of articular involvement. Traction films taken with the fluoro unit can give more information as to the personality of the injury and will often make the best surgical treatment options more apparent.

SURGICAL TECHNIQUES

The customary operating room setup for hand surgery cases is used. Anesthesia choices are at the discretion of the anesthesiologist, patient, and surgeon. The patient is supine, with the operative extremity on a hand table. We typically use a well-padded upper arm tourniquet, but a forearm or even a Penrose tourniquet at the base of the digit may be employed if desired. Mini C-arm fluoroscopy and all required implants should be available prior to bringing the patient to the room.

The surgeon will have chosen what type of fixation he or she wishes to utilize for the treatment of the PIPJ. Of course, this may change if fluoroscopic images in the operating room so dictate or if other factors not evident earlier become apparent. There are some general principles that may guide the decision as to what specific type of hinged dynamic fixator should be used. For example, unilateral fixation systems will obviously offer less stability than multiplanar modalities.

An exhaustive recount of the technical steps of the multiple surgical options available for hinged fixation dynamic traction is beyond the scope of this text. Instead, we will review a representative example of each of the two major classes of hinged dynamic fixation, namely those commercially obtainable and those made from materials that are readily on hand in the operating room.

The commercial PIP fixator we are most familiar with is the BioSymMetRic PIP Fixator, developed by the senior author (TJG) in association with Biomet (Warsaw, Indiana, U.S.A.). It is a bilateral frame that may be used in easily interchangeable static and dynamic modes, has a distraction option, and is biomechanically strong for stabilizing particularly challenging PIPJ fracture-dislocations. It also has a radiolucent frame, which allows complete visualization of the PIPJ during fluoroscopic or plain radiographic lateral and anteroposterior images (Fig. 2). We will then describe a simple bent wire fixator that does not require rubber bands, PMMA rods, or other materials and may be applied with ease and alacrity. It is similar to other models described in the literature (9,11,12). It is a construct that will not provide a large, reliable degree of distraction across the PIPJ and should be used as a stabilizing, force neutralization device only. Of course, this is likely the case for most if not all of the "homemade" bent wire-type mechanisms.

Application of the BioSymMetRic PIP Fixator

Step 1: Placement of the Axis of Rotation Pin

The PIP axis of rotation is located within the head of the proximal phalanx (7). All hinged dynamic traction devices for the PIPJ are built around this center of rotation. This centerpoint is equidistant from the distal, palmar, and dorsal surfaces of the head of the proximal phalanx. A true lateral of the

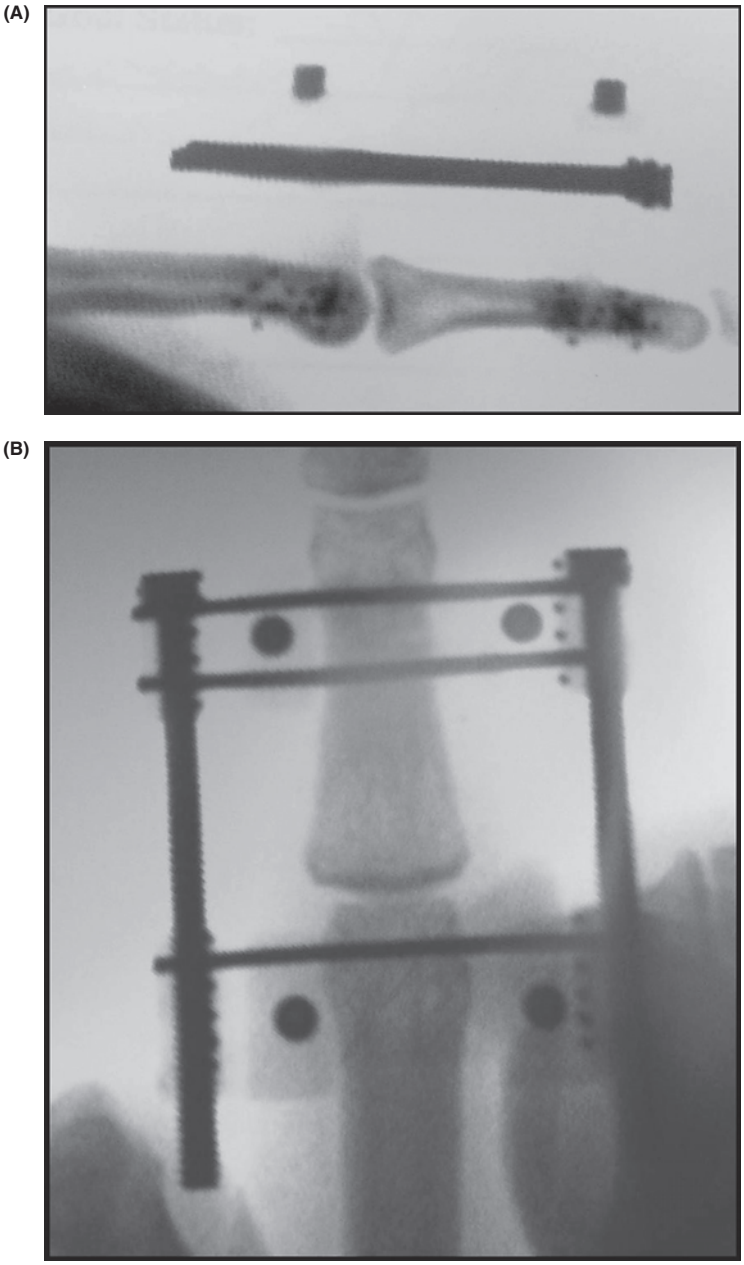


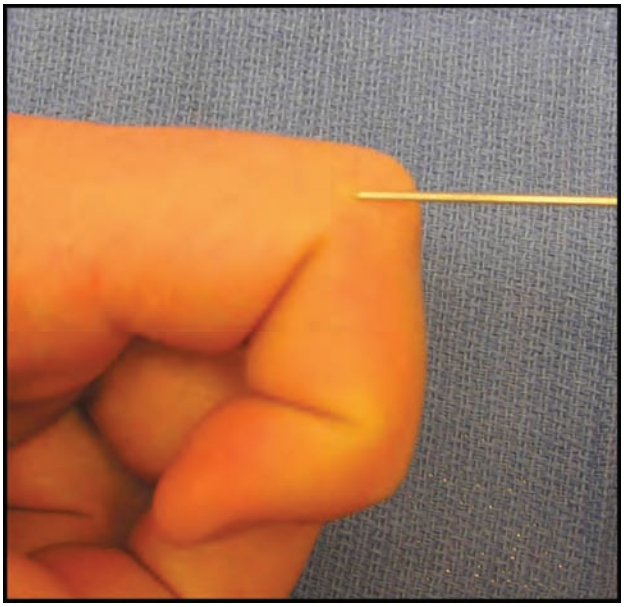
FIGURE 2 (**A**) Fluoroscopic lateral image of the Biomet BioSymMetRic Fixator demonstrating its radiolucent properties. (**B**) Anteroposterior fluoroscopic image of Biomet BioSymMetRic Fixator. *Source*: Photos courtesy of Kenneth R. Means, Jr.

proximal phalanx head with complete overlap of the condyles (no "double-shadow") must be attained in order to properly place this pin along the axis of rotation. Once this axis is found one of the external fixator pins may be placed using a "perfect circle" technique. First, the tip of the pin is placed on the skin and a fluoro perfect lateral image of the proximal phalanx head is taken. The tip of the pin is adjusted on the skin until the tip is over the exact center of the proximal phalanx (P1) head. Once this is confirmed, the pin is aligned with the axis of the fluoro beam and is driven into the head of P1 with a K-wire driver and through the skin on the other side of the digit. The starting point on the skin can also be very closely approximated by using specific skin markings. Namely, if the PIPJ is maximally flexed, a point midway between a line along the PIPJ digital flexion crease and the dorsal PIPJ skin marks the axis of rotation (Fig. 3). The fluoroscopic steps described above can then be used to confirm this. Once the pin is placed, it should appear as a single dot on a perfect lateral image of the proximal phalanx (Fig. 4).

Step 2: Placement of the Distal Pins in the Middle Phalanx

The fixator frame is checked to ensure that it is set up so that distraction may be used once applied, if desired. The distal pin in the middle phalanx is placed first, under fluoroscopic guidance. This pin is placed transversely in the distal third of the shaft of the middle phalanx along the midaxial line of the bone and through the skin on the other side of the digit. It is placed such that it is parallel to the exact transverse axis of the middle phalanx. The PIPJ is then reduced as necessary and the second, more proximal pin is placed in the middle phalanx. The frame may be used as a guide to place this second pin so that one is assured that the frame will easily be affixed to the two pins in the middle phalanx.

(A)



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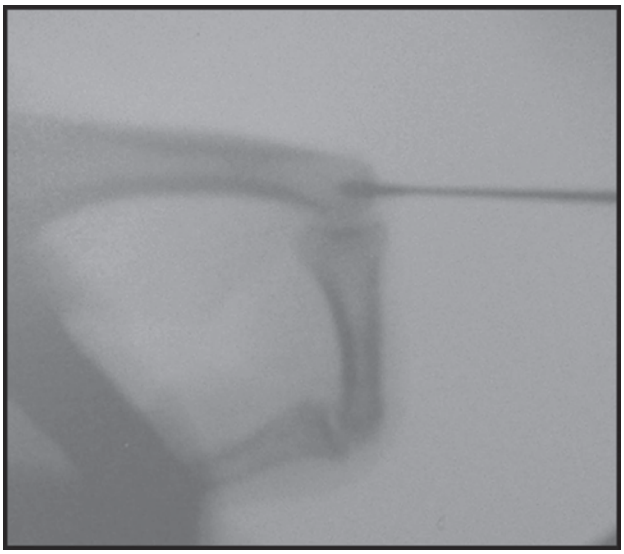

FIGURE 3 (**A**) Localizing the proximal interphalangeal joint axis of rotation in the P1 head based on the topographic anatomy. (**B**) Fluoroscopic "perfect circle" technique. *Source*: Photos courtesy of Kenneth R. Means, Jr.

Step 3: Application of the Frame

The locking portions of the frame are loosened for ease of application and adjustment. The frame is applied to the protruding fixator pins on the radial and ulnar sides of the digit. Once the frame is positioned as preferred to the optimal width and so there is adequate skin clearance, the Allen wrench is used to tighten the locking screws. The pins may now be cut flush with the frame and caps placed over the cut ends (Fig. 5A,B).

Step 4: Applying Distraction

The distal aspect of the frame houses the screw mechanism for distraction. The radial and ulnar sides may be distracted the same amount or differentially as needed to attain the desired PIPJ reduction and alignment.

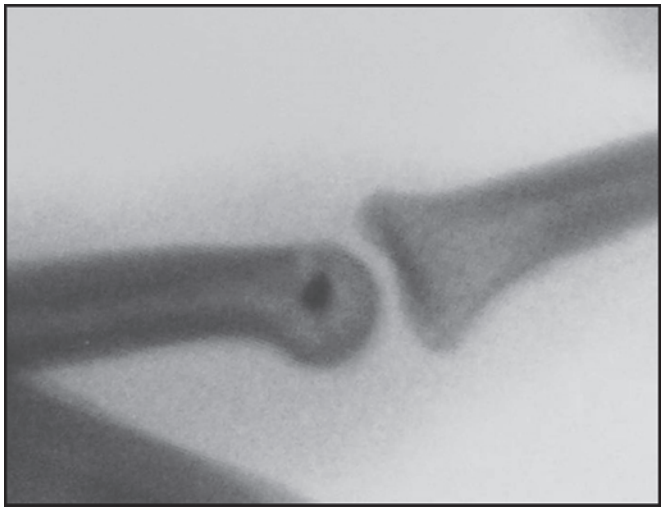

FIGURE 4 The pin should appear as a single dot on a perfect lateral view of the P1 head. *Source*: Photos courtesy of Kenneth R. Means, Jr.

Step 5: Static Mode vs. Dynamic Mode

The frame may be easily converted to a static external fixator by placement of a second pin in the proximal phalanx, which will prevent rotation about the central axis of the head of the proximal phalanx. The pin is placed through the guide hole in the frame in the proximal phalanx, proximal to the central head pin. The pin is cut flush with the frame and a cap applied. This pin may later be removed to return the frame to dynamic mode. This is carried out by loosening the dorsal distraction track screws so that the frame may be collapsed centrally, decreasing the width of the frame while still maintaining longitudinal traction (Fig. 6). This then allows access to the proximal most pin of the proximal phalanx. One side of the pin is cut flush with the skin, prepared with betadine, and the other, uncut end of the pin is grasped with a needle holder or pliers and removed. The frame width is restored and the dorsal screws tightened.

■ Application of Bent Wire Fixator

Step 1: Placement of the Axis of Rotation Pin

A 0.045-inch smooth K-wire is placed in the head of the proximal phalanx along the central point of rotation of the PIPJ as described above in "Step 1" of the application of the Biomet Fixator (7).

Step 2: Placement of the Middle Phalanx Pin

A second 0.045-inch smooth K-wire is placed in the middle phalanx in its distal third or as needed to span the bony injury. This pin is parallel to the transverse axis of the middle phalanx and along the midaxial line of the bone, through the skin on the other side of the digit (Fig. 7).

Step 3: Bending the Pins

The proximal phalanx axis of rotation pin is bent 90° on each side of the digit, such that the tips of the pin extend distal to the fingertip (Fig. 8). These tips are bent into an "S" shape at about the level of the DIPJ (Fig. 9). Lastly, the middle phalanx pin is bent into a "U" design on each side of the finger. This is done such that the curved portion of the "U" is distal and is in-line with the vertical area of the "S" portion of the proximal phalanx wire.

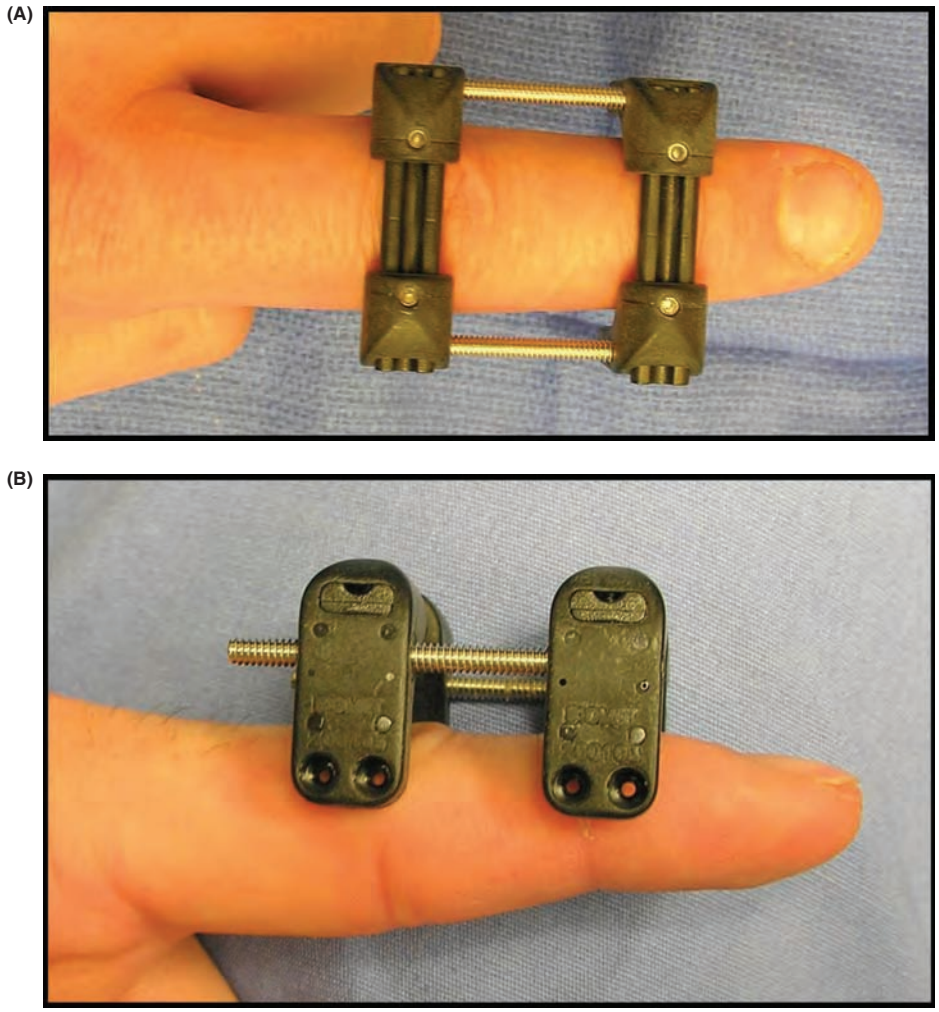

FIGURE 5 (**A**) Posteroanterior clinical view of the Biomet BioSymMetRic Fixator. (**B**) Lateral view of Biomet BioSymMetRic Fixator. *Source*: Photos courtesy of Kenneth R. Means, Jr.

Step 4: Linking the Bent Wires and Final Adjustments

Now, the "S" and "U" forms may be linked by sliding the "U" around the "S" and engaging into the dorsal portion of the "S" (Fig. 10A–C). The PIPJ reduction can be checked under fluoroscopy and the joint brought through a range of motion to ensure stability. If the joint is still unstable in certain directions, a third pin may be used to further stabilize the reduction. If the middle phalanx base is dislocating or tending toward subluxation dorsally, the joint is reduced and another transverse pin is placed in the proximal aspect of the middle phalanx, *volar* to the longitudinal "S" pin of the proximal phalanx. This will help prevent the middle phalanx from traveling dorsally. Alternatively, if the PIPJ has the middle phalanx still being unstable in a volar direction, the joint may be reduced and a transverse K-wire placed in the proximal portion of the middle phalanx *dorsal* to the longitudinal "S" proximal phalanx wire. This will hold the middle phalanx reduction, helping avoid volar subluxation of its base.

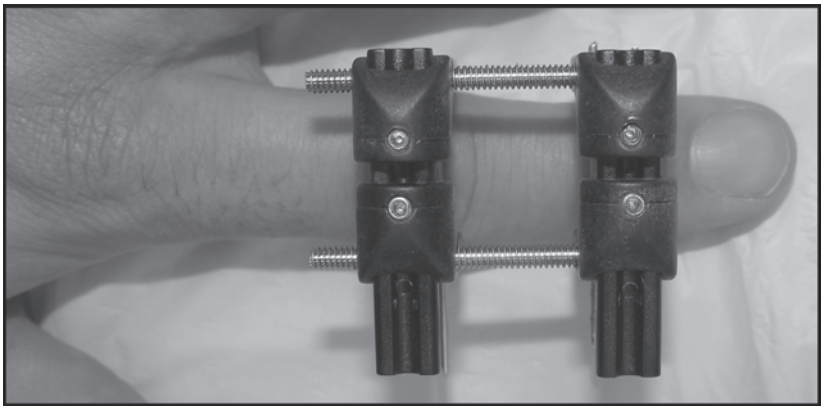

FIGURE 6 Frame collapsed centrally to allow conversion to dynamic mode by removal of the proximal "static-locking" fixator pin. *Source*: Photos courtesy of Kenneth R. Means, Jr.

FIGURE 7 Proximal and distal pin placement for a bent wire fixator. *Source*: Photos courtesy of Kenneth R. Means, Jr.

FIGURE 8 The proximal pin is bent 90° on both sides toward the fingertip. *Source*: Photos courtesy of Kenneth R. Means, Jr.

Postoperative management is similar for both of the traction fixation techniques. Nonadhesive dressings are placed at the pin–skin junctions and gauze wrap or other dry dressing may be applied around or over the frame if preferred. No other splints are necessary. Radiographs are checked at standard intervals for the PIPJ injury. We typically allow range of motion, if indicated, once postoperative swelling has started to decline. This is usually permissible any time after a few days following surgery. One key concern is to not neglect the other joints of the injured finger or the other digits of the hand. If allowed, range of motion of the surrounding joints and digits should begin as soon as possible after the surgical intervention. This has been especially true of the DIPJ in our experience, specifically with regard to terminal extension. The ability to terminally extend the DIPJ should be checked frequently and should be actively encouraged. If needed, night splinting in extension may be used.

The frame is removed when no longer needed. This is typically around four to five weeks postoperatively. Therapeutic range of motion continues following removal of the fixator and is typically allowed to be more aggressive at that point.

■ COMPLICATIONS

Complications encountered with hinged fixation dynamic traction consist of those that may be expected in a certain percentage of any operative procedure. These include but are not limited to bleeding, infection, damage to structures, failure of surgery, possible need for more surgery, and untoward effects of anesthesia. Pin tract infections may be treated with standard methods. However, the surgeon must have a lower threshold for removing the fixator early if necessary given possible concerns for the development of septic arthritis or osteomyelitis, especially due to the pin within the head of the proximal phalanx.

The patient must also be counseled regarding realistic expectations following these seemingly innocuous injuries that belie their truly difficult nature. Namely, post-injury pain, loss of motion, loss of function, and degenerative change relative to their pre-injury state is nearly guaranteed to a certain degree. The patient must understand that it is the uncertainty of the degree of these limitations that makes predicting final outcome impossible.

Specific concerns related to these dynamic traction methods include possible loss of reduction with continued instability, failure of the hardware, and nonunion. Clearly, these problems are somewhat interrelated. The simplest way to avoid this cascade of surgical dilemmas is to ensure that the frame is stable at the time of initial surgery as well as at follow-up visits. Also, using the frame as indicated and not purposefully overextending its capabilities is important. For example, a grossly unstable PIPJ with tenuous fixation or other complexities is likely not appropriate for immediate active range of motion. Improperly using the dynamic mode of the fixator too early will inevitably lead to a loss of PIPJ congruity and eventual failure of the construct. Similarly, a dorsal fracture at the base of the middle phalanx where the central slip inserts should be immobilized in extension with the static mode for three weeks to allow some bony healing to occur and prevent late formation of a boutonnière deformity. Even with these considerations the primary concern following these injuries remains stiffness rather than instability. However, lack of early joint stability combined with

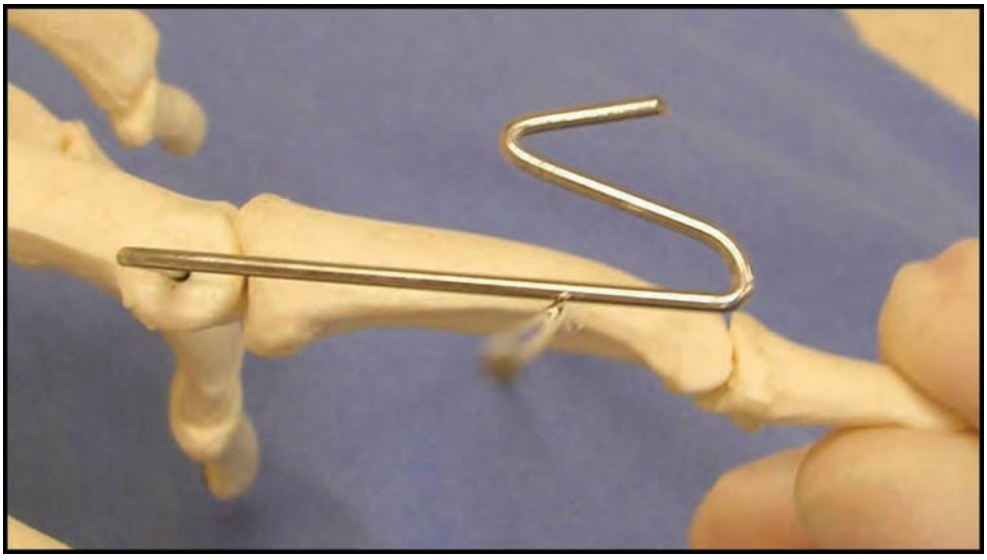

FIGURE 9 The proximal pin is bent on both sides into an "S" configuration. *Source*: Photos courtesy of Kenneth R. Means, Jr.

aggressive range of motion may lead to a damaging cycle of pain and swelling followed by stiffness if therapeutic motion is attempted in an unstable joint situation.

OUTCOMES

Our results using the bilateral external fixator for the most difficult cases have been promising. In over 50 cases that have been followed, we have achieved a minimum of 75° of motion at the PIPJ. In over half of the cases more than 90° of motion at the PIPJ was attained. A terminal extension lag of five° or more at the PIP and distal interphalangeal (DIP) joints has been seen in over 40% of patients treated. Pin tract infections requiring oral antibiotics have occurred in approximately 20% while early pin removal has been deemed necessary secondary to infection in approximately 5%. There have been no cases of septic arthritis, and no infections requiring a return to the operating room have been encountered. We have not had any hardware failures in this series.

It must be remembered that this fixator is typically used in the most challenging of injuries, where optimal control of the PIPJ is required while attempting to minimize aggressive open dissections of the joint, usually because of the significant associated comminution and soft tissue concerns.

Reviews of reports of dynamic traction options are predictably variable given the plethora of design options and PIPJ damage spectrum, to make no mention of the different study methods employed. Badia et al. described their retrospective results in six patients using a wire-form fixator modification of Gaul and Rosenberg's system (13). They achieved an average of 89° of flexion of the PIPJ and one patient had "mild pain with extreme flexion." This system is similar to the bent wire fixator described in this chapter. Syed et al. similarly described a modification of Gaul and Rosenberg's fixator (14). Theirs was a prospective study of nine fractures involving the PIPJ. Average arc of motion was 79° and all patients were pain free during activities of daily living and returned to prior employment positions. They experienced two episodes of uncoupling of their dynamic traction mechanism, one of which was easily corrected and the other which presented in a significantly delayed fashion resulting in the decision to simply remove the fixator. Duteille et al. used Suzuki's "pins and rubbers" traction system, which consists of K-wires and rubber bands, to treat 20 patients with PIPJ fractures and fracture-dislocations (3). One patient was unable to tolerate the device and one patient had a pin track infection while two other patients were lost to follow-up. The remaining 16 patients demonstrated an average of 85.9° of motion with only one patient having intermittent pain. Their post-op regimen included intense therapy including hospitalization for three weeks. They noted that only 56% of the joints achieved anatomic restoration despite good functional results. De Smet and Boone achieved similar results with the Suzuki technique. They treated eight patients and attained an average of 82° of PIPJ total active motion, though they had a wide range for total active motion (42–125°) (15). Deshmukh et al. modified Suzuki's system for 13 PIPJ injuries (16). They obtained an average active ROM of 85° for the PIPJ (range 60–105°). Sarris et al. reviewed results in four PIPJ injuries treated with limited open reduction, minimal internal fixation, and Schenk's dynamic traction splint (17). Average PIPJ motion arc was 94° and all patients returned to previous occupational activities.

There are also nonhinged traction devices available for the treatment of the PIPJ. Khan and Fahmy retrospectively reviewed 81 fractures of the PIPJ treated with the S-Quattro external fixator designed by their senior author, which uses a dual spring column system to achieve traction fixation with limited ability to move the joint that is spanned (18). They obtained an average arc of 92° of motion (range 60–120°) of the PIPJ and a satisfaction rate of over 95%. Johnson et al. revealed their results with another spring/coil fixator mechanism in 11 patients that had spanning of the PIPJ, though in only eight cases was the primary injury at the PIPJ (19). Their average PIPJ range of motion was from 7° to 84°.

These results realistically cannot be compared with results for closed reduction and splinting, open reduction internal fixation (ORIF), or closed reduction internal fixation (CRIF) of the PIPJ. This is because most PIPJ injuries amenable to closed reduction and splinting, ORIF, or CRIF have larger fragments that are stable once reduced or that may be treated with simple interfragmentary screws or pins. These are much lower energy injuries in general and should be considered as separate entities for the purposes of predicting outcomes.

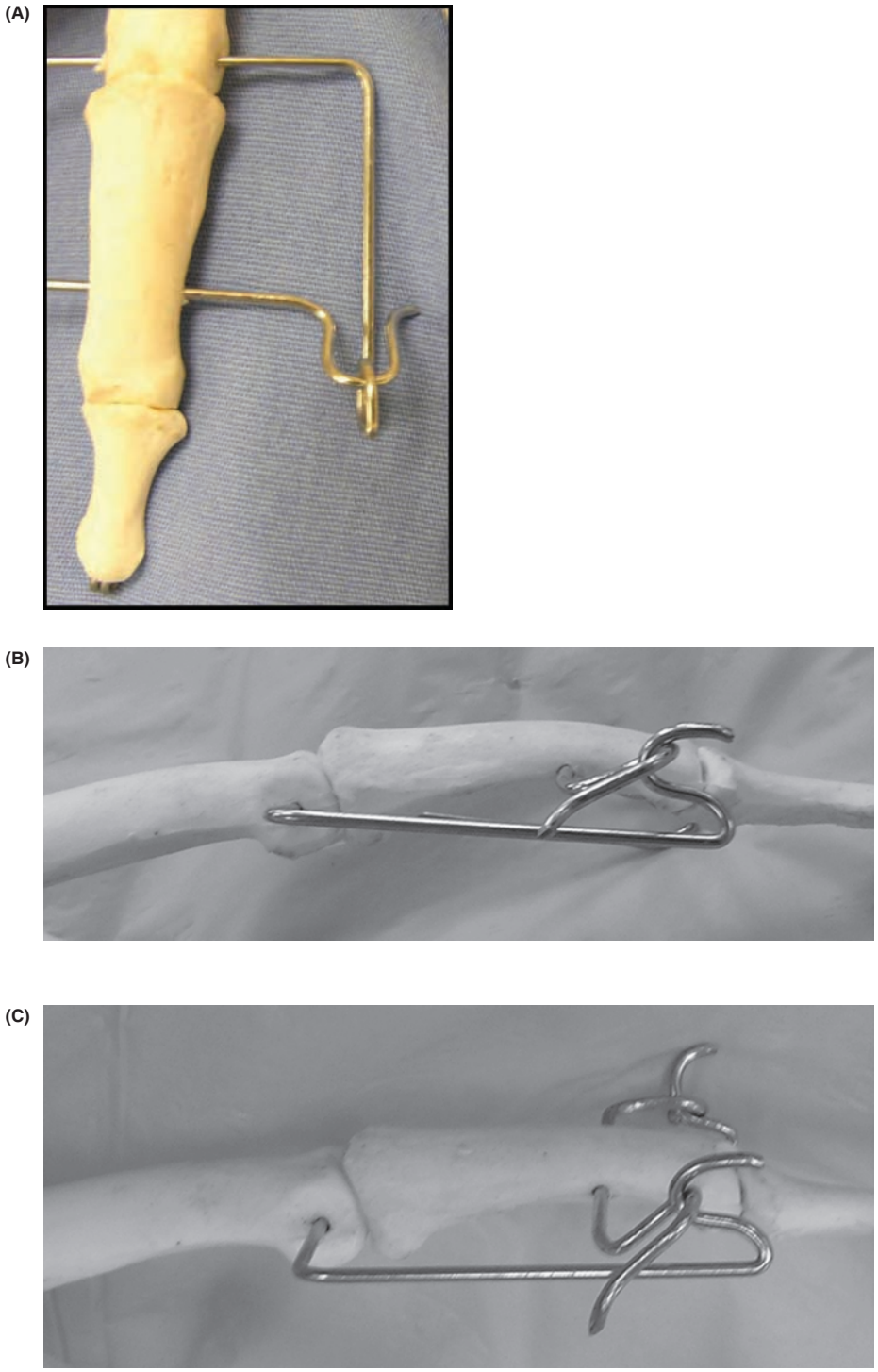

FIGURE 10 (**A**) Close-up view of one side of the bent wire fixator showing the distal pin bent into a distally based "U" configuration and engaged with the "S" bend of the proximal pin. (**B**) Engaged pin arrangement from the lateral view. (**C**) Oblique view. *Source*: Photos courtesy of Kenneth R. Means, Jr.

■ SUMMARY

Hinged fixation with dynamic traction may be a useful adjunct to the overall treatment of complex PIPJ injuries. Following guidelines for indications and technique as described above should allow surgeons to attain the desired benefits of the fixators.

■ SUMMATION POINTS

Indications

Complex injuries of the PIPJ, especially those involving primarily the base of the middle phalanx, also in "pilon" fractures or fracture-dislocations.

Outcomes

With the proper indications and technique for a salvageable joint, one may expect reasonably good functional outcomes including 75° or more of PIPJ motion, relative comfort during daily activities, and the ability to return to vocational and avocational endeavors.

Complications

Typically those inherent to the severe damage sustained by the PIPJ such as stiffness and degenerative changes; pin tract and other fixator issues are dealt with in a routine manner. Resubluxation and septic arthritis are complications that are especially unique to hinged fixation and must be watched for diligently.

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10

External Fixation of the Metacarpals and Phalanges and Distraction Osteogenesis

Bruce A. Monaghan
Orthopedics at Woodbury, Woodbury, New Jersey, U.S.A.

INTRODUCTION

External fixation is a minimally invasive technique by which transfixing pins inserted into the bone are attached to a rigid external frame as a method of stabilization of fractures and joints. Reduction of fractures is accomplished by indirect means (closed reduction) and maintained by distraction and ligamentotaxis. Since the first description of an external claw-type device for the treatment of a patella fracture by Malgaigne in 1853, external fixation has evolved to be an accepted and versatile treatment option for open long bone fractures and periarticular fractures of the lower extremity. In the upper extremity, external fixators are used for bony injuries proximal to the carpus (1). Significant technical advancements were made to external fixation systems in the 1960s that permitted correction of deformities in three planes. While this allowed for placement of transfixing pins prior to fracture reduction and for adjustments after initial applications, these systems were too large for practical use in the metacarpals and phalanges.

Initial reports of external fixation of the metacarpals and phalanges utilized smooth Kirschner (K) wires stabilized by acrylic resin (2,3). Crockett described this technique for stabilization of a first metacarpal osteotomy and a small joint arthrodesis, while Dickson employed the external fixation for unstable closed metacarpal fractures. Shehadi reported the use of this technique in 30 closed fractures (4). Pritsch et al. treated 36 unstable metacarpal fractures in this fashion (5). A modification of this technique whereby a plastic cap of a hypodermic needle or a suction catheter is substituted for the acrylic as the rigid external frame has also been described (6,7). Both techniques involve readily available materials and the authors comment on the ease of assembling the construct. This early experience, however, required achieving and maintaining a reduction while the frame was assembled; remanipulation of the construct could not easily be accomplished.

Jacquet is credited with developing the first external mini-fixator system for use in the hand in 1976 by modifying the Hoffman fixator (8). Asche et al. reported their experience with the Jacquet mini-fixator and noted the versatility of the system and its capability for distraction and compression. Several miniaturized external fixators have subsequently been developed (9–13). These systems now appear to offer the versatility of skeletal fixation achieved by the larger predecessors, including stable uniplanar or multiplanar constructs, simultaneous correction of deformities in all three planes, modularity, and the ability for dynamization to achieve compression or distraction (Fig. 1). They confer sufficient stability to obviate the need for supplementary postoperative splinting and allow rapid mobilization of neighboring joints and digits. In treating fractures, external fixators have the extra benefit of preserving the soft-tissue sleeve and periosteum, which are important in fracture healing. Additionally, the fixator can often times obviate the need for internal fixation, thereby eliminating complications from internal hardware, such as tendon irritation, adhesions, and hardware prominence.

Matev was the first to describe the use of an external fixator for skeletal lengthening in hand by a process known as distraction osteogenesis (14–16). This technique allows for gradual lengthening of a metacarpal or phalanx which has been stabilized at an osteotomy site by an external fixator. In many instances, gradual lengthening is preferred over a single acute lengthening because it allows the soft tissues (including nerves) to slowly accommodate to the stretching and minimize any possibility of acute neurovascular compromise. When the desired length has been achieved (up to 4 cm), the external fixator then provides stability until bony union occurs. Although the initial application was for posttraumatic amputations of the first ray, distraction osteogenesis can also be employed in the medial four digits for reconstruction of posttraumatic and congenital conditions in children and adults (17–25).

INDICATIONS

Operative indications for use of external fixation in the hand vary with authors, but can be employed in a myriad of clinical situations.

Open Fracture

Although open fractures are common in the metacarpals and phalanges, traditional methods of percutaneous Kirschner wire (K-wire) fixation and open reduction internal fixation have been preferred (26). External fixation should be considered in open hand fractures with extensive comminution, segmental injuries with bone or soft tissue loss, and significantly contaminated wounds (Fig. 2) (27–32). Some believe that all gunshot wounds to the hand should be considered open and potentially infected and are amenable for treatment by external fixator (32,33). The ability to obtain stabilization of severely comminuted open fractures with an approach that minimizes the risk of devascularization of small bony fragments while placing the construct far from the zone of injury can facilitate wound management.

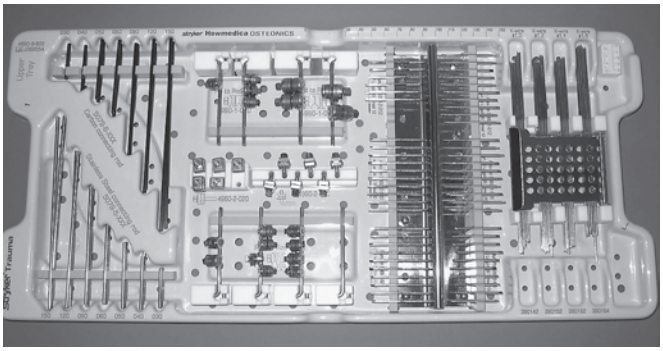

FIGURE 1 An example of a miniaturized modular external fixator system that permits construction of a wide variety of uniplanar and multiplanar frames (Hoffmann II Micro from Stryker Orthopaedics, Mahwah, NJ, USA).

Closed Fracture

Extensively comminuted closed fractures of the phalanges and metacarpals may defy even the most meticulous surgeon's ability to achieve alignment and rigidity by open or closed means. For extra-articular fractures, the distraction afforded by external fixation can correct translational, rotational, and angular deformity with minimal impact on the biology of the healing fracture. With intra-articular fractures or fracture dislocations, comminution and small fragment size often preclude open operative stabilization (26). Indirect reduction of these injuries by the principle of ligamentotaxis can provide reasonable joint congruency. Limited open reduction of articular fragments when they are large enough to make interfragmentary fixation feasible can also be combined with an external fixator (34). There are several reports of these techniques for comminuted fracture dislocations of the thumb metacarpal base (34–36). Repeated surgery after a failed attempt at fracture fixation is also an indication for use of an external fixator as it can bypass some of the mechanical (comminution) and biological (infection) factors that may have led to recurrent fracture instability (26).

Malunion

When combined with a corrective osteotomy, an external fixator can facilitate achieving alignment and maintaining skeletal stability (2,37).

Osteomyelitis, Delayed Union, and Established Nonunion

Bone infections present one of the most difficult treatment dilemmas in orthopedics and hand surgery. Infections can frequently coexist and be the underlying cause of delayed union and nonunions of the hand. External fixation allows maintenance of length and alignment of the bone–soft tissue unit after debridement so that subsequent bone grafting and even soft tissue coverage, when necessary, can be more readily accomplished (38). Depending on the status of the wound, bone grafting can be accomplished as a delayed primary or secondary procedure (29). In addition, this stability can be conferred from a site distant from the actual infection.

Arthrodesis

Seitz et al. adapted the Charnley's technique of compression arthrodesis and careful cup and cone preparation of the joint surface to achieve a stable arthrodesis in 95% of their

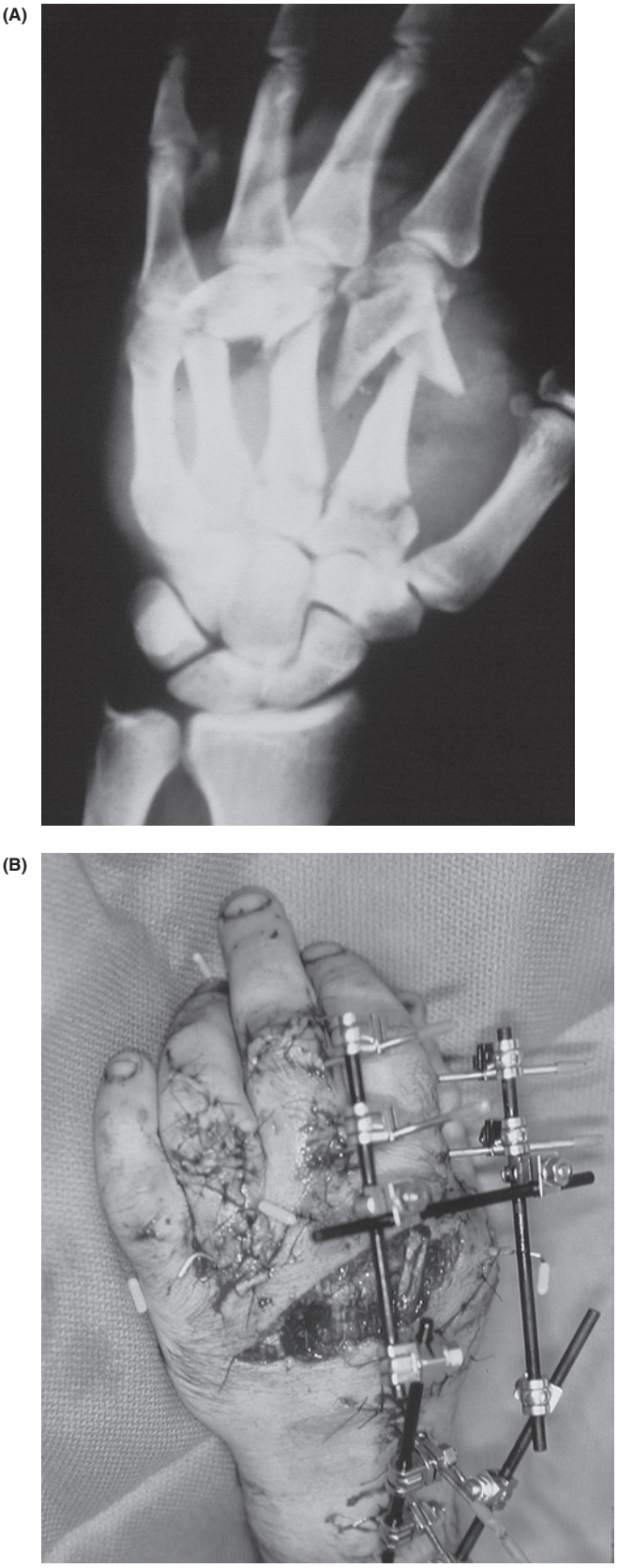

FIGURE 2 Extensively comminuted open multiple metacarpal fractures treated by debridement, application of a multiplanar external fixator which spanned the metacarpals by pins into the proximal phalanx, and carpus supplemental K-wire fixation was also utilized. (**A**) Preoperative X ray and (**B**) postoperative clinical appearance. *Abbreviation*: K-wire, Kirschner wire. *Source*: Courtesy of David J. Bozentka, M.D.

FIGURE 3 This external fixator is being utilized to stabilize a basilar joint arthroplasty in a 47-year-old female who has failed three other reconstructions of the thumb carpal metacarpal joint. The frame allows for rapid mobilization and proper positioning of the first web space.

patients (39). The avoidance of a second anesthetic for hardware removal or tenolysis, the ability to compress and/or adjust the arthrodesis after the initial application, and the functional use of the hand and adjacent joints during healing are distinct advantages of this technique over open procedures with hardware placement.

Joint and Soft Tissue Stabilization

External fixation has been described as an adjunct for extensor tendon reconstruction and to stabilize the digits to prevent tension on a cross-finger flap (26). It can also be used for joint stabilization in selected settings, particularly in the first ray and web space (Fig. 3).

Distraction Osteogenesis

This is the preferred reconstructive option for amputation of the first ray around the level of the metacarpophalangeal (MP) joint (e.g., the proximal half of the middle third of the thumb).

CONTRAINDICATIONS

External fixation is a versatile method of skeletal fixation that should be a part of each hand surgeon's armamentarium. Several authors even report routine use of this device for closed fractures. Nagy believes that preservation of the integrity of a gliding surface, which is tantamount to good hand function, is better achieved with external fixation than percutaneous and open methods (26). To that end, there are no absolute contraindications to this method of bony fixation of the hand. The decision of whether to pursue an open or minimally invasive method of bony stabilization should be predicated upon the extent of soft tissue injury and contamination, the fracture pattern and the likelihood of achieving sufficient bony stability for early motion by each treatment option, and the experience of the individual surgeon with each technique.

Perhaps more than percutaneous and open methods of fracture fixation, external fixation requires significant patient compliance postoperative pin care and cooperation with a directed rehabilitation program. A relative contraindication, therefore, would be any behavioral, physical, or neurological impairment that would interfere with the patient's ability to assist in the postoperative regimen.

CONSIDERATION FOR PRE-OPERATIVE PLANNING

Preoperative planning for acute injuries should include a directed examination of the neurovascular status and concomitant injuries to other digits and more proximally in the extremity that might alter surgical management. In general, standard anteroposterior, lateral, and any pertinent specialized plain radiographs (hyperpronated, Brewerton, or Bora view) should be obtained to fully assess the extent and pattern of bony injury. Occasionally, additional imaging of the joint surface by computed tomography scanning or tomography may add useful information for articular reconstruction. Scintigraphic (i.e., Ceretec scanning) or magnetic resonance imaging should be reserved to situations where localizing an area of infection may guide the extent of bony and soft tissue debridement.

SURGICAL TECHNIQUE

Operating Room Setup and Equipment

Application of an external fixation to a metacarpal or phalanx is best accomplished under regional or general anesthetic, with the injured extremity abducted 90° at the shoulder onto a radiolucent hand table. Real-time fluoroscopy is employed to accurately assess pin placement and bony reduction. A simple external fixator can be fashioned from material readily available in any operating room (K-wires, needle caps, bone cement, and suction catheter). Standard miniature external fixator systems, however, offer more stable and versatile constructs for any situation that may be encountered in the hand (Fig. 1).

In planning the construction of an external fixator in the metacarpal or phalanx, it is important to consider radiographic assessment of the outcome even before the placement of the first pin. The diminutive size of the bone relative to the components of even the most miniaturized external fixator can obscure one's ability to evaluate bony reduction radiographically. Every component, therefore, should be assembled with maximum care being taken to allow clear visualization by fluoroscopy.

Operative Approach—Fractures

The complex gliding relationship between the bone and the extensor apparatus must be understood and respected to minimize the likelihood of soft tissue tethering. Behrens has

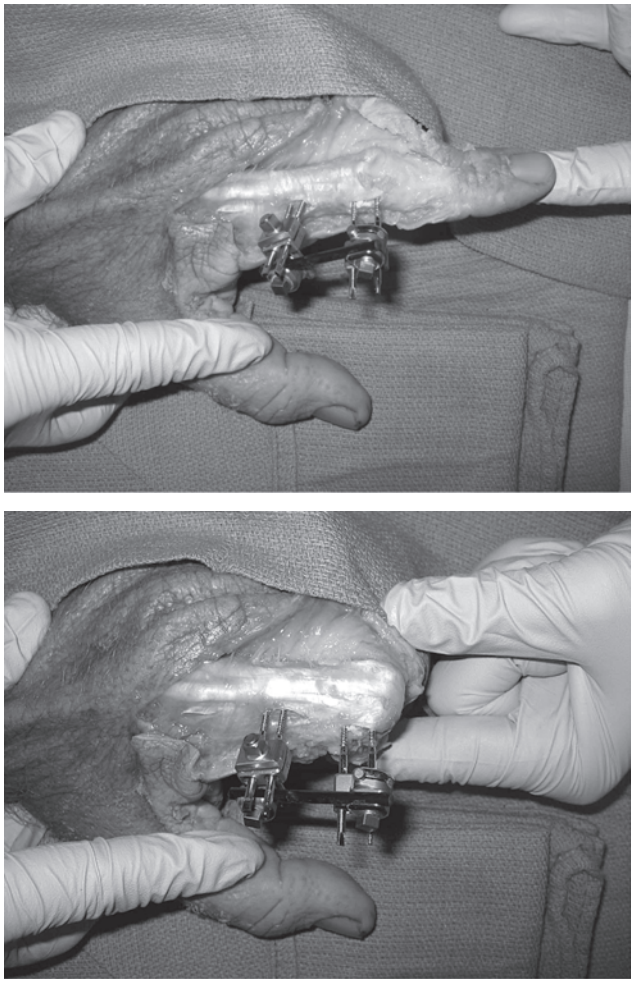

FIGURE 4 Appropriate placement of pins and soft tissue release is essential to prevent limitations of (**A**) extension and (**B**) flexion.

divided limb segments into longitudinal regions or corridors based upon the soft tissue elements present (40). In a *safe* corridor, the bone is subcutaneous and no neurovascular or musculotendinous structures are at risk with pin placement. A *hazardous* corridor is one in which a musculotendinous structure is at risk. A neurovascular structure is at risk in an *unsafe* corridor. Since at the level of the metacarpals and phalanges almost the entire circumference of the bone is surrounded by tendinous and neurovascular elements, no safe corridor for pin placement exists. The appropriate hazardous corridor, therefore, should be selected with forethought for the structure at risk and a plan to minimize the potential tethering effect of the pin (Fig. 4).

The first, second, and fifth metacarpal can be approached through a midlateral or dorsolateral incision (26,32). Pins in the thumb metacarpal can be placed just radial to the extensor pollicis brevis tendon. For metacarpal neck fractures, the distal pins can be placed within the collateral recess, but through a limited open incision to assure that the sagittal fibers about the MP joint are not tethered. The third and fourth metacarpals require pin placement in a dorsolateral plane to prevent extensor tendon tethering. A percutaneous insertion of the pin or drill with a gentle sweep to displace the tendon out of harm's way prior to predrilling may also prevent extensor mechanism binding (Fig. 5A,B).

The proximal aspect of the proximal phalanx is best approached through a dorsolateral limited approach as well (41). A short incision in the extensor hood at this level is well tolerated and its fibers allow for a clean longitudinal split that does not inhibit digital motion. In the distal aspect of the proximal phalanx and the middle phalanx avoidance of lateral band impingement can be accomplished by a straight midlateral approach to pin placement. Straight dorsal placement in the middle phalanx and the distal phalanx, with care be taken to avoid the germinal matrix, is also an acceptable, although a rarely employed, pin location (26).

In assembling an external fixator, it is important to consider that each component (bone, transfixing pin, pin clamp, pin-to-rod clamp, and connecting rod) contributes incrementally to the ultimate strength of the construct. Nevertheless, it is generally understood that pin characteristics and placement represent the single most important determinant to the ultimate stiffness of the construct (42,43). Ideally, pins of at least 1.5 to 2.0 mm in diameter should be used, although some authors feel smaller pins allow for capturing of smaller bony fragments. Low-speed predrilling with insertion of the pins by hand will limit thermal damage to the bone and early pin loosening. Increasing the number of pins in each bony segment, increasing the inter-pin distance, placement of the connecting rod closer to the bone, and placement of a second connecting rod will improve the ultimate stability of the frame. In general, a unilateral frame with four half-pins will provide sufficient fixation for most injuries.

After initial bicortical pin placement in each bony segment, a second parallel pin can be placed by using the multipin clamp as a drill guide (Fig. 5C). Most systems allow for slight convergence or divergence of these pins in small bony segments, a distance of 2.5 times the pin diameter must be left between fracture site and pin or between pins to prevent bony fragmentation. A second pair of pins is then placed in the other main bone fragment. The surgical wounds are then closed and the pins of each bony segment are then firmly tightened into a multipin clamp. A rod-to-rod coupling is placed on each pin clamp and a rod is then placed loosely between each pin clamp (Fig. 5D). At this point, a closed reduction of the metacarpal or phalanx is then performed and alignment is assessed fluoroscopically. If acceptable, the rod is firmly tightened to each clamp. In some instances, a limited open reduction at the fracture site can be performed to achieve better alignment. Residual articular incongruity can also be corrected with a limited open reduction with bone grafting after ligamentotaxis has been established by the frame. After the external fixator is fully assembled, full passive digital range of motion should be possible to confirm the absence of tendinous tethering and the tenodesis effect should be observed to rule out subtle residual rotational deformities (Fig. 5E).

Unrestricted range of motion exercises should be initiated as soon as possible based on the ultimate stability of the bone external fixation construct. Most surgeons begin within three days postoperatively under the guidance of a hand therapist. Weekly follow-up radiographs and clinical assessments confirm maintenance of reduction and healing. The frame can typically be removed in an office setting when clinical and radiographic healing has been confirmed.

Operative Approach—Distraction Osteogenesis

Distraction osteogenesis employs a similar surgical technique. The pins are placed and the frame is preassembled on the intact

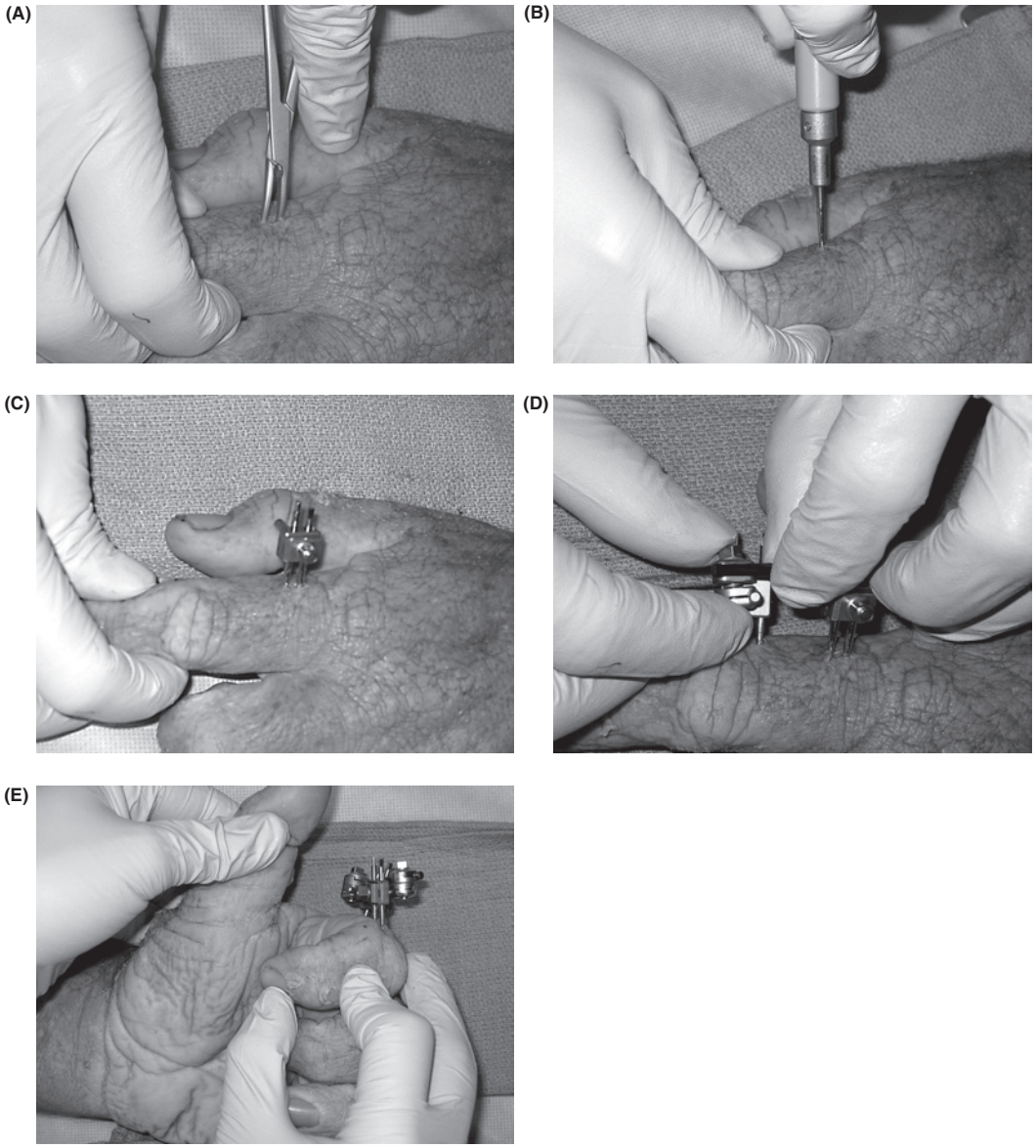

FIGURE 5 (**A**) Placement of a uniplanar external fixator on the proximal phalanx. An incision is made through skin and a longitudinal rent in the extensor mechanism is created to prevent tendinous binding with postoperative motion. (**B**) Placement of a uniplanar external on the proximal phalanx. After low-speed drilling, a bicortical fixation pin is placed and the position is confirmed fluoroscopically. Alternatively, a self-tapping, self-drilling pin can be utilized. (**C**) Placement of a uniplanar external on the proximal phalanx. Parallel pin placement using a pin clamp as a guide. (**D**) Placement of a uniplanar external on the proximal phalanx. In a modular external fixator, the pins in each bony segment are connected to each other by clamps and each of the clamps is connected by a radiolucent rod. (**E**) Placement of a uniplanar external on the proximal phalanx. Full passive motion after complete assembly of the frame assures the absence of extensor mechanism impingement.

bone with a specialized connecting rod that allows controlled distraction in intervals as small as 0.125 mm (lengthener) according to the principles delineated above (distraction lengthener). The specialized lengthener and clamps are removed and an osteotomy is performed through an open incision, with an attempt made to preserve a periosteal sleeve for closure. If a bony segment on the one side of the proposed osteotomy site is too small to allow for two longitudinal pins perpendicular to the axis of the osteotomy, they can be placed as a transfixing pin. Alternatively, a technique where distraction osteogenesis occurs using a frame with a single pin over a longitudinally placed K-wire has been described (19). After wound closure, the external fixator is reapplied and tightened. Most surgeons commence lengthening between the third and seventh postoperative day (14,17–23). Daily lengthening rate of 0.125 to 1.0 mm/day has been utilized. Once the desired magnitude of lengthening has been attained, the frame is left in place to stabilize the bone until radiographic and clinical union is present (Fig. 6). Typically, this will require twice the time required for lengthening in children and three times that

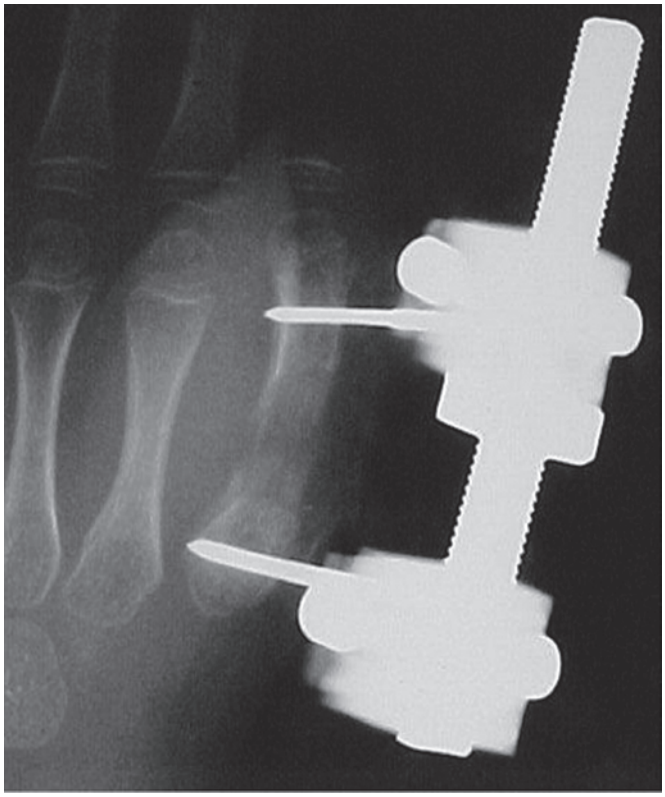

FIGURE 6 Radiographic appearance during distraction phase. Clinical example of a lengthening frame for distraction osteogenesis after a thumb blast injury in a child. After desired lengthening has been achieved, the frame provides stability until bony consolidation has been achieved. *Source*: Courtesy of Pedro K. Beredjiklian, M.D.

period in adults. For example, if 3 cm of lengthening was achieved in 45 days, the external fixator may be required for an additional 90 to 135 days in order to achieve stable osseous union. Some authors shorten the period of external fixation, by bone grafting and even internal fixation when the desired length has been achieved.

Illustrative Case Example

An 82-year-old housewife sustained an open middle phalanx and distal tuft fractures of her dominant right index finger and an open bony mallet fracture of her left ring finger as a result of a dog bite. While the fracture of the index finger was a minimally comminuted displaced transverse fracture through the base, there was a relatively extensive soft tissue injury. The extensor mechanism was shredded along the radial lateral band, but was functionally intact (Fig. 7A). It was felt that percutaneous fixation and immobilization would lead to significant stiffness, and formal open reduction and internal fixation would lead to further injury to the extensor mechanism. The patient underwent application of a biplanar external fixator, closed reduction of the middle phalanx fracture, and wound debridement and closure; the size of the proximal fragment dictated that orthogonal pins be placed for stable fixation (Fig. 7B). She underwent K-wire fixation of the contralateral bony mallet. She was begun on active and active-assisted range of motion on the first postoperative day and was able to achieve 100° of proximal interphalangeal joint active motion (Fig. 7C). The external fixator was removed uneventfully after four weeks.

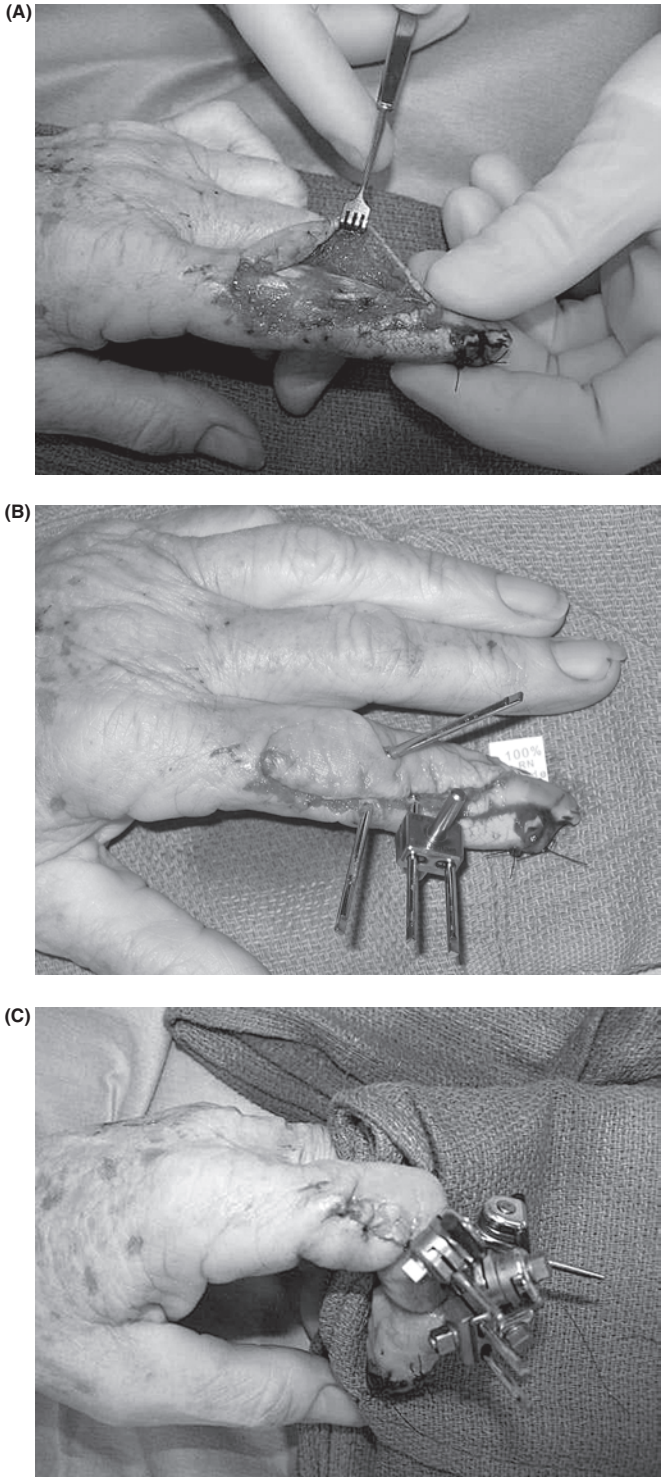

FIGURE 7 (**A**) External fixation of an open middle phalanx fracture as a result of a dog bite. Extensive soft tissue injury with relative sparing of the extensor mechanism. (**B**) External fixation of an open middle phalanx fracture as a result of a dog bite. Application of multiplanar external fixation. Orthogonal pins were necessary in proximal fragment because of fragment size. (**C**) External fixation of an open middle phalanx fracture as a result of a dog bite. Range of motion observed after assembly of frame and fracture reduction.

COMPLICATIONS

Perceived complications may be the primary reason that external fixation remains a relatively underutilized technique in hand trauma. Margic believes that this technique has not gained popularity for treatment of closed fractures in the hand because of the possibility of infection, pin loosening, loss of reduction, interference with the gliding capabilities of the extensor mechanism, difficulty in application, and over exposure to X ray during application (13).

It is generally felt that pin loosening is the antecedent to pin site infection more than the converse (43). Meticulous attention to details in pin placement with low-speed drilling, bicortical pin fixation, and a reduction that allows sufficient bony contact to minimize dynamic stresses on the bone–pin interface will help to prevent pin loosening, infection, and loss of reduction. Patient compliance with an appropriate regimen of pin care is also essential. Oral antibiotics should be initiated if pin care does not eradicate pin site drainage or erythema. Occasionally, pin removal and new pin placement may be required. Margic believes that in about half of his patients who developed deep bone infections, technical errors with pin placement were responsible (13).

A complication that can occur intra- or perioperatively is a fracture at the half-pin site. This can happen if the half-pin is eccentrically placed, causing a stress riser in the bone. After the external fixator is removed, there is a theoretical risk of fracture through the half-pin hole(s).

As with any fixation technique, loss of reduction and malunion can occur (29,33). External fixation, however, is more amenable to correction of this problem, in that the fracture can be easily remanipulated and stability improved by placement of additional pins. Nonunions have been reported with this technique and can be a consequence of the original severity of the injury, as well as be a consequence of the treatment (e.g., over distraction) (28,29,33). An intraoperative assessment of soft tissue tension via the intrinsic tightness test and passive range of motion can give some evidence for over distraction. Careful radiographic interpretation of the final alignment can also help to minimize over distraction and possible delayed or nonunion. An overall rate of nonunion of 1.1% for closed fractures and 14% for open fractures has been reported (26).

Distraction osteogenesis has risks in addition to all those stated for external fixation. Extended treatment periods (more than six months in some cases) with external fixation can lead to a higher rate on pin tract infection. Rapid bone elongation has also been associated with excessive pain and digital contracture. Bosch et al. recommends pinning of the interphalangeal joint during metacarpal lengthening to minimize the risk of contracture (25). In addition, poor bone formation at the osteotomy site, delayed union, nonunion, premature closure of the osteotomy, and fracture have also been described with distraction osteogenesis (17–19,22,23).

OUTCOMES

Fractures

Asche et al. were the first to report their experience with the Jacquet mini-fixator in the English literature in 25 patients in 1979 (8). The system was versatile enough to be used in open fractures, infections, replantation, and arthrodeses. They noted that compression and distraction could be achieved. Pin site infection occurred in only one of the 100 fixation pins that were inserted. Riggs and Cooney utilized the same fixator in 10 hand fractures, three of which were open fractures (28).

Bilos and Eskestrand treated 15 patients with low-velocity gun shot wounds to the proximal phalanx utilizing a mandibular external fixation system with 1.1 or 1.6 mm pins (33). Treatment goals were correction of deformity, avoidance of over distraction, bony healing, and stable ankylosis of the proximal interphalangeal joint when it was involved in the injury. Although 25% of digits required remanipulation of the frame, acceptable alignment with maintenance of MP motion was achieved in 86% of the patients.

Freeland utilized an Arbeitsgemeinshaft für Osteusynthesefr (AO) external fixator for 20 open fractures of the hand in 12 patients (29). Delayed bone grafting and early bone grafting (within one week of injury) were both selectively employed and resulted in an 80% primary union rate. Nevertheless, he did note a 55% rate of joint ankylosis and 10% rate of angulation in this group of severely injured digits.

Seitz et al. presented their results of use of an external fixator for 28 hand fractures, of which 18 were open (30). They reported achieving an 85% fracture union rate at eight weeks postinjury and 70% of expected motion, although they also experienced a 23% complication rate; most of these complications were attributed to the severity of injury. Parsons et al. presented their results of the Shearer micro-external fixator in 37 unstable metacarpal and phalangeal fractures in 30 patients; 24% of these injuries were open (44). Four 1.8-mm threaded pins were placed prior to placement of the frame. With immediate postoperative motion initiated, they achieved good or excellent results in 94% of metacarpal injuries and 85% of phalangeal injuries. Delayed union occurred in three cases, pin tract infections occurred in two cases and malunion resulted in two instances. The authors commented that immediate painless and stable fixation provided the perfect circumstance for rapid mobilization of the digits. Ashmead et al. employed external fixation for 27 acute injuries and eight reconstructive cases in the hand (45). Of the 12 open fractures, 10 healed primarily, 20 of 22 acute fractures united, and all arthrodeses proceeded to fusion without complications. This method of treatment was also effective in helping to eradicate three infected nonunions and in obtaining union in two of them.

Several authors presented their experiences with an external fixator as a primary treatment for closed metacarpal and phalangeal fractures. Pritsch et al. reported their results of treatment of 36 closed metacarpal fractures using a simple external fixator composed of two 1.5-mm K-wires drilled dorsally through the metacarpal and bonded together by acrylic resin (5). Immediate postoperative motion was encouraged and the fixators were removed after an average of five weeks. They reported a 100% union rate and 80% range of motion compared with the contralateral unaffected digit. Shehadi also treated 30 closed hand fractures with an external fixator consisting of four K-wires (0.9–1.1 mm in diameter) bonded by polymethylmethacrylate bone cement. Active range of motion exercises were initiated one week postoperatively and about 50% of patients required more than four weeks of formal therapy. He reported an average of 84% of expected range of motion for phalangeal fractures and 96% for metacarpal fractures.

Margic recently reported the largest series of external fixation in 100 closed hand injuries (13). His indication for placing this device was failure to achieve stable reduction with more than one K-wire or requiring more than two attempts at closed reduction. These were 40 metacarpal fractures, 40 phalangeal fractures, and 20 combined injuries. The pins employed were 1.2 and 1.4 mm in diameter; in 17% of the cases, an adjunctive open reduction was needed. Active range of motion was encouraged as soon as possible

postoperatively. A good outcome, which was described as greater than 230° of active digital motion, was achieved in 76% of phalangeal fractures, 89% of combined fractures, and 100% of metacarpal fractures. Seven phalangeal fractures were felt to have poor stability, yet only three of these fractures had a poor outcome. An overall pin site infection rate of 11% was found and 2% ultimately developed osteomyelitis. Pressure necrosis of the skin of adjacent digits due to interference with the apparatus was observed in three cases. There was a 5% refracture rate observed with high-risk activities and/or noncompliance; no delayed unions or nonunions were observed. The author felt his outcomes were comparable to those reported in the literature for percutaneous or open methods of fixation of these fractures.

Büchler et al. presented 12 cases of comminuted fractures of the thumb metacarpal base and one trapezial fracture treated with a spanning external fixator, limited internal fixation, and bone grafting (34). In spite of radiographic evidence of joint irregularities in 44% of the cases, about 80% of range of motion and 88% of pinch strength of the contralateral thumb were observed at an average of 37 months postinjury. Soyer reiterated that anatomic restoration of the articular surface is desired, but not essential for a good functional result (46). Kontakis et al. reported excellent results in seven of 11 patients, good results in three patients and a poor result in one patient treated with an external fixator, with two pins in the thumb metacarpal and one pin in the trapezium; a 44% incidence of radiographic osteoarthritis was observed at 30-month follow-up (36). Nonnemacher utilized a quadrilateral frame between the first and second metacarpals to stabilize 20 thumb metacarpal base fractures, 60% of which were intra-articular (35). Of those with sufficient follow-up, 77% were pain free and 23% demonstrated only intermittent pain.

Distraction Osteogenesis

Matev reported his experience with thumb reconstruction by metacarpal lengthening after amputation in 35 adult patients (14). He noted complete consolidation at the distraction osteotomy site in 25 patients and that 10 patients required supplemental bone graft to achieve union. Elongation of the amputated stump of 2 to 4 cm was achieved and the results were maintained at a follow-up of four to eight years after the procedure. He later recommended that lengthening of more than 3 cm in an adult requires the addition of bone graft at the distraction site. He also showed favorable results in seven children (15,16).

Toh et al. presented 26 cases of thumb and digital lengthening in adults and observed better results with a proximal metaphyseal osteotomy; five patients required bone grafting and four patients sustained a fracture (23). The disadvantages of the technique were stated to be the length of time for treatment and external fixator, a higher rate of complication than other reconstructive techniques, and the bulky, complicated external apparatus required. Seitz reported lengthening of 2 to 3.5 cm in 14 patients with various posttraumatic and congenital digital deficiencies (18). Premature closure of osteotomy site was not observed and only one patient required supplemental bone graft. Minguella reported on 15 cases of metacarpal lengthening in a larger series of 31 congenital shortenings of the hand and foot (21). An overall complication rate of 22.5% (mostly self-resolving) was reported, leading the authors to recommend that a fast lengthening period (1 mm/day) followed by bone grafting with pin fixation would minimize the length of external fixation use and, therefore, the rate of complication. Pensler et al. presented 12 congenital deformities in nine patients who were treated with distraction osteogenesis (17). Although all osteotomies healed without grafting, two required operative manipulation for angular deformities. Housian and Ipsen reported their experience with distraction osteogenesis in 14 patients (20). Lengthening rates averaged 0.5 mm/day and they reported one nonunion requiring grafting. Dhalla compared traditional distraction using four transfixing pins and a lengthening frame to lengthening over a K-wire with two transfixing pins and a frame that was necessitated by the size of the bone (19). While the latter technique was successful, it carried a substantially higher complication rate.

Bosch, in his report of reconstruction of thumb amputations by this method in 18 patients, emphasized that the patient should be well informed of the expected duration and results of the procedure (25). In his population, the external fixator was required for an average of 6.8 months. Zimmerman reported a functional outcome of 12 patients undergoing posttraumatic distraction osteogenesis of the thumb (24). All patients could pick up a pencil, could write, and could hold a glass of water. About 70% of patients could employ the reconstructed thumb for fine motor skills and heavy grasping.

SUMMARY

External fixation is a minimally invasive technique that has clear applications and indications throughout orthopedics; however, it remains relatively underemployed in the treatment of phalangeal and metacarpal injuries. External fixation can be considered for:

- open fractures with significant soft tissue loss or contamination
- comminuted closed fractures that are not amenable to stable open fixation
- delayed union, nonunion, and osteomyelitis which may require significant bony reconstruction after debridement
- small joint arthrodesis
- joint stabilization
- skeletal lengthening (distraction osteogenesis).

With the advent of modern, miniaturized external fixation systems, the hand surgeon now possesses the capability of achieving excellent skeletal stability with a limited open technique that allows mobilization of all the joints of the injured digits. More importantly, because the fixator does not impede the gliding of the extensor apparatus, it helps to facilitate a rapid recovery of digital motion and functional outcome.

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11

Percutaneous Release of the Post-traumatic Finger Joint Contracture: A New Technique

Joseph F. Slade III
Hand and Upper Extremity Service, Department of Orthopedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut, U.S.A.

Thomas J. Gillon
Department of Orthopedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut, U.S.A.

INTRODUCTION

Finger joint stiffness can result in severe impairment of hand function and is a difficult problem to treat. Stiffness can result from injury, infection, excess immobilization, and inappropriate splinting (1). An accumulation of fluid or blood within the capsule after trauma will subsequently lead to stiffness. The open surgical management of joint contractures has led to unpredictable results, with some conditions actually worsening postoperatively (2). The lack-luster results of open release of the proximal interphalangeal (PIP) joint have led some surgeons to try less invasive or indirect means of contracture release. These methods, such as external fixators, have shown some early promise in regaining some motion, but are associated with high complication rates (3). It has been suggested that the results of open surgical release of flexion contractures greater than 60° (1) is so poor that arthrodesis is the preferred treatment. We describe a minimally invasive technique for the surgical release of selected joint contractures, through percutaneous surgical release of pathologic structures alone, avoiding injury to normal structures and reducing postsurgical swelling and pain. The reduction in pain and swelling allows for an accelerated rehabilitation program and a more complete recovery of hand function.

Anatomy

The PIP joint is a constrained hinge joint whose stability is conferred by both the matched bone contouring at the joint interface and the capsular complex composed of stout lateral cords and mobile volar plate (4–7). The head of the proximal phalanx is cam-shaped and composed of a bicondylar head with a central groove. The doubly concave surface of the base of the middle phalanx is divided by a midline tongue to guide the joint through its eccentric arc of motion. The main lateral stabilizer of this joint is the proper collateral ligament (4,8,9). This ligament originates from the head of the proximal phalanx and inserts into the base of the middle phalanx. The volar plate is a thick fibrocartilagenous structure distally and a thin membranous structure proximally (9). Distally, it has a firm attachment to the base of the middle phalanx. Proximally, it has a membranous central attachment with radial- and ulnar-sided thickened bands, the checkrein ligaments (9–11). The proper collateral ligament is joined to the volar plate by shroud-like fibers of the accessory collateral ligament. These two structures function as a composite unit to resist both the lateral and hyperextension stresses on the joint. In extension, the volar plate is tight and the collateral ligament is moderately lax. As the joint flexes, the collateral ligament tightens over the larger volar condyles to seat the base of the middle phalanx firmly against the proximal phalangeal head. In flexion, the volar plate is lax. The dorsal capsule is thin and borders the proper collateral ligaments laterally. The dorsal capsule is reinforced and intimately in contact with the central tendon dorsally (9). The average range of motion at the PIP joint is approximately 110° (12).

The metacarpophalangeal (MCP) joint is a condyloid or cam joint. The metacarpal head is eccentric, the radius and width increasing toward its palmar base (4). The MCP joint has a dorsal capsule that extends from the neck of the metacarpal to the base of the proximal phalanx and is reinforced by a loose insertion to the extensor tendon. The volar plate inserts on the base of the proximal phalanx with a stout attachment. Proximally, the volar plate is thin as it attaches to the neck of the metacarpal. Laterally, the volar plate is stabilized by the deep transverse intermetacarpal ligaments. The collateral ligaments complete the sides of the capsular box and are taut with flexion of the MCP joint. The stability of the MCP joint is ensured by this box-like construct. The MCP joint is weakest dorsally and ulnarly, making it vulnerable to dislocations in these directions.

Etiology

In 1954, Curtis described the pathoanatomical tissues that may be involved in both flexion and extension contractures of the PIP joint (8). Extension contractures of the PIP joint can be due to traumatic global scarring of multiple structures, extensor tendon adhesions, interosseous contractures or adhesions, capsular or ligament contractures, and osteophytes or exostosis. Flexion contracture of the PIP joint can be due to volar skin contracture, fascial cord contracture as in Dupytren's disease, flexor tendon adhesion or sheath contracture, contracture of the volar plate or the capsular structures, collateral ligament contracture or a dorsal bony block (8). Trauma to the finger or hand causes soft tissue edema and hematomas that can impair hand function (9).

The PIP joints' volume is also affected by position. The PIP joint in moderate flexion permits maximum joint volume and is

the position the joint assumes with joint swelling. Full flexion of the joint will be limited by the edematous dorsal skin and soft tissues (9). If the PIP joint remains in a moderately flexed position, fibrosis, and shortening of the intracapsular and extracapsular structures may occur, leading to a fixed contracture of the PIP joint. Pathologic tissues involved in contracture include exostosis, malunion, adhesions, and Watson's checkrein ligaments—a thickening of Eaton's previously described check ligaments.

Secondary to the cam effect of the metacarpal–phalangeal joint, where the intracapsular volume is maximal in extension and the capsular ligaments are lax, the accumulation of fluid in the MCP joint forces the MCP joint into extension (9).

There are a variety of etiologies that result in soft tissue contractures and joint stiffness. Many authors have written on the importance of the various pathological structures, from the checkrein ligaments to the collateral ligaments (1–3,8–11,13–19). A careful physical exam and knowledge of the pre-existing condition can help distinguish between malunions or capsulo-ligamentous contractures or tendinous adhesions or muscle weakness/contractures or skin/fascial contractures. Clinically, it can be difficult to identify which structures are predominately responsible for a joint contracture. Therefore, previously described surgical releases have emphasized a stepwise release, which vary from author to author.

Current Treatment Options

The current standard of care for flexion contractures is still preventive and non-operative management. Prevention is based on the principle of early joint motion within the safe arc of motion. Injuries requiring surgical repair should be performed as soon as soft tissues allow in order to achieve the earliest return of joint motion.

Once a flexion contracture has occurred, the first modality should always be nonsurgical. A variety of techniques have been described: serial casting, dynamic, and/or static splinting. The decision to abandon conservative treatment has no definitive time line. The literature does not give any specifics as to when to proceed with surgical release. Most hand surgeons would consider surgical options after a failure to progress with three months of therapy and a range of motion of less than 45°.

Shin and Amadio suggest surgical release is indicated when residual joint motion is functionally disabling, there is normal to near normal joint articular surface and congruence, the joint motors are intact, and all nonoperative modalities have been correctly applied and exhausted (9). "Surgical release of the severely contracted PIP joint yields unpredictable results and should be considered only when both surgeon and patient understand its limitations" (9).

A variety of external fixators have been developed and applied to PIP flexion contractures. External fixators have the advantage of transmitting the extension force through the bone, as opposed to through the skin in splinting or casting. The few small case series in the literature have shown initial favorable results. However, they tend to have a high long-term recurrence of contracture and high rate of pin site infections (1,3,10).

Curtis made some of the first descriptions of the technique for a capsulectomy (8). He described this through a volar Bruner incision. In 1999, Bruser and colleagues retrospectively reviewed the results of 45 fingers comparing a palmar incision to a midlateral incision for capsulectomy. They found the improvement in range of motion of the midlateral incision group was statistically significantly better than in the volar incision group (14).

There have been many reports on the open release of PIP joint contractures with varying results (2,8,10,11,13–18). Curtis reported that the greater the number of anatomic structures involved in the limitation of motion, the worse the postoperative range of motion (8). Ghidella et al. performed a retrospective review of 68 PIP joints released as previously described by Curtis (8), which identified preoperative and intraoperative factors that were associated with worse outcomes. According to their study, the ideal surgical candidate for correction of a contracted PIP joint has an exostosis (which can be removed), a simple diagnosis, is younger than 28 years, and has a preoperative maximum flexion measurement of $<43°$ (2). In a recent literature review of the treatment of post-traumatic PIP flexion contractures, Hogan and Nunley found that after open release finger extension most commonly improves approximately 25° to 30° but is often accompanied by a loss of finger flexion (10). Overall, there has been a net improvement in motion, but some patients even lost motion after open release (2,10).

Cadaveric Studies

Five fresh frozen hands were thawed and the index, long, ring, and little were examined using imaging to ensure congruent gliding and to rule-out bony deformity. The dorsal joint capsule of the MCP and PIP joints was located using fluoroscopy. A 19-gauge needle was placed laterally into the dorsal joints under the capsule and perpendicular to the digit. A 15-blade scalpel was used to incise the skin longitudinally and a small curved hemostat was used to bluntly dissect the soft tissue and punch into the dorsal joint through the capsule. Imaging was used to confirm the position of the hemostat in the dorsal joint. The hemostat was then pivoted at the joint entrance sweeping the tips proximally over the dorsal head, rupturing the proximal dorsal capsule attachment. Sweeping more proximal the extensor tendon was elevated off the proximal phalanx. Having completed the percutaneous release, traction was placed on the extensor, flexor, and intrinsic tendons, which were previously identified and tagged. Each of the digits demonstrated normal congruent joint gliding through a complete flexion and extension arc, with tip to palm and full extension without extensor lag. Lastly, each of the digits was dissected by making a longitudinal incision and the dorsal joint portal site was identified. The dorsal proximal capsule was completely divided. No extensor or joint injury was identified.

INDICATIONS

Once a flexion contracture has occurred, the patients are enrolled in a hand rehabilitation program before surgery until progress in therapy has reached a plateau, usually not before three months. Patients selected for surgical release complained of joint stiffness impairing hand function, possessed a normal congruent articular joint surface, and had normal motor function. Extensive previous surgery with altered anatomic landmarks may be a contraindication to surgery.

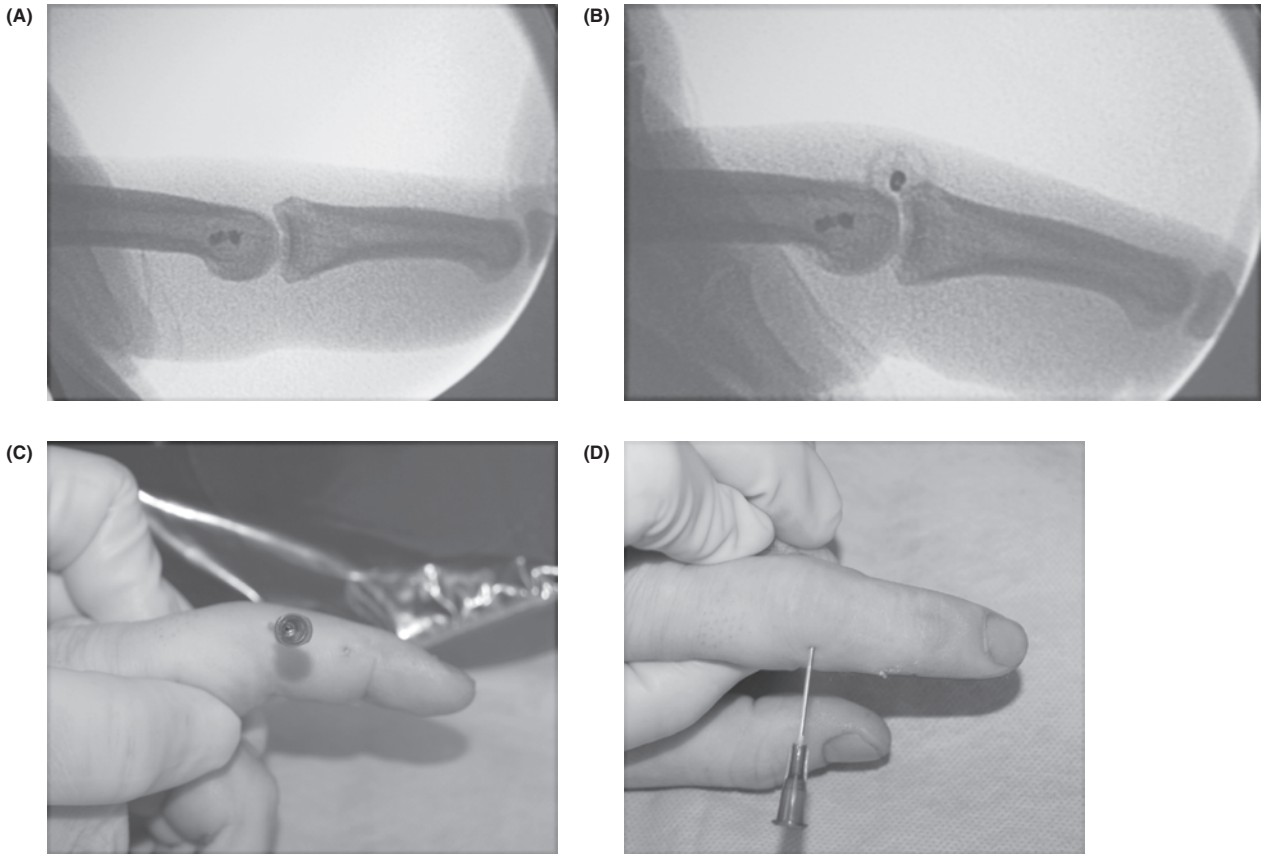

FIGURE 1 Percutaneous release of PIP extension contracture. (**A**) Lateral fluoroscopy of previously injured PIP now with extension contracture. (**B**) Fluoroscopically guided placement of 19-gauge needle into dorsal aspect of PIP joint. (**C**) Lateral view of anteriolateral placement of 19-gauge needle. (**D**) AP view of anteriolaterally placed needle. *Abbreviation*: PIP, proximal interphalangeal.

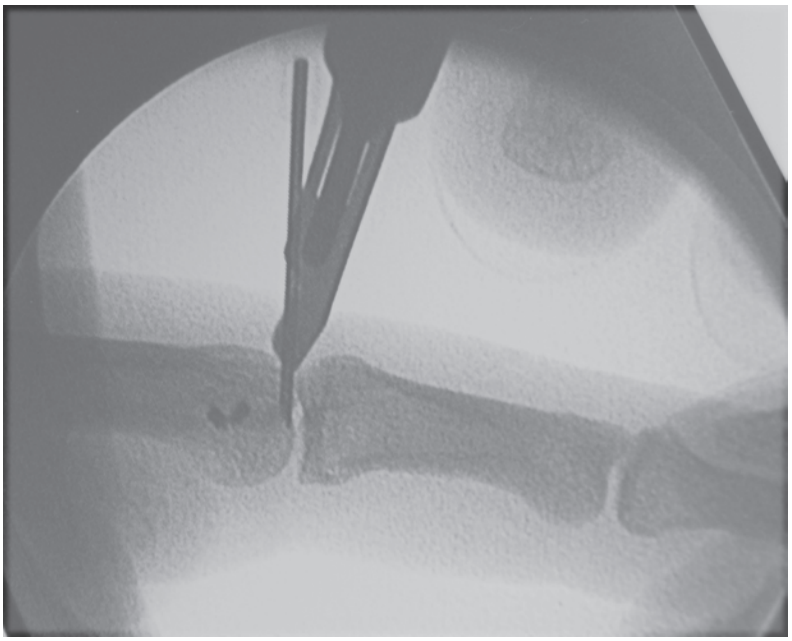

FIGURE 2 Fluoroscopic image of 15-blade anteriolateral stab wound into dorsal skin.

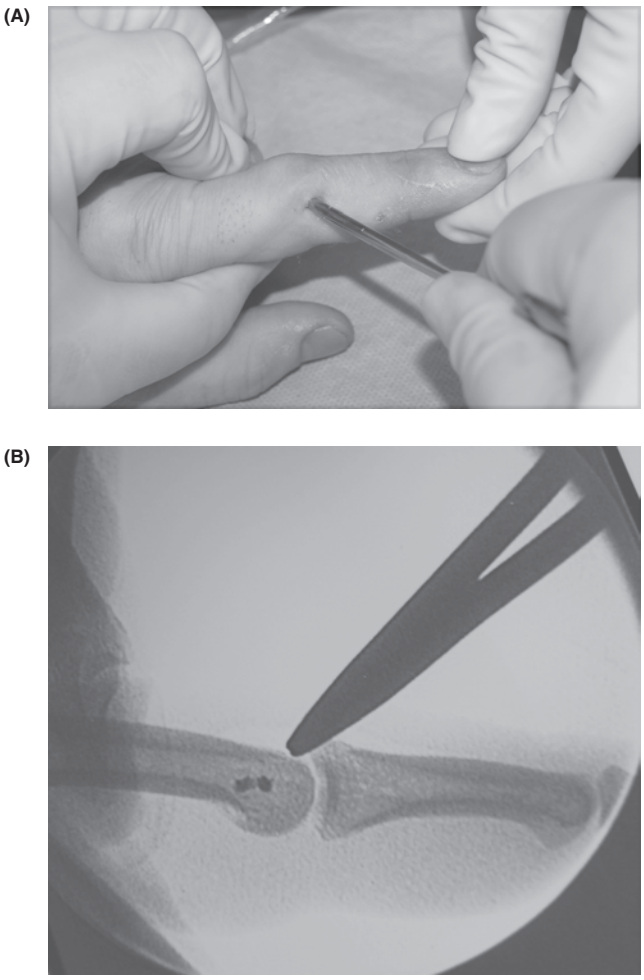

FIGURE 3 Percutaneous dorsal capsular release with hemostat. (**A**) Intraoperative view of small curved hemostat placed percutaneously into dorsal PIP joint. (**B**) Intraoperative lateral fluoroscopic view of small curved hemostat placed percutaneously into dorsal PIP joint to release dorsal capsular and extensor tendon adhesions.

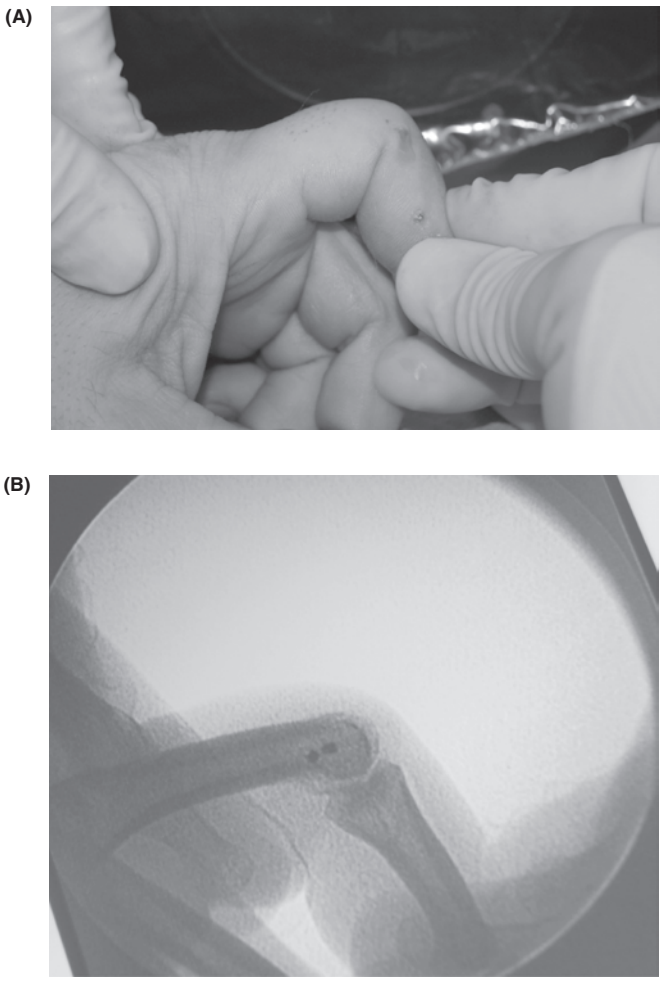

FIGURE 4 (**A**) Intraoperative view showing regain of full flexion at PIP joint after percutaneous release. (**B**) Intraoperative lateral fluoroscopic view showing regain of 85° of flexion at PIP joint after percutaneous release.

■ PERCUTANEOUS SURGICAL TECHNIQUE

The procedure can be performed under local, regional, or general anesthesia. A tourniquet is placed on the patient's arm and inflated after the finger, hand, and forearm have been exsanguinated. Under fluoroscopic guidance, a 19-gauge needle is placed into the PIP or MCP joint from an anteriolateral direction at the joint line, volar to the joint capsule and extensor mechanism (proximal to the central slip of PIP joint) and dorsal to the collateral ligaments (Fig. 1A–D). A scalpel is used to incise the skin only (Fig. 2). The needle is removed and a small hemostat snap is inserted and the skin is bluntly dissected to the dorsal joint capsule and with direct pressure the joint capsule is penetrated under fluoroscopic guidance (Fig. 3A,B). Using live fluoroscopy, the small curved hemostat position is confirmed in the dorsal joint under the capsule and extensor tendon (Fig. 3B). The hemostat is swept proximally rupturing the dorsal capsule and elevating the extensor tendon capsule and breaking any adhesions from the dorsal aspect of the proximal phalanx or metacarpal head. The hemostat is then swept laterally between the collateral ligaments and the head of the proximal phalanx or metacarpal, breaking up any additional adhesions. With flexion contractures, the hemostat can be swept volarly and used to break adhesions between the distal attachment of the volar plate and the base of the middle phalanx, as well as the proximal attachments of the volar plate and checkreins to the volar head of the proximal phalanx. Care must be taken to glide the hemostat volarly close to bone avoiding the neurovascular structures. With severe scarring of the soft tissue, this maneuver is contraindicated because of the potential for injury to the neurovascular structures.

The joint is then passively flexed and extended under imaging to determine the intraoperative gain in the arc of motion and to confirm congruent gliding (Figs. 4A,B and 6). This percutaneous joint release can also be performed on the distal interphalangeal joint (DIP) joint in a similar fashion since the DIP has similar anatomical structures to the PIP joint (Fig. 5A–C).

Figures 1–6 show percutaneous release of both the PIP and DIP in a 25-year-old male who had previously undergone a radioulnar ligamentous reconstruction with bone anchors after a dislocation injury. He subsequently developed an extension contracture at his index finger and failed conservative management.

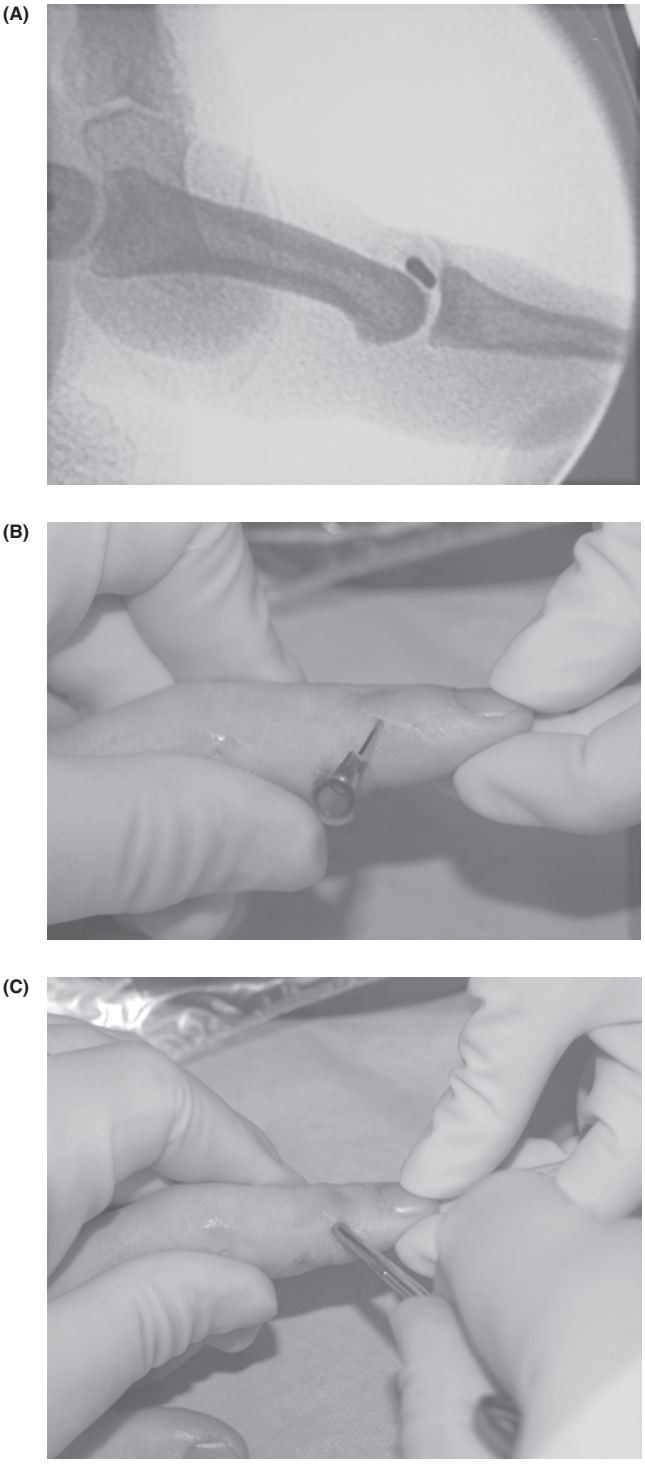

FIGURE 5 Percutaneous release of DIP joint extension contracture by same method described for PIP joint. (**A**) Fluoroscopically guided placement of 19-gauge needle into dorsal aspect of DIP joint. (**B**) Lateral view of anteriolateral placement of 19-gauge needle into DIP. (**C**) Percutaneous placement of small curved hemostat into dorsal DIP capsule.

If extracapsular structures, i.e., tendon adhesions, are suspected to be an additional etiology of the contracture, they can be addressed at this time. A single 5-0 nylon interrupted suture is used to close the PIP joint wound. The finger is placed in a light dressing and splinted into the corrected position.

Postoperatively, the patient is started on an immediate rehabilitation program to maintain the motion gained intraoperatively. Therapy will employ digital wraps to control swelling and selective blocks are used to control pain. Narcotics and NSAIDs are employed postoperatively, the former to control pain and the latter to reduce inflammation. Prior to surgery, arrangement for postoperative rehabilitation with a skilled hand therapist is essential, as well as patient knowledge of and compliance with the postoperative program.

RESULTS

Between 2003 and 2006, 60 patients were treated with percutaneous release of the MCP and PIP joints. Patients were started on an immediate hand therapy program postoperatively. The best results were observed in the young with a single pathological diagnosis. Those with crush injuries and scarring of multiple structures did the poorest and required multiple procedures. No complications were recorded including neurovascular injury, tendon disruption, or joint arthrosis.

SUMMARY

In 1977, Harrison suggested that "adhesions between the collateral ligaments and the sides of the phalangeal head are a more important cause of stiffness than shortening of the collateral ligament itself" (18). Since then many papers have been written on the stiff PIP joint and implicated various pathoanatomical etiologies, most of which pertain to either the collateral ligaments or the checkrein ligaments (2,8,11,13–19). Stanley et al. described a series of percutaneous releases of the accessory collateral ligament of the PIP joint (19). While their case number was small and follow-up limited, they reported a mean correction of 64% of the original contracture—similar to the results of many open release case studies (19). They recognized that their procedure also had the benefit of dividing adhesions between the collateral ligament and the phalangeal head.

We believe that intracapsular adhesions and fibrosis play a large role in the post-traumatic MCP and PIP contracture, which is evident by the significant increase in motion postoperatively in our series. While this procedure does not address all the pathological components of a flexion contracture, the motion gained and the minimal invasiveness of the procedure substantiate its use prior to subjecting the finger to the more invasive open procedures.

This technique has certain advantages over both open and external fixation procedures. In the described percutaneous release, all of the soft tissue stabilizers of the joint remain intact, thus, avoiding the potential of joint instability. The procedure can be performed in a matter of minutes, enabling multiple fingers to be addressed at once and it can be used as an adjunct to other procedures such as tenolysis or fasciectomy. The healing time is quicker than an open procedure, allowing a theoretical improved patient compliance with the postoperative rehabilitation. As opposed to external fixators, which have approximately a 40% infection rate (3), we had no incidence of postoperative infection. Patients also do not have to worry about pin loosening, external fixator care, or the prominence of the fixator, which can be cumbersome with certain activities especially if dealing with multiple or non-border digits.

FIGURE 6 Intraoperative fluoroscopy and photo showing 90° of flexion at the PIP and 60° at the DIP joints with flexor tendon tensioning after percutaneous release of both joints.

SUMMATION POINTS

Indications

- Soft-tissue contractures of MP, PIP, and DIP joints
- Normal articular anatomy
- Joints that fail conservative treatment including therapy and splinting

Outcomes

- Excellent range of motion with less soft-tissue scarring
- Low complication rate
- Short surgical time allowing multiple digits to be treated

Complications

- Failure to achieve adequate release
- Tendon injury (theoretical)

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Percutaneous Scaphoid Fixation via a Dorsal Technique

Joseph F. Slade III
Hand and Upper Extremity Service, Department of Orthopedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut, U.S.A.

Greg Merrell
Department of Orthopedics, Brown University School of Medicine, Providence, Rhode Island, U.S.A.

INDICATIONS

This technique is appropriate for any acute scaphoid fracture in the waist or proximal pole. Many angular or translational displacements can be corrected and rigidly fixed percutaneously. Fractures of the distal pole may be more appropriately treated conservatively or with volar fixation to maximize screw purchase in the distal fragment. We recommend starting with nondisplaced fractures to establish the skill set needed for more difficult displaced fractures.

CHOICE AND POSITION OF IMPLANT

An increasing variety of compression screws are available for fixation of scaphoid fractures. Toby found resistance to cyclic loading was proportional to the radius of the screw to the fourth power (r^4) (1). Further, he found the cannulated Acutrak (Acumed, Beaverton, Oregon, U.S.A.) screw was the strongest headless compression screw, giving the highest number of cycles to failure. The Herbert-Whipple (Zimmer, Warsaw, Indiana, U.S.A.), and AO (Synthes Corp., West Chester, Pennsylvania, U.S.A.) lag screws failed catastrophically with a resulting "windshield wiper" effect under conditions of volar comminution. The Acutrak screw underwent gradual separation via plastic deformation rather than catastrophic failure. Trumble described the clinical importance of central axis screw placement (2).

TECHNIQUE

A Simple New Targeting Guide

We now use an external cross Kirschner (K) wire targeting guide. This simple technique permits external sighting of the central axis by percutaneously placed perpendicular K-wires. This system also decreases radiation exposure as imaging is used primarily to set up the initial targeting system. This guide requires the placement of two K-wires in the distal scaphoid in the same axial plane, one perpendicular to the scaphoid, and one offset in a 90° arc. First a wire is driven dorsal to volar in the Posteroanterior (PA) plane of the distal scaphoid while ulnar deviating the wrist to extend the scaphoid (Fig. 1). A second wire is placed in the lateral scaphoid-radial to ulnar (Fig. 2). These wires cross at the distal scaphoid central axis and form a crosshair target for guidewire placement (Fig. 3). With the wrist extended and ulna deviated, PA imaging of the dorsal scaphoid wire if correctly perpendicular to the bone axis will appear as a single dark point. The lateral radial wire is introduced also perpendicular to the distal scaphoid and driven toward and across the dorsal wire as it appears on image as a single point. A lateral fluoroscopic image will confirm that the lateral wire has been placed in the mid axis of the distal scaphoid.

Technique for Displaced Fractures

After the "external cross K-wire scaphoid guide" is in place, a PA image is obtained and the fracture site is identified. Since the distal scaphoid fracture fragment is usually flexed exposing the dorsal intramedullary canal of the scaphoid, a K-wire can be introduced into the fracture site and driven through the distal scaphoid intramedullary canal. The "external cross K-wire scaphoid guide" provides direction as the wire is driven from dorsal to volar. The proximal fragment at this time is irrelevant, and will later be reduced. The wire is withdrawn volarly until the trailing edge of the wire is at the fracture site. Now a 0.062 K-wire joystick is placed in the proximal fragment, dorsal to volar. The wrist is placed in a neutral position and imaged, as the two dorsal joysticks (one in the distal fragment and one in the proximal scaphoid fragment) are manipulated until fracture alignment is obtained (Fig. 4). The lateral view of the concave scaphoid surface serves as the key reference for fracture reduction. Fracture reduction is secured by driving the volar wire retrograde across the fracture site.

Note if a dorsal intercalated segment instability deformity is present due to the extreme scaphoid flexion at the fracture site, fracture reduction can be achieved by hyper flexion of the wrist until the lunate is in a neutral position and a wire is driven through the distal radius into the lunate securing it provisionally in a neutral position. Or the wire can be placed dorsal directly into the lunate in a neutral position. As long as an intact scapholunate interosseous (SLIO) ligament exist the reduction force is transferred from the lunate to the scaphoid (Fig. 5).

Technique for Nondisplaced Fractures

Once reduction and provisional fixation of the displaced fracture has occurred or in the case of a nondisplaced fracture proceed as follows. With the wrist partially flexed a mini-fluoroscopic unit is used to locate the tip of the proximal scaphoid pole, the starting point for the central axis scaphoid guidewire. Drive the central axis wire toward the thumb base,

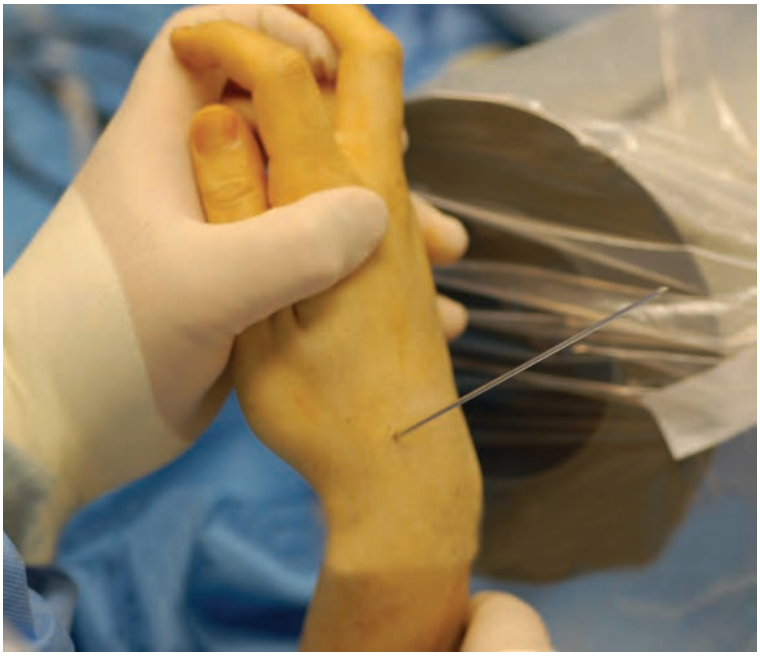

FIGURE 1 First 0.062″ targeting wire placed dorsal to volar in the distal scaphoid with the wrist in ulnar deviation to extend the scaphoid.

correcting its direction with the use of the external K-wire targeting guides (the dorsal wire provides radial–ulnar guidance and the lateral K-wire provides dorsal–volar orientation). A correctly placed central axis scaphoid wire will hit the crossing wires in the distal scaphoid, the location of the central axis. The wire is driven volarly past this intersection, through the trapezium, and exits at the thumb base in a safe zone without neurovascular structures. The wire is advanced volarly until the trailing edge crosses the radiocarpal joint and the wrist can be safely extended. In the case of a displaced

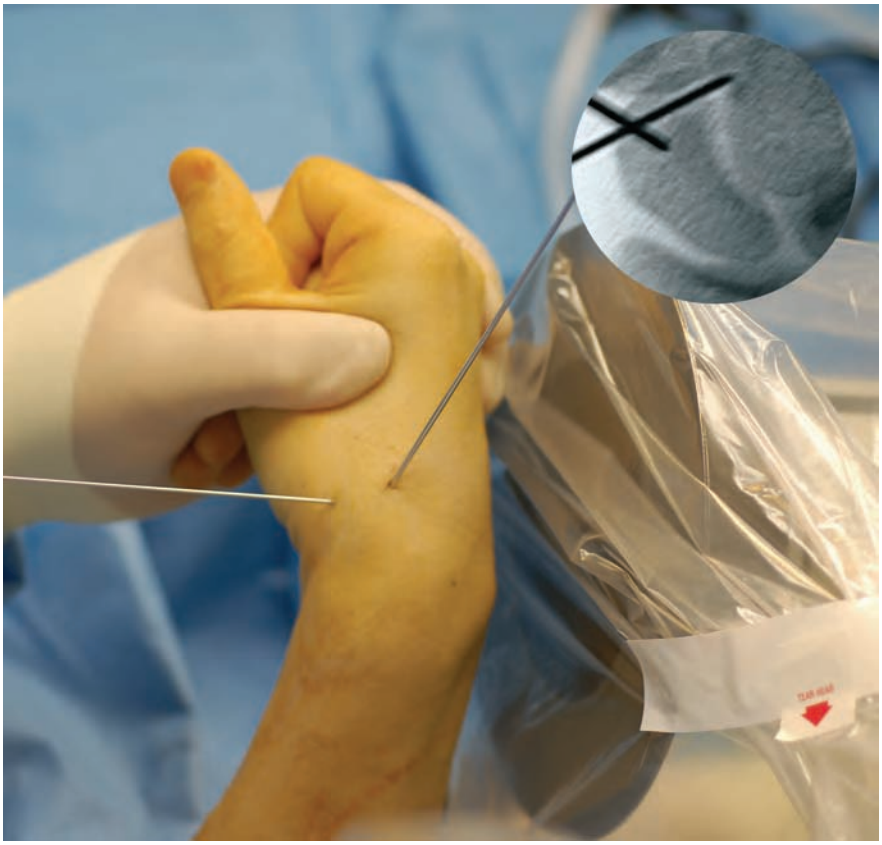

FIGURE 2 Second 0.062″ targeting wire placed radial to ulnar in the mid-lateral position of the distal scaphoid.

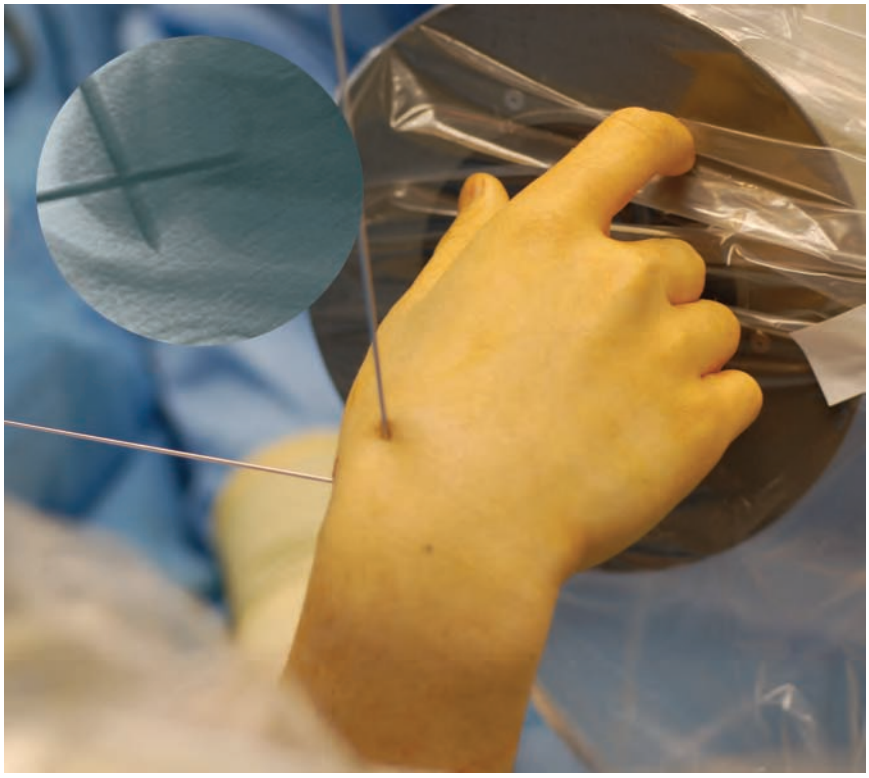

FIGURE 3 Pronated, ulnarly deviated view of the central axis with the targeting system guide wires in place.

fracture there are now two wires down the length of the scaphoid, one was used to capture the initial reduction and the second placed down the long axis (Fig. 6). The wire used to capture the reduction also acts as an anti-rotation construct during scaphoid reaming and screw placement. For nondisplaced fractures a second wire is rarely needed. Imaging confirms the position of the wire and the scaphoid fracture reduction. If satisfactory, the next step is an arthroscopic inspection of the joint.

■ ARTHROSCOPY

The goal of arthroscopy is to identify and treat ligament injuries, and directly inspect the quality of the reduction. The elbow is flexed and the wrist is positioned upright in a spring-scale driven traction tower. Twelve pounds of traction is distributed between four finger traps to reduce the possibility of a traction injury. If the finger traps slip off, apply mastisol or steristrips circumferentially at the base of the finger trap. The arm is exsanguinated. A fluoroscopy unit is placed horizontal to the floor and perpendicular to the wrist as the radiocarpal and midcarpal joint are identified with imaging. 19-gauge needles are introduced into the wrist joint identifying the radiocarpal and midcarpal portals. This maneuver minimizes iatrogenic injury to the joint.

The skin is incised and a blunt hemostat is used to separate the soft tissue and enter the wrist joint. A blunt trocar is placed at the radial midcarpal portal and a small joint angled arthroscope is inserted. A 19-gauge needle is inserted to establish outflow. A probe is introduced at the

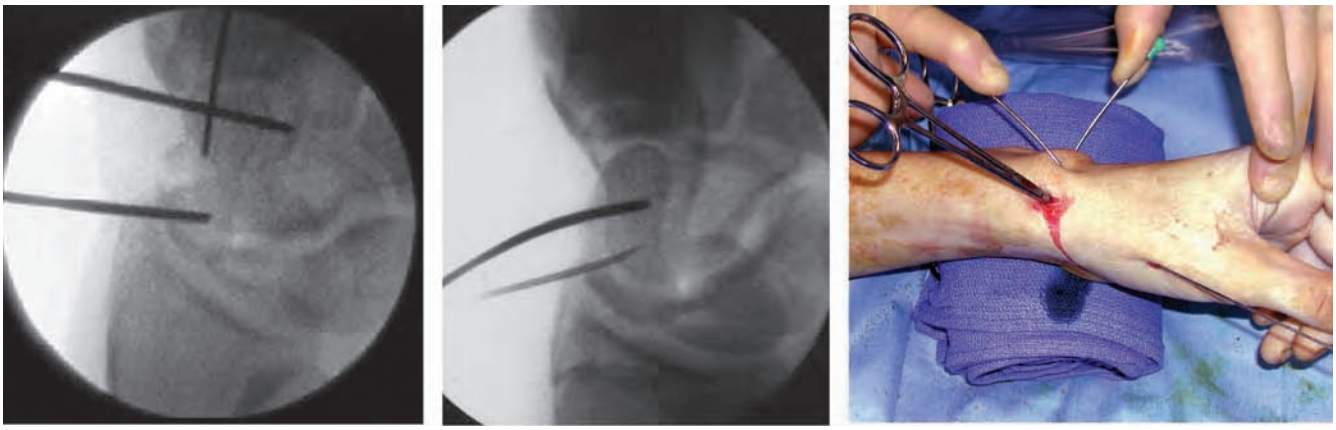

FIGURE 4 Displaced scaphoid fracture with 0.062″ joysticks in place prior to reduction, fluoroscopic image of fracture reduction using joysticks, capturing the reduction with the central axis wire.

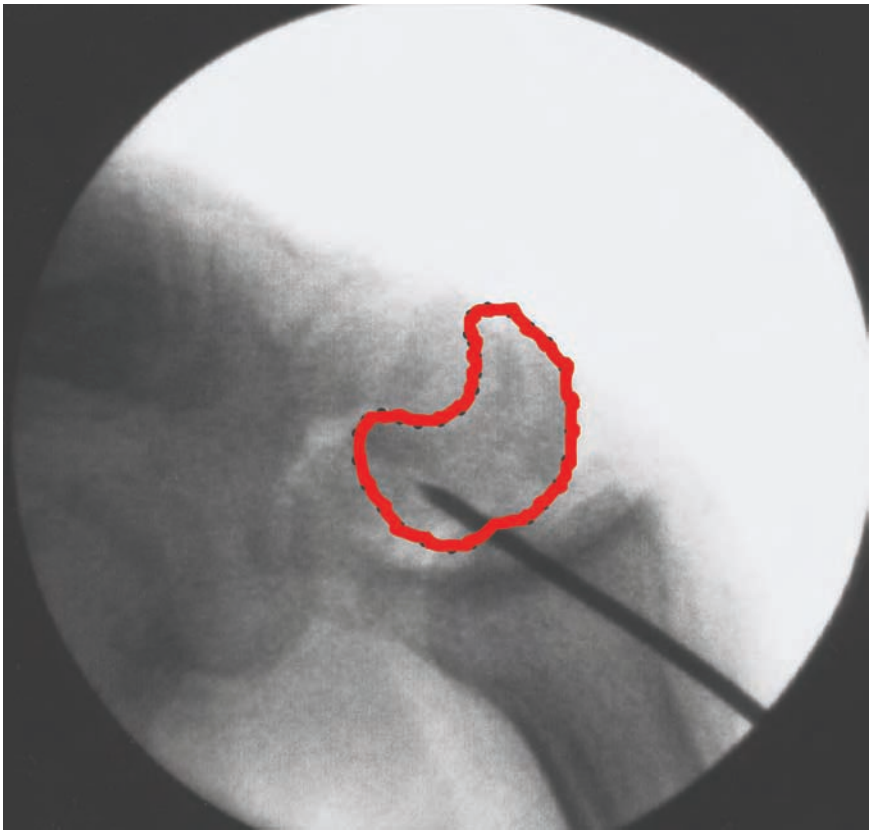

FIGURE 5 Wire to control dorsal intercalated segment instability deformity of the lunate.

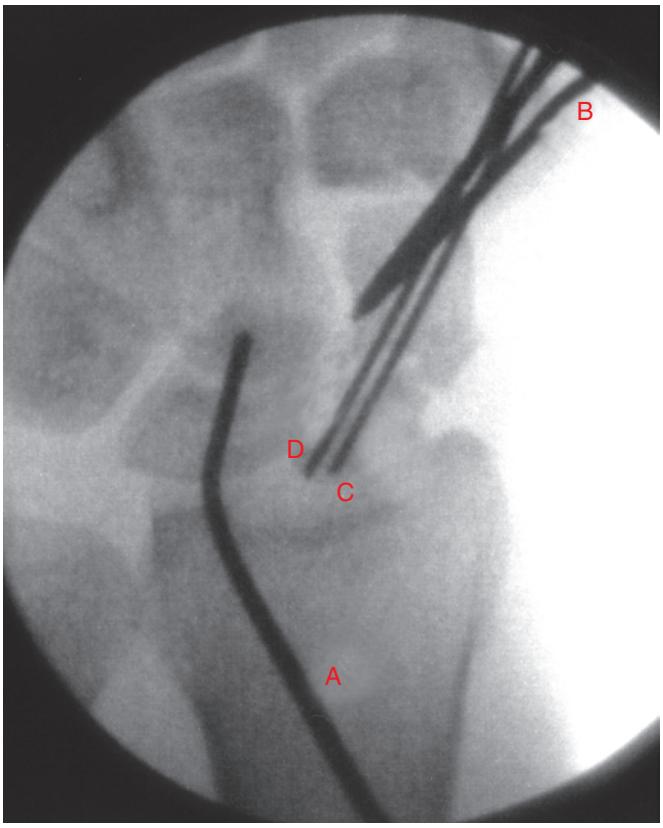

FIGURE 6 (**A**) Wire to control lunate position, (**B**) percutaneous snap to assist with reduction, (**C**) wire used to capture reduction and now serves as derotation wire, and (**D**) central axis wire.

ulnar midcarpal portal and subsequently at the third and fourth portal to assess the competency of the carpal ligaments by directly stressing their attachments to detect partial and complete tears.

First identify the scapholunate ligament sulcus. Injuries to the scapholunate ligament detected are graded using the Geissler grading system (3). Grade I and II ligament injuries are debrided. Grade III injuries are debrided and pinned for six weeks. Grade IV ligament injuries require open repair of the dorsal SLIO ligament with bone anchors and carpal pinning. The need for the addition of a dorsal capsulodesis tether is determined by the quality of the acute repair after scaphoid fixation. Tears of the triangular fibrocartilage complex are classified using the Palmer classification and treated accordingly (4).

■ SCAPHOID LENGTH

The screw length should be 4 mm less than the scaphoid length. This permits 2 mm of clearance at each end of the scaphoid, thus minimizing the risk of prominent hardware. The most common complication of percutaneous scaphoid fixation, is implantation of a screw which is too long (5).

■ FIXATION

Remove the extremity from the arthroscopy traction tower, flex the wrist and advance the wire retrograde until it is equally exposed on both ends. This prevents the wire from becoming dislodged during reaming. It is crucial that the wrist maintains a flexed position to prevent the wire from bending. Dorsal placement is recommended for fractures of the proximal pole

FIGURE 7 Increasing fracture stability by mechanical block of scaphoid lever arm.

and volar implantation is used for distal pole fractures. Fractures of the waist may be fixed from either a dorsal or volar approach. Volar implantation often requires reaming through part of the trapezium, since this is the central axis. Blunt dissection along the guide wire exposes a tract to the dorsal wrist capsule and the scaphoid base.

The scaphoid is reamed 2 mm short of opposite cortex with a cannulated hand drill. Newer self-drilling screws have reduced the need for extensive reaming, but the scaphoid should still be reamed past the fracture site to prevent gapping. It is critical to use fluoroscopy to check the position and depth during reaming. The scaphoid should never be reamed to the opposite bone cortex (over-drilling). This reduces fracture compression and increases the risk of motion at the fracture site. A standard Acutrak screw is advanced under fluoroscopic guidance down the central scaphoid axis to within 1 to 2 mm of the opposite cortex. If the screw is advanced to the distal cortex, attempts to advance the screw further will force the fracture fragments to gap and separate.

With unstable or displaced fractures, a counter force is applied with the dorsal K-wire holding pressure against the proximal fragment to prevent gapping. Unstable fractures may not achieve rigid fixation with screw implantation alone. Other temporary fixation may be required, to achieve a rigid construct, until healing has occurred. The distal scaphoid pole acts as a long lever arm to the proximal scaphoid pole and proximal carpal row during wrist motion. Proximal pole fractures have only a few threads crossing the fracture line. Wrist motion results in continuous rocking at the fracture site. The forces concentrated here are significant and can result in reduction of compression and loosening of fixation. These forces can be balanced by the placement of a 0.062 inch K-wire or headless compression screw from the scaphoid into the capitate (Fig. 7). These instruments temporarily blocks midcarpal motion and reduce forces acting on the scaphoid fracture site. Another mechanical block is a 0.062 inch K-wire placed between the II or III web-space into the capitate and the lunate. After healing has been confirmed with computed tomography (CT) scan, these mechanical blocks are removed percutaneously.

Severe comminution may make rigid fixation impossible. In these cases, align the scaphoid fracture fragments with multiple K-wires down the central axis, and stabilize the capitolunate joint with K-wires. After, one month, these provisional fixation wires are removed. Dorsal percutaneous bone grafting of the scaphoid and rigid fixation of the scaphoid with a headless compression screw can then be accomplished.

POST-OPERATIVE CARE AND SCAPHOID HEALING

Immediate post-operative care includes a bulky compressive hand dressing and a volar splint. The patient is encouraged to initiate early finger exercises to reduce swelling. The therapist fashions a removable volar splint that holds the wrist and hand in a functional position at the first post-operative visit. An immediate strengthening program is initiated to axially load the fracture site. This early motion also decreases swelling and permits an early return of hand function. Patients with ligament injuries or proximal pole fractures, are restricted from wrist motion until CT scan confirms bridging bone at the fracture site at six weeks post-op. Post-operative radiographs are obtained with the first post-operative visit and at six week intervals. CT scans with 1 mm cuts and sagittal and coronal reconstructions are used to evaluate bridging bone at the fracture site. CT scans are ordered at six weeks intervals until final union is established.

Standard radiographs at three months are unreliable in detecting scaphoid healing (6). Patients are often pain free, prior to CT evidence of healing. Contact sports and heavy labor are restricted, until fracture healing is confirmed by CT. If bridging bone is not identified by 12 weeks one must consider aggressive treatment including percutaneous bone grafting. Delay in treatment for early nonunions, delays healing. We do not routinely cast our scaphoid fractures post-operatively, but candidates for additional protection are evaluated on an individual basis.

SUMMARY

Scaphoid fractures are common injuries that often require surgical treatment. Closed treatment is complicated by prolonged casting and associated stiffness. The advent of cannulated headless screws has simplified the treatment of these difficult fractures. Percutaneous treatment of scaphoid fractures offers high healing rates with minimal soft-tissue trauma.

SUMMATION POINTS

Indications

- Non and minimally displaced scaphoid fractures
- Displaced fractures are amenable, but require additional joy stick K-wires and is more technically challenging.

Outcomes

- High healing rates
- Quicker return to activities and work
- Less wound problems and scar tenderness.

Complications

- Similar to open technique
- Nonunions
- Hardware problems (screw excessively long).

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13

Percutaneous Fixation of Acute Scaphoid Fractures

John T. Capo, Tosca Kinchelow, and Virak Tan
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Fractures of the scaphoid are common injuries, representing 60–70% of carpal fractures (1,2). Inadequate treatment of these injuries can result in nonunion, osteonecrosis, carpal instability patterns, all of which can lead to impaired function, and arthrosis (3–5). Early results of cast immobilization of acute fractures were quite favorable, reporting union rates of 88–100% and good motion, grip strength, and function (6–9). However, subsequent series have shown more discouraging results, particularly with fractures displaced more than 1 mm (10,11). The first factor in initiating appropriate treatment is the proper and timely diagnosis of these fractures. Once diagnosed, the fracture can be managed by closed, open, or percutaneous methods. Internal fixation has the advantage of providing compression and a stable construct which can allow early range of motion (ROM) (12–17). However, an open approach risks stripping of the critical blood supply to the scaphoid and also division of important carpal ligaments, such as the radioscaphocapitate ligament (18). Percutaneous techniques have since been developed, providing the benefits of ORIF with a smaller incision, preservation of the carpal ligaments and potentially fewer wound problems.

INDICATIONS

The ultimate goal in any scaphoid treatment is to obtain and maintain anatomic alignment while preserving vascularity until complete fracture healing has occurred. Operative fixation is suggested when acceptable alignment cannot be reached by closed treatment. In addition, with the documented success of percutaneous screw fixation (3,19–22), we believe that this technique should be offered to all patients with a complete scaphoid fracture, even if minimally or non-displaced. The patient should be educated about the two treatment options: long-arm followed by short-arm casting versus operative percutaneous screw fixation. We explain the risks and advantages of operative treatment as well as the risks and details concerning the prolonged length of non-operative treatment. In our experience, approximately 50% of patients select operative fixation.

Other indications include the multiply injured patient either in the same or other extremities. Patients with ipsilateral distal radius fractures and elbow fractures, as well as those with lower extremity injuries that need to use assistive aids to mobilize, are good candidates for operative treatment of minimally displaced scaphoid fractures. Fractures with a small amount of displacement (2–3 mm) or angulation (20° intrascaphoid angle) and no comminution at the fracture site may also be treated with percutaneous means. Kirschner (K)-wires can be used as joysticks to manipulate the proximal and distal fragments before guide wire placement.

Contraindications to percutaneous fixation include moderate or severe fracture displacement requiring open reduction, nonunion with significant bone resorption requiring supplemental cancellous bone graft, avascular necrosis (AVN) requiring a vascularized bone graft, and a displaced nonunion with a "humpback" deformity requiring a structural bone graft to restore normal carpal alignment.

PREOPERATIVE PLANNING

Physical Examination

The ideal patient for this technique is a young healthy male laborer or athlete with a mid-waist acute fracture with minimal displacement. The mechanism of injury usually includes load to the dorsiflexed, radially deviated wrist. On physical exam, there is typically mild to moderate edema, painful, limited ROM, and tenderness of the scaphoid. The body of the scaphoid can be palpated in the interval between the first and second dorsal compartments dorso-radially and becomes more prominent with ulnar deviation of the wrist. The scaphoid tuberosity can be palpated volarly at the wrist crease, just radial to the flexor carpi radialis tendon. The scaphoid compression test (23) is positive when axially loading the thumb metacarpal toward the wrist causes pain.The Distal radial–ulnar joint, ulnar side of the wrist, and elbow should be examined for tenderness and crepitus. Soft tissues need to be evaluated, including a thorough neurovascular exam. For proper edema management, the patient should be instructed on finger motion exercises and elevation of the extremity, in either definitive closed management or for temporary immobilization before operative treatment.

Imaging

Standard plain radiography is mandatory, including posteroanterior (PA), lateral, oblique, and PA ulnar deviation views. This last view is termed the "scaphoid view" and extends the scaphoid, thereby visualizing an elongated view of the entire bone (Fig. 1). Images of the contralateral side may be useful, particularly in assessing any deformity. It is important to evaluate radiographs for the presence of an acute or chronic fracture and scaphoid deformity, since this will influence whether fixation can be done percutaneously. Radiographic parameters for inadequate reduction are: displacement >1 mm, a scapholunate angle $>60°$, radiolunate angle $>15–30°$, an intrascaphoid angle $>35°$, or a scaphoid height-to-length ratio >0.65 (7,24–27).

Advanced Imaging

When plain films are equivocal for fracture and the patient has scaphoid tenderness, management is controversial. While

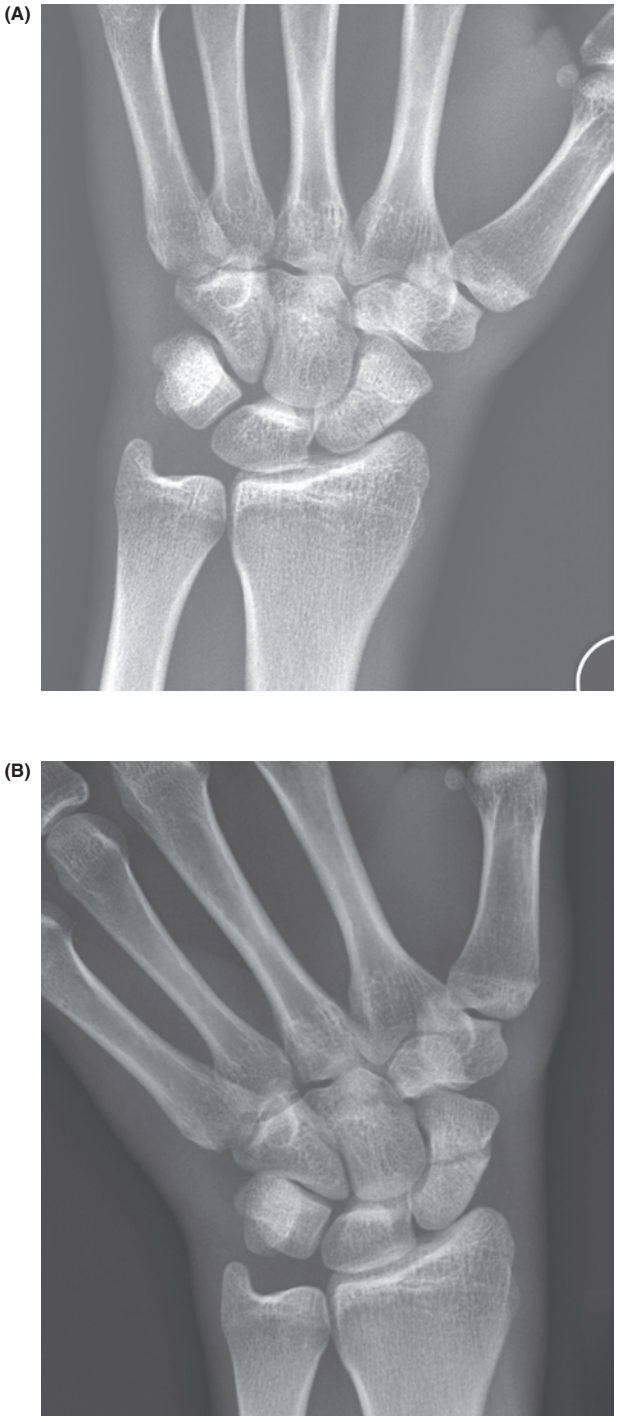

FIGURE 1 (**A**) PA view of the wrist with a questionable scaphoid waist fracture. (**B**) Ulnar deviation PA view clearly demonstrating complete scaphoid fracture. *Abbreviation*: PA, posteroanterior. *Source*: Courtesy of John T. Capo, MD.

it has been proposed that any fracture not seen on radiographs is incomplete and does not require immobilization (8), the usual practice is to presume that a complete fracture is present. Traditionally, the patient is immobilized for one to two weeks and then re-examined and re-imaged. By that time, bony resorption at the fracture may demonstrate lucency within the scaphoid, confirming a fracture. If plain films remain equivocal and/or the patient remains tender, another immobilization trial can be done (8) or advanced imaging [bone scan or magnetic resonance imaging (MRI)] should be obtained (23).

Attention has been given to the inaccuracy of plain radiography in diagnosing occult scaphoid fractures initially and postinjury (8,28). Furthermore, advanced imaging has been shown to be much more reliable (29–31), with a quoted sensitivity of 100% and specificity 95–100% for MRI scanning. Dorsay (32) compared the reliability of plain films and MRI in diagnosing occult scaphoid fractures and evaluated the costs associated with each. MRI was more sensitive, specific, and had a higher interobserver reliability than plain films. Additionally, the cost of an early screening MRI in a case with clinical suspicion and negative radiographs was comparable to the cost of lost work time due to keeping a patient immobilized for one to two weeks. In our practice, if a patient has an injury mechanism and clinical exam consistent with a scaphoid fracture with negative radiographs, we immobilize the wrist in a short-arm thumb-spica cast. If these parameters are the same follow-up exam in one to two weeks, then an MRI study is ordered.

SURGICAL TECHNIQUE

Operating Room Setup and Equipment

The following equipment is needed: a mini-fluoroscopy machine, non-sterile arm tourniquet, small battery drive drill, K-wires, and a cannulated, headless screw set (headed screws may also be used). While there are currently several commercially available screws that can be used, most instrumentation systems are similar and utilize some variation of the following: a guide wire, a cannulated drill bit, reamer, tap and screwdriver, a countersink, and screws. Wire size and screwdriver/instrumentation gauge vary, but we have found that a guide wire of at least 0.035 inch is ideal, as it provides better control for accurate placement into the proximal pole.

General or regional anesthesia may be used. The patient is positioned supine with a radiolucent hand table. Some authors place the patient in fingertraps, with traction and weights, as needed (3,11,20). This helps to ulnarly deviate the wrist, which uncovers the distal scaphoid from the radial styloid and allows free rotation of the hand (11,20). We prefer to place the hand over a small towel role for wrist extension and apply only manual, intermittent traction to the fingers (Fig. 2). However, in the case of a displaced fracture, traction can aid in closed reduction (29).

Surgical Technique

Ultimately, the location of the skin incision will be directed by wire placement. This is usually on the distal volar–radial aspect of the scaphoid near the scaphotrapezial (ST) joint. Care should be taken to avoid the dorsal aspect of the ST joint because the dorsal branch of the radial artery is in this area. There exist key landmarks to aid in proper guide wire starting hole placement. This location can be approximated by simply drawing bony structures with a skin marker and noting the level of the ST joint and radial aspect of the scaphoid (Fig. 3). Alternatively, the location can be found at the intersection of two lines drawn in line with K-wires placed on the outside of the skin parallel to the long axis of the scaphoid on frontal and lateral views (22,33). Typically, the wire must start through the volar, proximal corner of the trapezium, thus allowing access to the center of the distal scaphoid pole. Therefore, the subsequent drilling removes this edge of trapezium and screw placement traverses the defect to be countersunk in the scaphoid. Alternatively, a small piece of

FIGURE 2 The wrist is extended over a small towel roll. This allows guide wire access to the trapezium and distal scaphoid pole. *Source*: Courtesy of John T. Capo, MD.

the trapezium can be removed with a rongeur to allow unhindered placement of the guide wire, requiring a larger incision and dissection to directly visualize the ST joint. Another alternative is to avoid violating the trapezium by using a more radial starting point (34).

The final position of the wire (and subsequent screw) is the most critical part of the procedure and should be in the center of the proximal pole of the scaphoid in all radiographic views. In Trumble's (35) study of screw fixation with bone graft in 34 patients with scaphoid nonunion, those with screws placed in the central one-third of the proximal pole had a significantly faster time to union than those with peripherally placed screws. McCallister (36) supported these results in a biomechanical study, finding that a center–center screw placement in the proximal pole of the scaphoid provided a construct that was significantly stiffer (43%) and more resistant to displacement (113%) than an eccentrically placed screw.

The guide wire must be within the scaphoid body in all views, with enough clearance on each side for screw placement (Fig. 4). A 45° pronated (oblique) view is helpful to assess the proximal pole wire placement, as wire penetration through the proximal scaphoid articular surface can be missed on standard PA and lateral views (22,33). Once the wire is in place, and its position confirmed fluoroscopically, consideration should be given to placing a second, derotational wire, which can be helpful in more unstable fractures (22,24). We have not found this second, derotation wire to be necessary in most cases.

Often, the guide wire on the implant set is of a small caliber and easily bent. As an example, the Acutrak (Acumed, Beaverton, Oregon, U.S.A) mini-sized screw is preferable as it

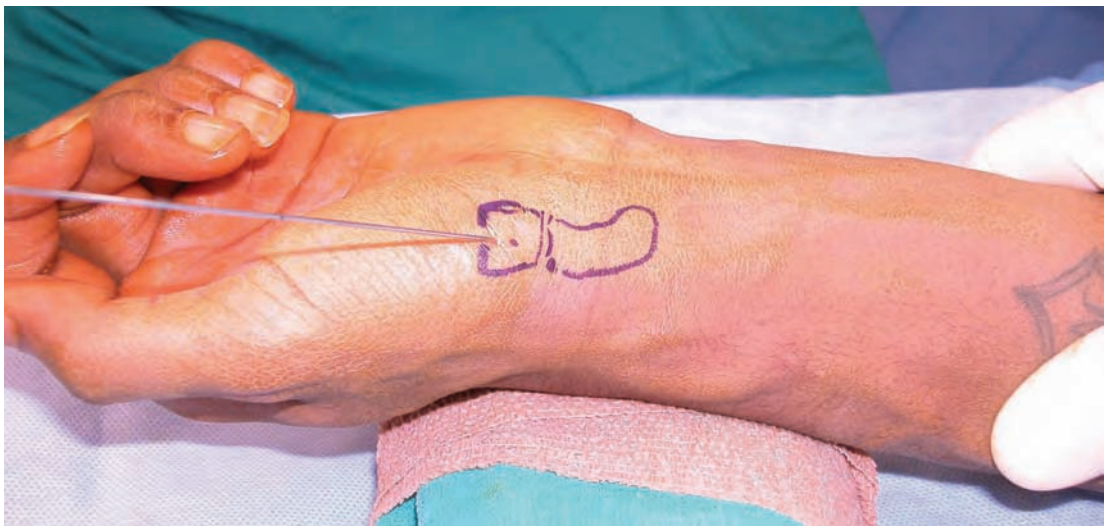

FIGURE 3 The outlines of the trapezium and scaphoid are drawn on the volar wrist. The guide wire is placed starting at the trapezial edge and advanced in a proximal ulnar and dorsal direction. *Source*: Courtesy of John T. Capo, MD.

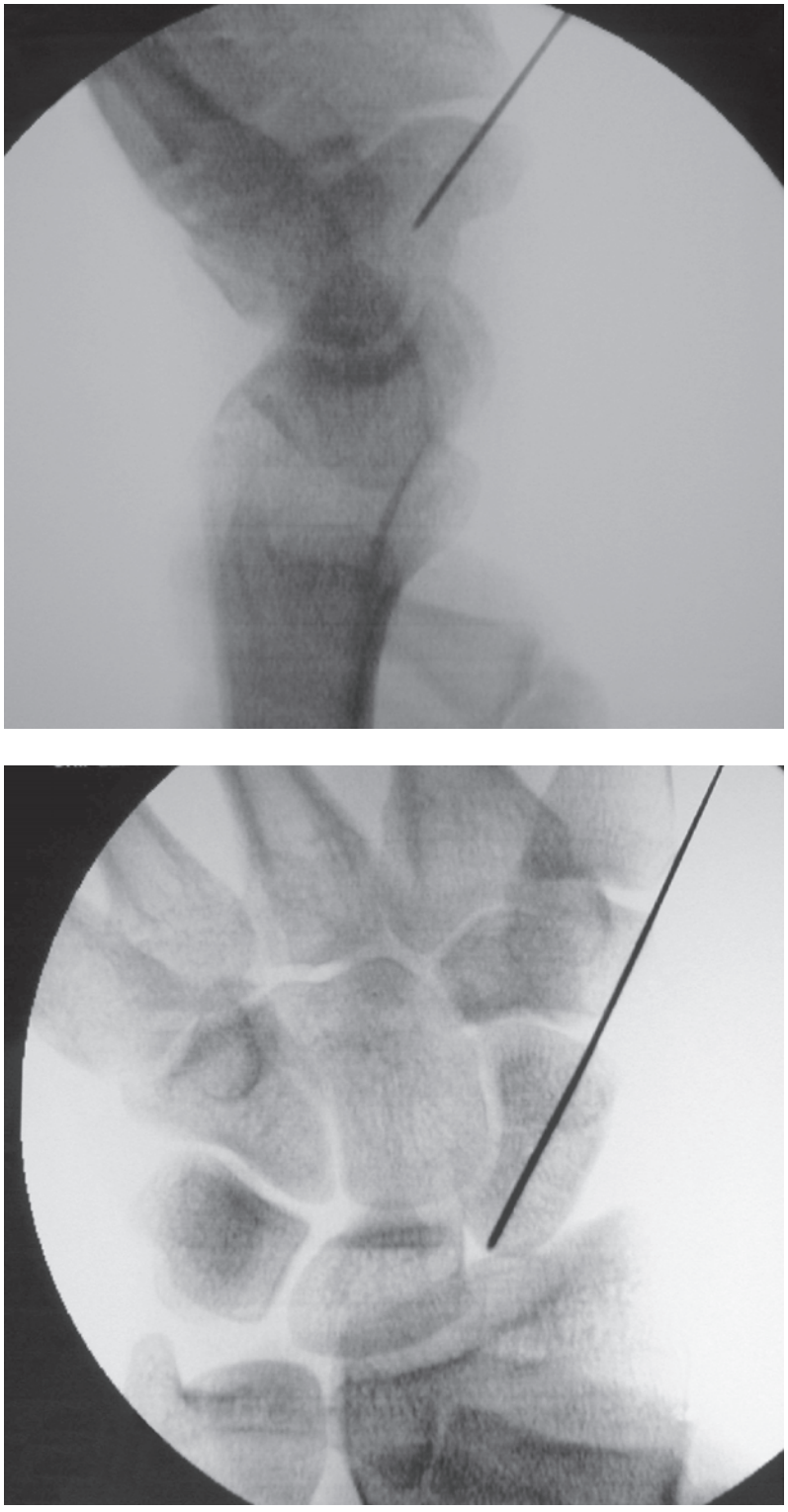

FIGURE 4 (**A**) The lateral fluoroscopic view demonstrates the proper starting point of the guide wire. The edge of the trapezium is traversed to allow access to the center of the distal scaphoid pole. (**B**) Final guide wire placement in the AP view. The wire starts at the distal radial edge of the scaphoid and is centered in the proximal pole. *Abbreviation*: AP, anteroposterior. *Source*: Courtesy of John T. Capo, MD.

removes less bone and creates a smaller starting hole in the scaphoid, but its guide wire is 0.028 inch. This size wire is insufficiently rigid to obtain accurate placement and easily bends with even gentle wrist motion. A technique to avoid this is to use a 0.035 inch wire for ideal placement and to use an additional identical length wire for measuring. Alternatively, the new Synthes (Synthes Corp., West Chester, Pennsylvania, U.S.A.) scaphoid screw set has a sufficiently large guide wire of 0.045 inch.

After appropriate guide wire placement, a longitudinal incision (approximately 5 mm, just large enough for the depth gauge and screw) is centered on the wire (20). Blunt dissection is then used to obtain access to the distal scaphoid and trapezium. Screw length is determined by using the supplied depth gauge or by an additional wire of identical length to calculate the amount of guide wire buried in the bone. It should be verified radiographically that the depth gauge or wire is on the distal scaphoid edge and not the trapezium to ensure accurate screw

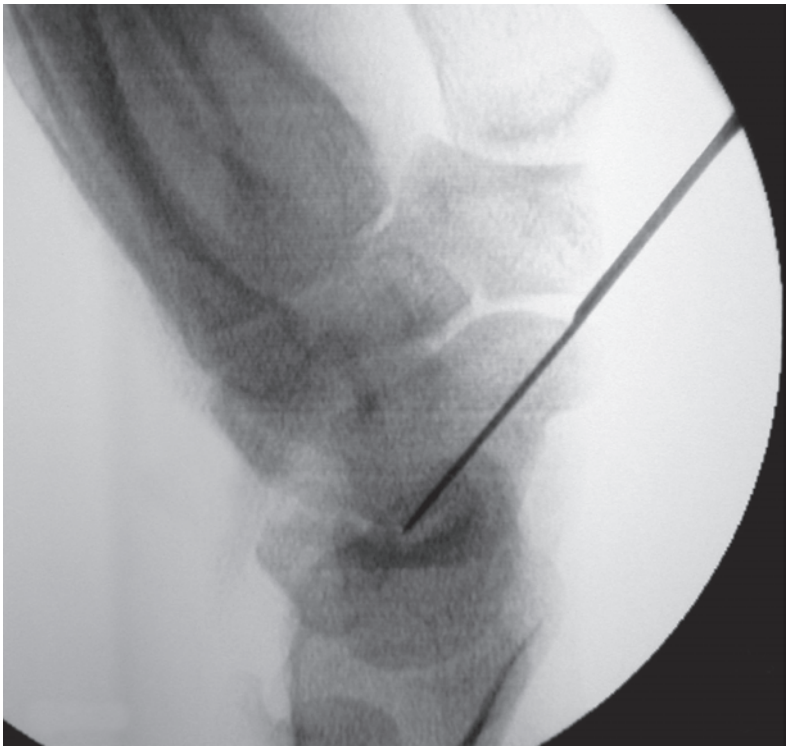

FIGURE 5 A second guide wire of equal length is placed on the scaphoid cortical surface to obtain a proper length measurement. If the measuring sleeve is used, it should be ensured to rest at the same location. *Source*: Courtesy of John T. Capo, MD.

length (Fig. 5). The screw length selected should be 2–4 mm shorter than the wire measurement, depending on the position of the proximal end of the wire. In our hands, the most accurate method is to place the proximal tip of the wire at the scaphoid cortical edge and then subtract 4–5 mm.

Hand or power drilling is then done, followed by tapping as needed (based on screw type, bone quality, and presence of sclerosis). Drilling, tapping, and screw placement are done with fluoroscopic guidance (Fig. 6). The screw is placed over the wire and inserted under fluoroscopic control to ensure maintenance of the reduction (Fig. 7). If any rotation between the proximal and distal fragments is noted, a derotational wire should be placed (33). The ideal screw provides appropriate compression and is countersunk at least 2 mm on either

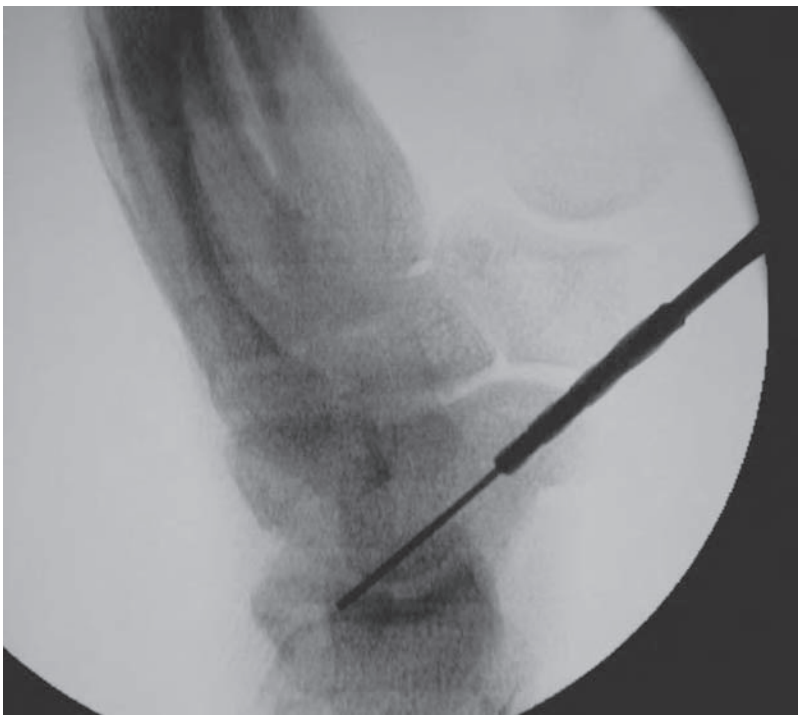

FIGURE 6 Cannulated drill advancing over the guide wire under fluoroscopic control. The drill has removed the volar edge of the trapezium. *Source*: Courtesy of John T. Capo, MD.

FIGURE 7 (**A**) Cannulated screw being placed through volar wound. (**B**) Lateral fluoroscopic view of screw being advanced into scaphoid body. Note that the guide wire has been further advanced out of the proximal pole to avoid loosening with drilling and screw placement. *Source*: Courtesy of John T. Capo, MD.

end of the scaphoid (5,22). Final screw placement is verified with imaging to ensure it is countersunk and within the confines of the scaphoid bone (Fig. 8). If traction is being used, it should be released before final screw tightening, allowing for more compression (11). When using a conical screw system (like the Acutrak set), care must be taken not to over-drill the channel in length or insert the screw too far. Due to the conical nature of the screw this may cause screw loosening or fracutre of the scaphoid proximal pole.

The wound is irrigated and closed with two to three nylon sutures (Fig. 9). A splint is placed for comfort and active finger ROM is allowed immediately. If the fracture was rigidly fixed, then we begin gentle wrist ROM once the wound is stable (usually at the first postoperative visit). However, this is controversial. Preferences for postoperative immobilization range from mandatory (24) to optional or unnecessary (20,22,33). In between ROM exercises, patients wear a removable thumb-spica splint (off the shelf or made by an occupational therapist). Patients can return to sedentary work when they feel ready or when their ROM is 75% compared to the contralateral side (20). Manual or athletic work can be resumed at the time of bony union (20). If plain radiographs

FIGURE 8 (**A**) AP and (**B**) lateral views demonstrating final placement of screw. Both proximal and distal aspects of the screw are countersunk well within the bone. *Abbreviation*: AP, anteroposterior. *Source*: Courtesy of John T. Capo, MD.

are inconclusive, a computed tomography scan can be obtained to verify bony healing.

■ COMPLICATIONS AND THEIR MANAGEMENT

Overall, the complication rate for this technique is low. However, the most frequent complications reported include nonunion, symptomatic hardware, residual pain, superficial radial nerve irritation, and superficial wound infection. Nonunion has been reported at rates ranging from 0% (20–22) to 11% (11,36). Nonunion has been attributed to improper screw placement, proximal pole fractures, and treatment delayed beyond four weeks (11,37). Mild residual pain has been reported from 5% (21) to 29% (37) of patients and associated with ipsilateral distal radius fractures, scaphotrapeziotrapezoid injury, adhesions, and scar sensitivity. Symptomatic hardware has occurred in cases of both headless and headed screws at a rate up to 10% (22,37). Of these cases, 50% were successfully treated with hardware removal (22,37). Transient superficial radial nerve irritation has been reported in 2–6% of cases. Superficial wound infection, occurring in up to 1% of patients, has been effectively managed with oral antibiotics.

Wozasek (2001) reported treatment of 146 scaphoid fractures with a percutaneously placed 4.8 mm cannulated, headed screw and detected mild trapezial erosions in one-third of his patients. The majority of these patients had painless, full ROM and no significant clinical consequences (11). He also reported one loose screw that required replacement and reflex sympathetic dystrophy in two of these 46 patients.

■ OUTCOMES

Percutaneous fixation of scaphoid fractures was first introduced in the German literature by Streli in 1970 (38). In 1986, Cosio (39) reported 77% union for percutaneous K-wire treatment of scaphoid nonunions. In 1991, Wozasak (11) reported results of percutaneous fixation, with cannulated 4.8 mm screws, of acute fractures, delayed unions, nonunions, and sclerotic nonunions. Of the 146 acute fractures treated, there was an 84% union at an average of four months. One-third of the nonunions were attributed to technical errors, including screw protrusion through the proximal fragment, threads across the fracture site, and screw length too long to provide adequate compression. Ledoux (40), in the French literature, reported 23 cases, demonstrating 100% union rate and wrist ROM of 95% compared to the contralateral side.

In 1998, Haddad (20) published results of 15 patients treated with percutaneous screws. He reported a 100% union rate within two months and ROM and grip strength similar to the opposite side. Return to work averaged four days for sedentary and five weeks for manual jobs. Brutus (37) reported a retrospective review of 30 patients treated with percutaneously placed Herbert screws and followed for at least six months. His results included a 90% union rate and a return to work at an average of 1.6 months for professional work and 1.8 months for sports. Yip (22) percutaneously treated 49 fractures with cannulated 3.5 mm screws and followed them for an average of four years. There was a 100% union rate at 12 weeks and no infection, AVN, nonunion, or arthrosis.

The percutaneous technique has also been directly compared to cast immobilization of non- and minimally displaced fractures and has had favorable results. Adolfsson (3) reviewed 53 patients treated with immobilization in a short-arm thumb-spica cast versus percutaneous Acutrak screw fixation. While rate and time to union were found to be similar, the operative group had significantly better ROM at 16 weeks. Inoue (21) compared the outcomes of 39 patients treated with a short-arm thumb-spica cast and 40 treated with a freehand standard Herbert screw placed through a 1 cm incision. This was a retrospective review and the type of treatment was determined by the patients, after informed discussion about each treatment method. The operative group

FIGURE 9 Three nylon sutures are used to close the skin of the entry site. *Source*: Courtesy of John T. Capo, MD.

had a significantly faster time to union (6 vs. 9.7 weeks) and return to work (5.8 vs. 10 weeks). There was one nonunion in the cast group that was successfully treated with subsequent screw fixation and bone graft. Two patients in the operative group had mild pain, which was thought to be related to ipsilateral distal radius fractures.

In a landmark study in 2001, Bond (19) prospectively randomized 25 military personnel with non-displaced scaphoid fractures to cast immobilization or percutaneous screw fixation. The one complication in the fixation group was a distally prominent and symptomatic screw that needed to be removed. There were no complications in the cast immobilization group. The times until union and return to work were significantly shorter for the percutaneous fixation group: seven and eight weeks versus 12 and 15 weeks, respectively. However, at two years, there were no significant differences in function or satisfaction between groups.

SUMMARY

General Conclusions

Internal fixation has the advantage of providing rigid stabilization that eliminates the need for above-elbow immobilization and permits early ROM. However, open fixation involves larger incisions, soft tissue stripping, and possible vascular compromise. The percutaneous fixation technique for selected scaphoid fracture and nonunions is a safe and effective treatment option, now yielding up to 100% union rates with minimal surgical complications and significantly faster return to work and activities of daily living. As surgeon familiarity continues to improve, percutaneous techniques are being used to treat a wider variety of fractures, nonunions, and AVN cases. The data justifying its use are compelling and suggest that percutaneous fixation for non- and minimally displaced scaphoid fractures is an ideal treatment option for a patient who desires early return to function.

Future Direction

Many advances continue to be made in the application and utility of the percutaneous technique for treating scaphoid injuries. Closed reduction maneuvers, e.g., ulnar deviation, and percutaneously placed K-wires as joysticks can be used to reduce unstable and displaced fractures (5,26,41–43) and reduction can be verified with arthroscopic assistance (5,43–46). Early nonunions can be treated with screw fixation alone if the cartilaginous shell is intact, there is no collapse, and cystic changes are mild (5). If the nonunions are more advanced with larger cyst formation, these can be debrided with percutaneously placed curettes and then injected with bone graft, followed by percutaneous screw placement (43). Select cases of AVN have also been treated percutaneously by providing "vascularized" bone graft through retrograde reaming (43).

Hardware improvement should include larger guide wires which provide more control during guide wire placement and avoid bending. Another implant advance that has recently been introduced is the development of self-drilling screws (Acutrak; Wright Medical Technology, Arlington, Tennessee, USA). These can save time and also allow further advancement of the screw to a more accurate final location while minimizing the chance of fracture of the proximal pole. New methods of percutaneously placed grafts would also be beneficial in difficult nonunion cases.

SUMMATION POINTS

Indications

- Acute minimally displaced scaphoid fracture in a healthy patient requiring early return to work/function or unwilling to accept prolonged closed, cast treatment
- Scaphoid nonunion with near-anatomic alignment and minimal cystic degeneration
- *Relative*: Displaced fractures and nonunions with significant cystic changes (only if surgeon is experienced with percutaneous techniques and assistive arthroscopy)

Outcomes

- Union rates >98%
- Less/minimally invasive
- Allows earlier ROM and return to work and regular activities
- Lessens immobilization
- Shorter operative time: (with experience)

Complications

- Residual pain (up to 29%)
- Nonunion (0–11%)
- Symptomatic hardware (5–29%)
- Transient superficial radial nerve irritation (2–6%)
- Superficial wound infection (up to 1%)

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14

Percutaneous and Arthroscopic Management of Scaphoid Nonunions

William B. Geissler
Department of Orthopedic Surgery and Rehabilitation, University of Mississippi Medical Center, Jackson, Mississippi, U.S.A.

INTRODUCTION

Wrist arthroscopy has revolutionized the practice of orthopedics by providing the technical capability to examine and treat intra-articular abnormalities of the wrist joint (1). Wrist arthroscopy allows for direct visualization and palpation of cartilage surfaces, synovial tissue, and the interosseous ligaments under bright light and magnified conditions. The scaphoid is well visualized from both the radiocarpal and midcarpal spaces. Fractures of the scaphoid are best visualized with the arthroscope in the midcarpal space (Fig. 1). This allows for arthroscopic assisted fixation of fractures of the scaphoid and nonunions under direct visualization.

The scaphoid is the most frequently fractured carpal bone and accounts for approximately 70% of all carpal fractures (2). This injury typically occurs in young adult males between the ages of 15 and 30 years (3). Scaphoid fracture is also a common athletic injury particularly in football and basketball where aggressive play frequently causes impact injuries to the wrist (4). It is estimated that approximately 1 out of 100 college football players will sustain a fracture of the scaphoid (4).

Acute nondisplaced fractures of the scaphoid have traditionally been managed with cast immobilization (5,6). Nondisplaced scaphoid fractures have been reported to heal in 8 to 12 weeks when immobilized in long- and short-arm thumb spica casts (5,6). However, the reported rate of nonunion for such fractures has been as high as 15% (5–7). The duration of cast immobilization also varies dramatically according to the fracture site. A fracture of the scaphoid tubercle may be healed within a period of six weeks, while a fracture of the waist of the scaphoid may take three months or more of immobilization. Fractures of the proximal third of the scaphoid may take six months or longer to heal with a cast due to the distal vascularity of the scaphoid (8).

Although cast immobilization may be successful in up to 90% of cases, it must be asked at what cost to the patient, who may not be able to tolerate a lengthy course of immobilization (9). Prolonged immobilization may lead to muscle atrophy, disuse osteopenia, possible joint contracture, and financial hardship (7). An athlete or worker may be inactive for six months or longer as the fracture unites. This may result in a loss of athletic scholarship or employment.

Displaced fractures have a reported nonunion rate of approximately 50% (3). Factors that decrease the prognosis for healing include displacement, the presence of associated carpal instability, and delayed presentation greater than four to six weeks (2). Traditionally, acute displaced fractures of the scaphoid and scaphoid nonunions have been managed by open reduction and internal fixation (2,3,10–17). This requires significant soft tissue dissection. Complications have been reported with the most common complication seen as hypertropic scar in one series (2,3). Other potential complications include avascular necrosis, carpal instability, donor site pain (bone graft), infection, screw protrusion, and reflex sympathetic dystrophy (15,18). Jigs have been designed to assist in fracture reduction, but are often difficult to apply requiring even further extensive surgical dissection (19).

There are several factors that make healing of the scaphoid difficult (20), if not prolonged. Scaphoid fractures unite by primary bone healing without external callus. The scaphoid is almost entirely covered with articular cartilage. This limits the amount of surface area for bone contact and consolidation. The potential for synovial fluid to pass between the fracture fragments may also occur due to its intra-articular environment.

The scaphoid receives its primary blood supply from the radial artery and branches of the anterior interosseous artery (8). The most important vascular supply enters along the dorsal ridge of the scaphoid. These vessels are responsible for the majority of perfusion of the proximal two-thirds of the scaphoid. This blood supply is quite tenuous and can be easily disrupted as the majority of scaphoid fractures (80%) occur at the waist area or mid portion of the scaphoid (21). The disruption of blood supply affects bone consolidation, and the time until union. Because of the retrograde circulation, more proximal fractures of the scaphoid require greater time until union. Approximately one-third of fractures of the waist of the scaphoid and virtually all proximal one-fifth fractures develop osteonecrosis (8).

INDICATIONS

Arthroscopic or percutaneous assisted fixation of scaphoid fractures offers a middle ground between the traditional treatment of cast immobilization for nondisplaced fractures and open reduction for displaced fractures of the scaphoid (22–30). The application of arthroscopic wrist techniques to scaphoid fracture management offers many advantages over conventional techniques. These techniques reduce surgical exposure and minimize soft tissue dissection, which may cause potential loss of vascularity to the fracture fragments. These techniques avoid the division of the important radioscaphoid capitate ligament and the volar capsule, which requires subsequent repair and healing (18). In addition, arthroscopic assisted fixation avoids potential scar formation and allows for detection and management of any associated intercarpal soft tissue injuries, which may occur with a fracture of the scaphoid.

Recent advances in arthroscopic assisted and percutaneous fixation of scaphoid fractures allow the majority of acute fractures of the scaphoid to be managed by these modalities.

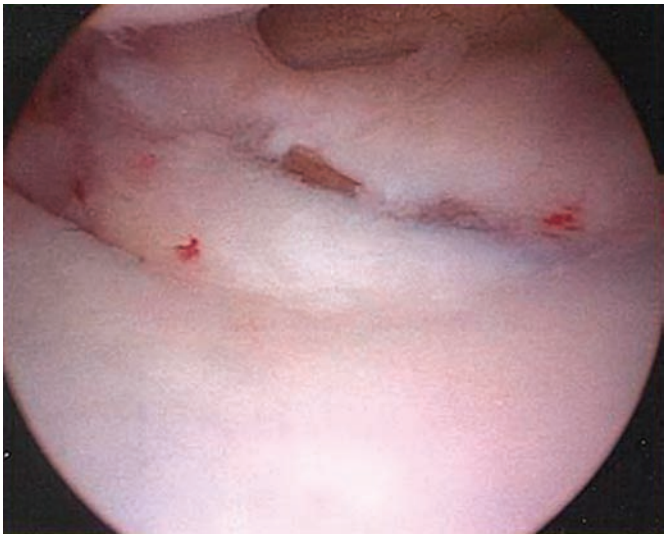

FIGURE 1 Fractures of the scaphoid are best seen from the midcarpal space. Fractures of the waist of the scaphoid are best observed with the arthroscope in the radial midcarpal portal. Fractures of the proximal pole are ideally visualized with the arthroscope in the ulnar midcarpal portal as seen here.

As surgeons gain more experience with these techniques, several authors now have reported their experience with arthroscopic and percutaneous management of nonunions of the scaphoid (1,22–25,27,28,30–32). The purpose of this chapter is to review the indications of surgical techniques for arthroscopic and percutaneous management of nonunions of the scaphoid. These techniques are particularly applicable to the young active population in which scaphoid fractures are most commonly seen and in particular, this group is least likely to tolerate prolonged periods of immobilization (33,34).

PREOPERATIVE EVALUATION

Posteroanterior (PA) and lateral radiographs are mandatory to assess displacement, alignment, and angulation of a scaphoid fracture. In addition, semi-pronated and semi-supinated views are helpful to demonstrate the proximal and distal pole of the scaphoid respectively. A posterior anterior radiograph with the wrist in ulnar deviation extends the scaphoid for detection of displacement. It is well recognized that a nondisplaced fracture may not be apparent on the initial radiographs for several weeks. It is important to immobilize the patient who presents with snuffbox tenderness until the pain resolves, or until a diagnosis is confirmed radiographically. Frequently, athletes simply choose to ignore the initial pain and discomfort with an acute scaphoid fracture and appear after the season has ended with a defined nonunion of the scaphoid (30,33).

Computer tomography (CT) parallel to the longitudinal axis of the scaphoid is used to evaluate displacement, angulation, and healing when further information is required to assess the scaphoid fracture. In this technique, the patient is placed prone with the arms extended overhead, and with the wrist radial deviated to obtain the longitudinal axis of the scaphoid. Coronal slices are performed with supination of the forearm to a neutral position. Percutaneous and arthroscopic reduction of scaphoid fracture is indicated in patients without a humpback deformity. If a humpback deformity or rotation of the lunate is demonstrated by plain radiographs, or by CT scan, open reduction and bone grafting is indicated.

TABLE 1 Scaphoid Nonunion Classification

	Slade and Geissler
Type I	Delayed presentation 4 to 12 weeks
Type II	Fibrous union, minimal fracture line
Type III	Minimal sclerosis <1 mm
Type IV	Cystic formation, between 1 and 5 mm
Type V	Humpback deformity, >5 mm cystic change
Type VI	Wrist arthrosis

Source: From Ref. 35.

Recently, Slade and Geissler published their radiographic classification of scaphoid nonunions (Table 1) (29). Type I fractures are the result of delayed presentation, i.e., 4 to 12 weeks from injury. A delayed presentation is well known to be a risk factor for nonunion of the scaphoid. In Type II injuries, a fibrous union is present. A minimal fracture line is seen on the plane radiographs. The lunate is neutral and there is no humpback deformity. In Type III injuries, minimal sclerosis is seen at the fracture site. The sclerosis is less than 1 mm in length. Again, the lunate is not rotated, and no humpback deformity is seen on imaging studies. In Type IV injuries, cystic formation has now occurred. The area of cyst formation is between 1 and 5 mm. In Type IV injuries, there is no humpback deformity of the scaphoid, and no rotation of the lunate as seen on plane radiographs. In Type V injuries, cystic changes are now greater than 5 mm. A humpback deformity may be seen either on plane imaging studies or CT evaluation. The lunate has rotated into a dorsal intercalated segment instability (DISI) position. Percutaneous and arthroscopic techniques for scaphoid nonunions are not indicated in Type V injuries. In Type VI injuries, a long-standing nonunion of the scaphoid is present. Secondary degenerative changes, scaphoid nonunion advanced collapse (SNAC), are seen with spurring along the radial border of the scaphoid and peaking of the radial styloid. Again, percutaneous and arthroscopic reduction techniques are not indicated in Type VI injuries. Fixation of the scaphoid nonunion may still be possible with removal of the bone spurs and radial styloidectomy. In advanced cases, salvage procedures such as proximal carpectomy or four-corner fusion may be indicated.

SURGICAL TECHNIQUES

Various arthroscopic assisted and percutaneous techniques for fractures of the scaphoid have been described in the literature (22–28,30,32,36). These include the volar approach (popularized by Haddad) and the dorsal approach (more recently popularized by Slade) (25,27,28). In general, these techniques include the use of a small amount of wrist arthroscopy and a significant amount of fluoroscopy. As described previously, fibrous nonunions of the scaphoid and cystic scaphoid nonunions without humpback deformity and rotation of the lunate are amendable to these techniques. Significantly displaced fractures with marked DISI rotation of the lunate particularly in a chronic situation are best managed by open reduction and internal fixation (2,3,37).

Volar Percutaneous Approach

The percutaneous volar approach was popularized by Haddad and Goddard (25). Utilizing this technique, the patient is placed

supine and the thumb is suspended in a Chinese finger trap while the patient is under general anesthetic or regional anesthesia. Placement of the thumb in suspension causes ulnar deviation of the wrist, which improves access to the distal pole of the scaphoid. Under fluoroscopic control, a longitudinal 0.5 cm incision is made at the most distal radial aspect of the scaphoid. Blunt dissection is used to expose the distal pole of the scaphoid. A percutaneous guide wire is introduced into the scaphotrapezial joint and advanced proximally and dorsally across the fracture site. The position of the guide wire is checked under fluoroscopy in the anterior/posterior, oblique, and lateral planes. The length of the guide wire within the scaphoid is determined with a depth gauge and a drill is inserted through a soft tissue protector to protect the surrounding tissues. A headless cannulated screw is placed over the guide wire after drilling. A second guide wire is helpful to protect against rotation of the fracture fragments while the screw is being inserted. More recently, self-drilling and self-tapping headless cannulated screws have been introduced (Acumed, Beaverton, Oregon, U.S.A.). Skin closure requires the use of a single suture and the patient is encouraged to begin active finger flexion exercises before discharge.

Haddad and Goddard report their initial results in a pilot study of 15 patients with acute fractures of the scaphoid (25). Unions were achieved in all patients in 57 days (range 38–71 days). The range of motion after the union was equal to that of the contralateral limb and grip strength averaged 90% of the contralateral limb at three months. Patients were able to return to sedentary work within four days and manual work within five weeks.

Dorsal Percutaneous Approach

Slade has described the dorsal percutaneous approach with fixation of stable, unstable acute fractures of the scaphoid and selected nonunions (27–29). This technique has become popular because of its simplicity and because it allows for further arthroscopic evaluation and reduction of the fracture. The patient is placed supine on the table with the arm extended. It is helpful to place several towels under the elbow to support the forearm so that it is parallel to the floor. The wrist is flexed and pronated under fluoroscopy until the proximal and distal poles of the scaphoid are aligned to form a perfect cylinder. Continuous fluoroscopy is useful as the wrist is flexed to obtain the true ring sign. A 14-guage needle with a needle driver is then used as a drill guide for a 0.045 guide wire. Under fluoroscopy, the needle is placed in the center of the ring and is parallel to the beam of the fluoroscopy unit. The guide wire is then driven across the central axis of the scaphoid from dorsal to volar until the distal end is in contact with the scaphoid cortex. The position of the guide wire is then evaluated under fluoroscopy in the PA, oblique, and lateral planes while maintaining the wrist in flexion. The wrist cannot be extended at this point; otherwise the guide wire may be bent. A second guide wire is then placed parallel to the first so that its tip touches the proximal pole of the scaphoid cortex. The difference between the lengths of the two guide wires is the resulting length of the scaphoid.

The tendency with these percutaneous techniques is to insert a screw that is too long. A screw that is too long may potentially distract the fracture site, or can violate the joint surface causing articular damage either to the scaphotrapezial joint or radiocarpal joint. Therefore, it is important to subtract at least 4 mm from the measurement between the guide wires, which provides the ideal length of the screw. In this way, the screw may be placed fully buried in the bone to avoid damage to the articular surface. In fractures that involve the proximal third of the scaphoid, more than 4 mm from the measurement between the guide wires may be subtracted because it is not essential to have the screw fill the entire length of the scaphoid.

The primary guide wire is then advanced volarly through the trapezium along the radial side of the thumb metacarpal and exits the skin after the screw length has been selected. The guide wire is advanced volarly until its proximal end is flushed with the proximal pole of the scaphoid. Now the wrist may be extended without damage to the guide wire.

The wrist is then suspended in a traction tower and the wrist can be evaluated arthroscopically. Fractures of the waist of the scaphoid are best seen with the arthroscope in the radial midcarpal portal. Fractures of the proximal pole of the scaphoid are best seen with the arthroscope in the ulnar midcarpal portal. The reduction of the scaphoid nonunion may be viewed directly arthroscopically. If the reduction is not satisfactory, the guide wire may be advanced volarly across the fracture site but still within the distal pole of the scaphoid. Kirschner wire or joysticks may be placed in the dorsum of the proximal and distal ends of the scaphoid fracture fragments. These joysticks are then used to further reduce the fracture anatomically as viewed directly arthroscopically with the arthroscope in the midcarpal portal. Once the reduction is felt satisfactory, the guide wire is then advanced back proximally from volar to dorsal into the proximal pole fragment of the scaphoid.

The wrist is then flexed, and the guide wire is advanced back dorsally so that it protrudes from the skin. A portion of the guide wire is left protruding from the volar aspect of the hand as well, so that the guide wire breaks or bends and can be easily removed from either the volar or dorsal aspect of the hand. A small incision is then made over the dorsum of the guide wire and blunt dissection is carried down to the level of the joint capsule. The guide pin may be evaluated so that it is not impaling any of the dorsal extensor tendons to the hand or sensory nerve branches. With the wrist in flexion, the scaphoid is then reamed through a soft tissue protector. A secondary guide wire helps prevent rotation of the fracture fragments during reaming of the scaphoid and screw insertion. A headless cannulated screw is then inserted over the guide wire to the depth previously reamed. It is important not to advance the screw to the far cortex unless this has been reamed because this may cause distraction of the fracture fragments. The position of the screw is then checked under fluoroscopy to confirm its central location within the scaphoid and the guide wires are removed.

It is important to re-evaluate the position of the screw and the proximal pole of the scaphoid arthroscopically following insertion. Under fluoroscopy, it may appear that the screw is well within the scaphoid. However, it potentially may still be protruding and arthroscopic evaluation is extremely helpful to insure that the screw is within the scaphoid. If the screw protrudes proximally it can potentially injure the articular cartilage of the scaphoid facet of the distal radius. The wrist is suspended again in the traction tower and the arthroscope is placed in the 3–4 portal to assess the position of the screw within the scaphoid. Following confirmation of the screw placement, the small dorsal incision may be closed with a single nylon stitch.

Dorsal Percutaneous Approach with Arthroscopic Confirmation of Starting Point (Geissler)

Most recently, Geissler described his arthroscopic technique for reduction of acute scaphoid fractures and scaphoid nonunions with cystic changes (Fig. 2) (38). In this technique, the wrist is initially suspended in an ARC (Hillsboro, Oregon, U.S.A.)

FIGURE 2 Posteroanterior radiograph of a cystic scaphoid nonunion in a 22-year-old male.

traction tower (Fig. 3). The arthroscope is initially placed in the 3–4 portal to evaluate any associated soft tissue lesions, which may occur with a scaphoid fracture. Upon evaluation and treatment of any associated soft tissue injuries, the arthroscope is then transferred to the 6-R portal (Figs. 4–6). The wrist is flexed to approximately 30° in the traction tower. A 14 guage needle is then inserted through the 3–4 portal and the scapholunate interosseous ligament (SLIO ligament) is palpated at the junction of the scaphoid. The junction of the SLIO ligament insertion onto the dorsal, middle third of the scaphoid is the ideal insertion point for a screw. The 14-guage needle is then advanced and impaled into the scaphoid right at the junction of the SLIO ligament onto the dorsal middle third of the scaphoid (Figs. 7 and 8).

FIGURE 3 The wrist is suspended in the ARC traction tower. The suspension bar, off to the side, does not block fluoroscopic visualization of the wrist.

FIGURE 4 The arthroscope is placed in the 6-R portal, and a probe is utilized to identify the junction of the scapholunate interosseous ligament to the scaphoid.

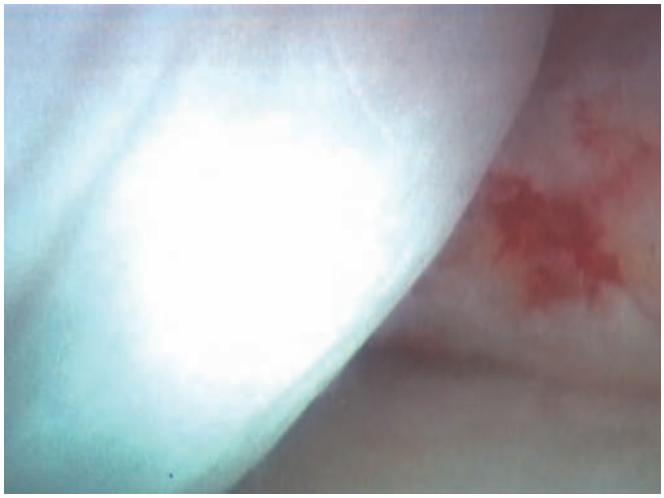

FIGURE 5 Arthroscopic view of the scapholunate interval as seen with the arthroscope in the 6-R portal.

FIGURE 6 Arthroscopic view with the arthroscope in the 6-R portal and a probe being placed in the 3–4 portal probing the junction of the scapholunate interosseous ligament to the scaphoid.

The traction tower is then flexed, and the starting point of the needle is evaluated under fluoroscopy (Fig. 9). Utilizing his technique, the starting point is always right at the most proximal pole of the scaphoid. The needle is then simply aimed toward the thumb and a guide wire is then placed through the needle down the central axis of the scaphoid to abut the distal pole (Figs. 10–12). The position of the guide wire is then evaluated on the PA, oblique, and lateral planes under fluoroscopy (Fig. 13). This is done by rotating the forearm in the traction tower, as the fluoroscopy beam is not hindered by the tower. A second guide wire is then placed against the proximal pole of the scaphoid, and the difference in length is measured between the guide wires to give the length of the scaphoid screw. Just as Slade has recommended, a screw at least 4 mm shorter is utilized. Reduction of the scaphoid is then evaluated with the arthroscope in the radial and possibly ulnar midcarpal portal. If the reduction is satisfactory, the guide wire is then advanced out the volar aspect of the wrist. The advantage of this technique is the wrist is not hyperflexed as compared to the percutaneous dorsal technique. Thus the fracture site is not potentially flexed to produce a humpback deformity.

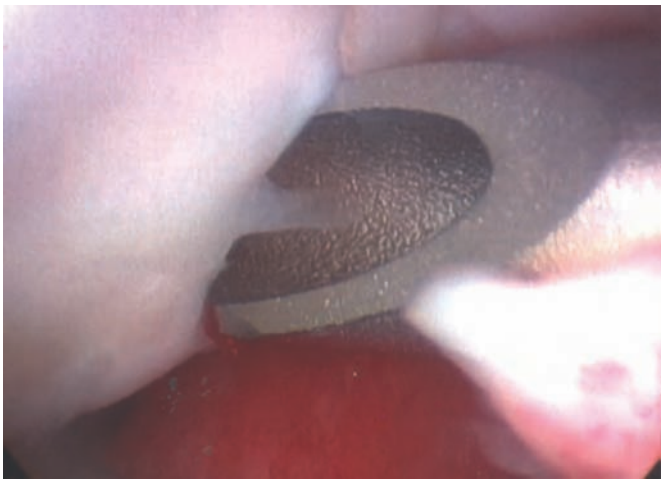

FIGURE 7 A 14-guage needle impales the middle third of the scaphoid at the junction of the scapholunate interosseous ligament on the scaphoid after it has been identified with the probe.

FIGURE 8 The proximal pole of the scaphoid is then impaled with a 14-guage needle at the junction of the scapholunate interosseous ligament on the scaphoid.

In addition, the insertion point of the guide wire into the scaphoid is precisely identified arthroscopically.

The scaphoid is then reamed over the guide wire with a secondary Kirschner wire to protect rotation in a standard fashion (Fig. 14). A headless cannulated screw is then inserted

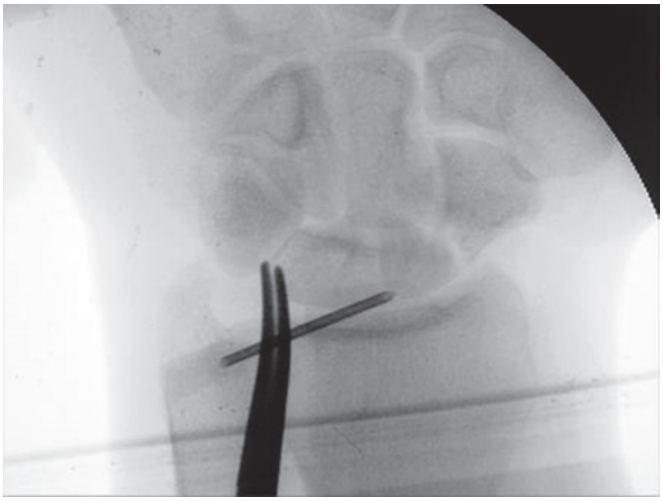

FIGURE 9 Fluoroscopic view confirming the ideal starting point for the guide wire on the proximal pole of the scaphoid. The ideal starting point has now been confirmed by direct visualization arthroscopically and fluoroscopically.

FIGURE 10 The ARC traction tower is then flexed down and the needle is aimed toward the thumb.

over the guide wire. The position of the screw within the scaphoid is checked under fluoroscopy in the PA, lateral, and oblique planes while the wrist is still in the tower. Following screw placement, the position of the screw within the scaphoid is evaluated arthroscopically with the arthroscope in the 3–4 portal

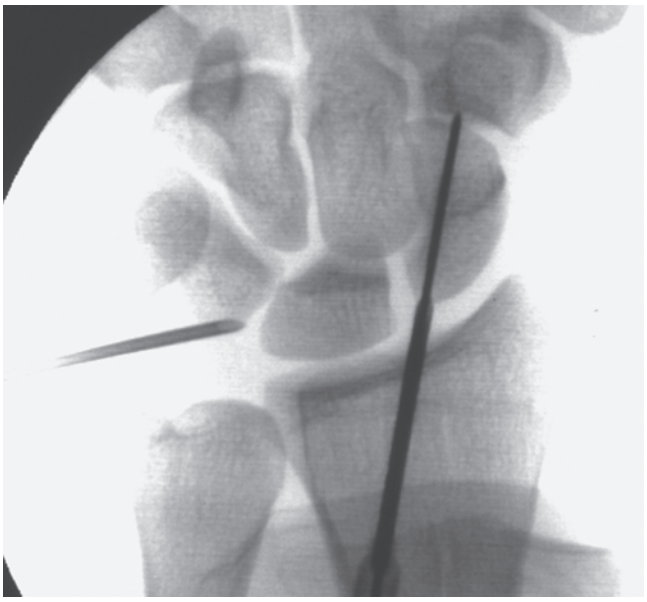

FIGURE 11 A guide wire is then placed with a headless cannulated screw down the long axis of the scaphoid and confirmed fluoroscopically.

FIGURE 12 The wrist may then be supinated in the ARC traction tower and the position of the guide wire confirmed on the oblique and lateral planes.

to insure that it is not protruding and potentially causing damage to the articular cartilage of the scaphoid facet of the radius.

OUTCOMES

Geissler and Slade described utilizing the dorsal percutaneous fixation technique in 15 patients with stable fibrous nonunions of the scaphoid (39). In their series, there were 12 horizontal oblique fractures, one transverse fracture, and two proximal pole fractures. Fourteen of the fifteen patients were male and relatively young. The average presentation time to the clinic following injury was eight months. All patients underwent percutaneous dorsal fixation with a headless cannulated screw. No patients had an accessory bone grafting procedure. In their series, all fractures healed at an average of three months. Of the 15 patients, eight patients underwent CT evaluation, which further documented healing. The patients had excellent range of motion as a result of minimal surgical dissection. Utilizing the modified Mayo wrist scale, 12 of the

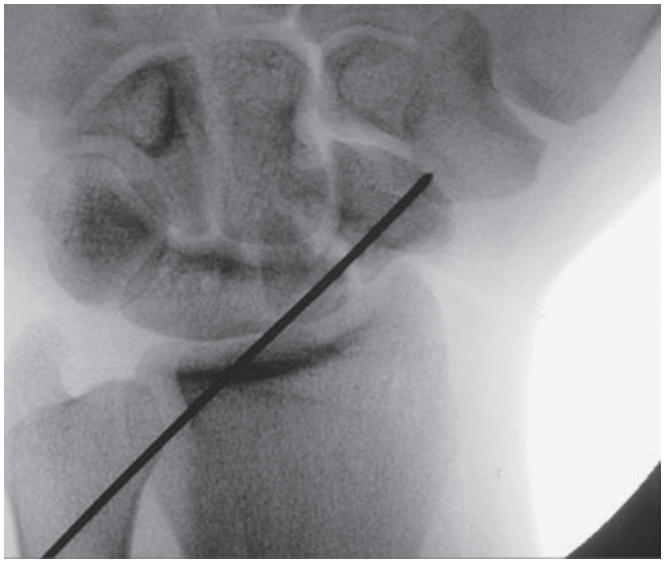

FIGURE 13 Fluoroscopic image in the oblique view confirming the ideal location of the guide pin down the mid axis of the scaphoid.

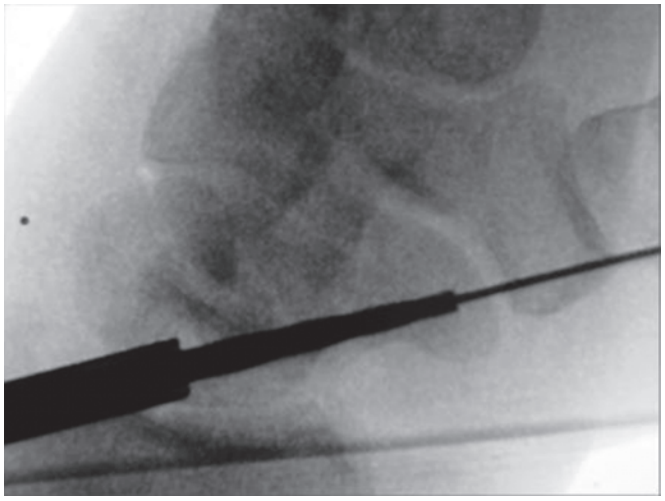

FIGURE 14 The scaphoid is then reamed through a soft tissue protector over the guide wire.

FIGURE 16 The demineralized bone matrix putty is initially loaded into a syringe, which then is used to inject the putty down the Jamshidi needle.

15 patients had excellent results. Dorsal percutaneous fixation was recommended for those patients with a stable fibrous nonunion without any signs of humpback deformity and without extensive sclerosis at the fracture site. Utilizing the scaphoid nonunion classification scheme as proposed by Slade and Geissler, patients with Type II and Type III scaphoid nonunions were included in the study.

Most recently, Geissler described his technique of arthroscopic reduction of cystic scaphoid nonunions without humpback deformity (38). Utilizing the scaphoid nonunion classification scheme of Slade and Geissler, his series was composed of Type IV scaphoid nonunions. In Geissler's technique, a guide wire is again placed arthroscopically as previously described with the arthroscope in the 6-R portal and the guide wire is placed through a 14-guage needle to the 3–4 portal. The scaphoid is then reamed with a soft tissue protector once confirmation of ideal placement of the guide wire is noted under fluoroscopy in the PA, oblique, and lateral planes. The guide wire is then advanced out volarly but still being maintained in the distal pole of the scaphoid. The nonunion site may be percutaneously curetted under fluoroscopy through the drill hole in the proximal pole of the scaphoid.

One cubic centimeter of demineralized bone matrix (DBM; Accell, IsoTis, Irvine, California) is then injected percutaneously into the nonunion site of the scaphoid. This may be done several different ways. A customized putty pusher was designed to inject the putty directly into the nonunion site. If this is not available, a Jamshidi needle is usually readily available in most operating rooms (Fig. 15). The demineralized bone matrix is injected into the bone biopsy needle, which is then inserted into the drill hole of the scaphoid, and the plunger is used to push the putty directly into the nonunion site (Figs. 16–18). Lastly, the

FIGURE 15 Demineralized bone matrix will be injected down the mid axis of the scaphoid after it has been reamed through a Jamshidi needle with the plunger.

FIGURE 17 The Jamshidi needle is then placed over the guide wire down the mid axis of the scaphoid into the nonunion site.

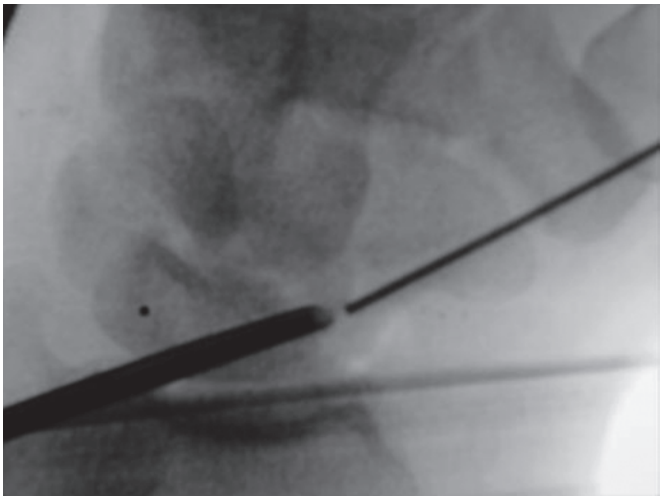

FIGURE 18 The guide wire is then advanced distally out of the nonunion site while still maintaining its position in the distal pole of the scaphoid. The putty is then injected into the nonunion site of the scaphoid.

FIGURE 20 The position of the headless cannulated screw may then be checked while maintaining traction in the ARC traction tower.

demineralized bone matrix may be injected into a standard syringe. A 14-guage needle or angio cath may then be placed into the drill hole of the scaphoid, and the putty again injected into the nonunion site. Once the demineralized bone matrix putty has been injected into the scaphoid nonunion, the guide wire is then advanced back dorsally and exited the skin. A headless cannulated screw is then placed over the guide wire and inserted into the scaphoid (Figs. 19–23). Arthroscopic evaluation of the wrist is then performed in both the midcarpal and radiocarpal spaces to evaluate reduction of the scaphoid nonunion, and to evaluate for any extravasation of demineralized bone matrix putty into the joint.

Geissler reported his results in 15 patients with cystic scaphoid nonunions (38). Fourteen of the 15 patients healed their cystic scaphoid nonunions utilizing his technique. Arthroscopic evaluation of the wrist both in the radiocarpal and midcarpal spaces showed no extravasation of the demineralized bone matrix putty into the joint.

DBM is allograft bone that has been demineralized. The bone morphogenetic proteins (BMPs) are preserved following the demineralization process. The entire cascade of bone morphogenetic proteins evokes conversion of the mesenchymal

FIGURE 19 The guide wire is then advanced proximally through the Jamshidi needle after the demineralized bone matrix putty has been injected. An Acutrak headless cannulated screw is then placed over the guide wire and advanced into the scaphoid.

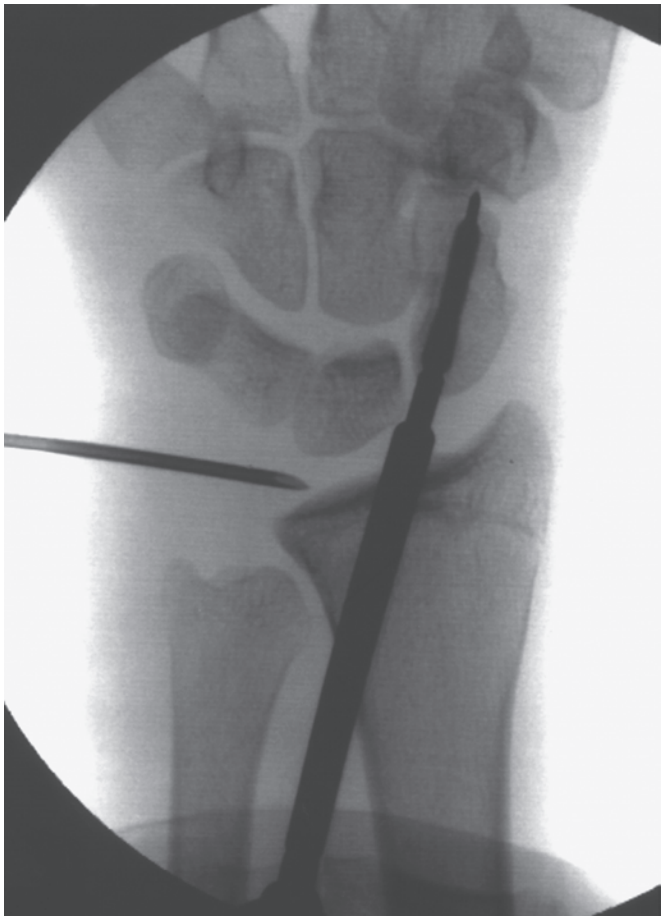

FIGURE 21 The position of the headless cannulated screw is then viewed fluoroscopically.

FIGURE 22 Once ideal placement of the screw has been confirmed fluoroscopically, the screwdriver is removed. Notice how the cystic area of the scaphoid has filled with the demineralized bone matrix putty.

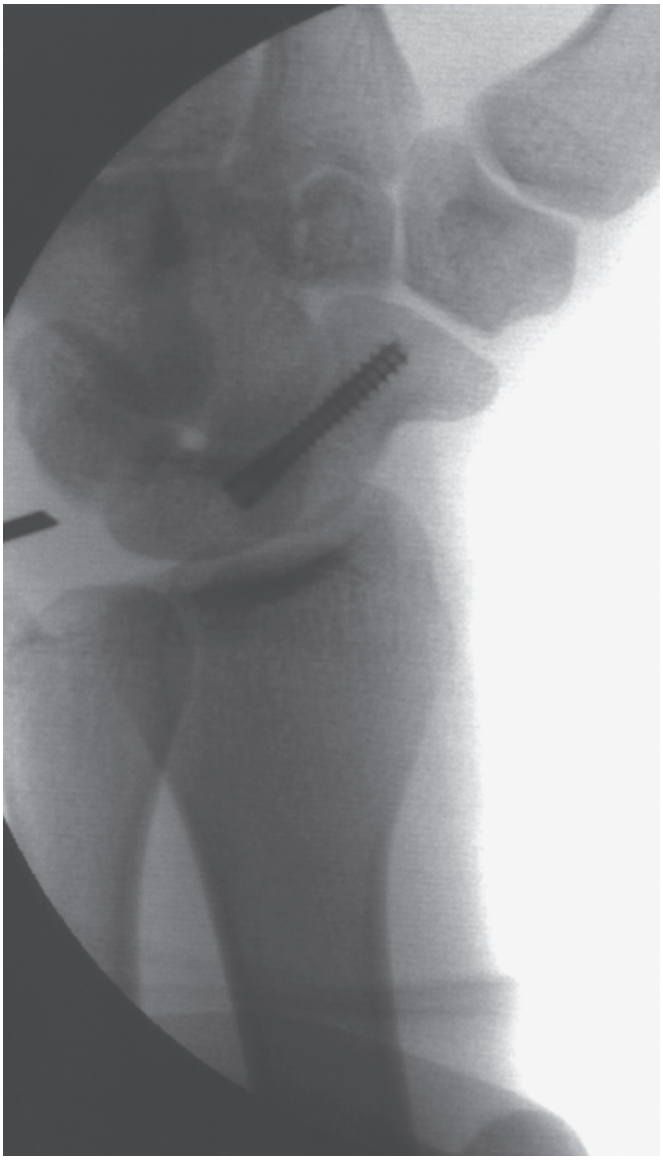

FIGURE 23 Oblique view of the scaphoid confirming ideal location of the headless cannulated screw.

cell to the preosteoblast and eventually to the osteoblast, which is involved in bone formation. DBM is available in two forms, dry or injectable. DBM is mixed with a carrier for the injectable form. Carriers include hyaluronic acid, collagen, glycerol, gelatin and the actual derivatives of DBM itself. Commercial providers may mix the DBM and carriers in different combinations and proportions. Products with higher DBM content may be considered more effective because of the active ingredient in BMP is contained within the DBM itself, and not within the carrier. Carriers such as hyaluronic acid, collagen, and glycerol are inert and do not induce bone formation.

One way to understand the various DBM putties is to imagine them as a chocolate chip cookie. The cookie itself is inert and acts as a carrier for the sweet chocolate chips (BMPs). The more chocolate chips (BMP) in the cookie, the sweeter or better the cookie is perceived. Analogously, DBM putties with a higher BMP content may be considered more effective. Second generation DBM putties have a higher content of BMPs. It is important that the surgeon understands the differences between the various commercial products available. In this way, the surgeon may pick a DBM putty with a high content of BMPs. In Geissler's study, a product that was 100% osteoinductive was utilized in that the carrier itself was DBM and has been shown to induce bone formation. This may be especially valuable in fractures where only a small amount of DBM putty may be injected, such as the scaphoid (Figs. 24–28).

SUMMARY

Fractures of the scaphoid are a common carpal injury. This fracture generally occurs in young males, and is a common athletic injury. Most fractures of the scaphoid will heal with cast immobilization. However, approximately 10% to 15% of scaphoid fractures will proceed to nonunion.

Arthroscopic and percutaneous fixation of scaphoid nonunions is not indicated in all cases. However, it is particularly useful in Type II, Type III, and Type IV scaphoid nonunions as described by Slade and Geissler (29). In patients with a fibrous nonunion, potentially stabilization alone is all that is necessary to promote healing (39). In cystic changes and in patients with cystic scaphoid nonunions, Geissler has shown good success with arthroscopic stabilization and percutaneous injection of DBM putty into the nonunion site (38).

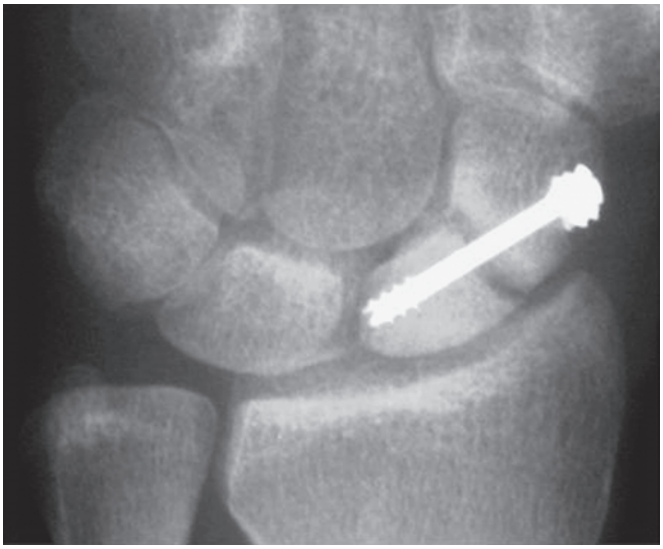

FIGURE 24 Posteroanterior radiograph of an 18-year old male who underwent previous open reduction and internal fixation of a scaphoid fracture with distal radius bone graft at another institution. Despite open reduction with open bone grafting, the scaphoid had not healed.

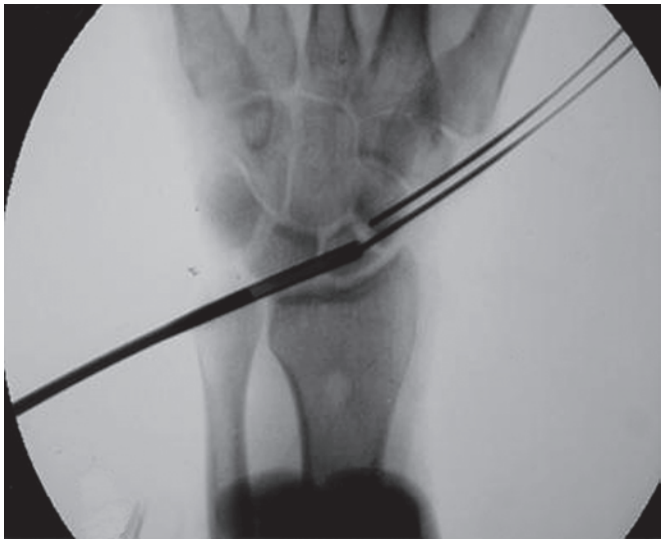

FIGURE 26 The wrist is suspended in the ARC traction tower and a guide wire was placed arthroscopically via the technique of Geissler down the mid axis of the scaphoid. The scaphoid was reamed and 1cc of Accell demineralized bone matrix (IsoTis) was injected into the nonunion site.

Percutaneous and arthroscopic reduction allows for stabilization with minimal soft tissue stripping, which results in improved range of motion in these patients (38,39).

Arthroscopic reduction of scaphoid nonunions as described by Geissler, allows for precise placement of the screw within the scaphoid (38). It limits the guesswork in locating the starting point of the screw with percutaneous fluoroscopic-type techniques. In addition, the wrist does not need to be hyperflexed, which potentially may flex the fracture fragments into a humpback deformity. The dorsal placement of the screw allows for central placement and compression over the scaphoid nonunion (40).

It is important to remember that these percutaneous and arthroscopic stabilization techniques are indicated for fractures of the scaphoid that do not present with a severe humpback deformity, DISI rotation of the lunate, or advanced arthrosis of the radiocarpal joint.

■ SUMMATION POINTS

Indications

- Relatively early scaphoid nonunions (Stage I–III) without humpback deformity or lunate rotation
- More severe nonunion with more extensive cystic changes (Type IV) may be treated with screw fixation combined with percutaneous DBM placement

Outcomes

- High Union rates (14 of 15 patients healed in Geissler's series)
- Less/minimally invasive
- Allows earlier range of motion and return to work and activities of daily living
- Lessens immobilization

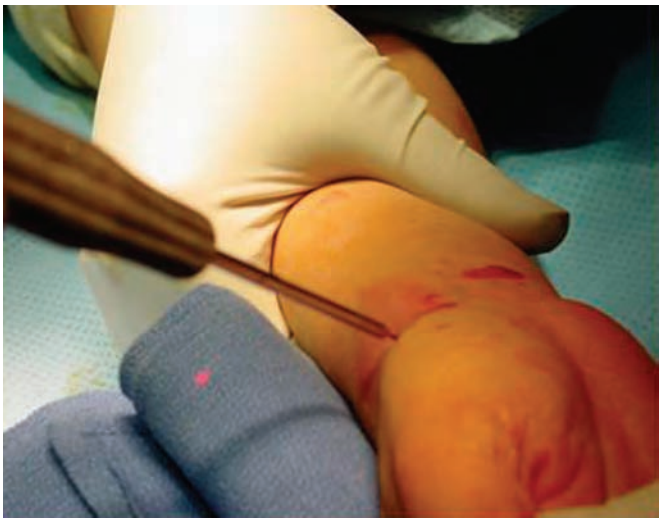

FIGURE 25 The previous screw is then removed percutaneously.

FIGURE 27 Fluoroscopic view showing placement of the headless cannulated screw.

FIGURE 28 Oblique radiograph confirming healing of the scaphoid nonunion.

Complications

- Nonunion
- Symptomatic hardware if screw left too long
- Superficial wound infection

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15

Reduction and Association of the Scaphoid and Lunate (RASL) Reconstruction for Scapholunate Instability

Steven H. Goldberg, Charles M. Jobin, and Melvin P. Rosenwasser
Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York, U.S.A.

INTRODUCTION

The reduction and association of the scaphoid and lunate (RASL) procedure can provide a predictable and satisfactory means to treat irreparable, symptomatic scapholunate (SL) ligament tears (1–3). SL ligament tears can occur as an isolated injury due to a fall on the extended wrist involving axial load, wrist extension, intercarpal supination, and ulnar deviation or in conjunction with associated injuries such as distal radius fractures, which may lead to a missed or delayed diagnosis (4). Carpal ligament injuries represent a spectrum from isolated and partial SL ligament tears involving only the thin central membranous portion to perilunate or lunate dislocations with involvement of both intrinsic and extrinsic carpal ligaments. Ascertainment of the severity of injury can be difficult and a "wrist sprain" may not recover with benign neglect. Fifty-five percent of patients with chronic tears develop a predictable pattern of arthritis, called scapholunate advanced collapse (SLAC) (5). Thus, a timely diagnosis and effective treatment are crucial for an optimal long-term outcome.

Wrist motion in one plane is due to the composite effects of individual carpal bones that undergo unique multiplanar and often reciprocal motions. Radial and ulnar deviation occurs in the coronal plane, with the proximal capitate serving as the center of rotation. Additionally, during ulnar deviation, the scaphoid and lunate extend and during radial deviation they flex (6,7). Finally, the proximal row pronates and the distal row supinates during radial deviation, with the opposite occurring during ulnar deviation (8). Thus, out of plane motion of the scaphoid and lunate is more apparent during wrist radial–ulnar deviation than during wrist flexion and extension (9). Furthermore, within the proximal carpal row, there is disproportionate flexion and extension between the scaphoid and lunate, with the scaphoid rotating fastest and to a larger degree (approximately 20°). It is this obligate rotation that produces the most stress on SL reconstructions.

SL ligament injury can be categorized based on radiographic patterns of instability. *Static* instability occurs when abnormal scaphoid and lunate alignment is present on routine posteroanterior (PA) and lateral radiographs (Fig. 1). *Dynamic* instability occurs when abnormalities occur only during stress radiographs (e.g., pronated grip or ulnar deviation PA views). *Predynamic* instability consists of a history and physical examination suggestive of SL injury, with SL interval pain on palpation, a negative Watson's maneuver, and no radiographic changes on any views. Dorsal intercalated segment instability (DISI) refers to the position of the lunate, with its distal articular surface pointing dorsally (Fig. 2), as measured by an abnormal increase in the radiographic carpal angles (Table 1).

CONTRAINDICATIONS FOR THE RASL PROCEDURE

We would like to emphasize that the RASL procedure is contraindicated in the presence of a repairable SL ligament. The authors strongly believe that a primary repair should be attempted in all patients with a SL ligament that has sufficient tissue quality and quantity to withstand suture placement and healing. When the ligament is avulsed from bone, typically off the lunate, suture anchors can be used to reattach the ligament. Supplemental SL and scaphocapitate transarticular pinning with Kirschner (K) wires and external immobilization should be employed to protect the repair during healing for eight weeks, particularly when carpal derotation is performed. Repairable ligaments are typically found in the acute setting, arbitrarily defined as less than six weeks. However, we recommend examination of the ligament at surgery in all cases as some may be repairable despite being chronic. The RASL procedure is also contraindicated in the presence of significant capitolunate arthritis. Focal arthritis between the radial styloid and scaphoid is not a contraindication because radial styloidectomy is part of the procedure and will adequately decompress this contact region.

INDICATIONS FOR THE RASL PROCEDURE

The degree of instability and the chronicity of the injury can guide the surgical decision-making. Partial ligament injuries which are stable may be treated with arthroscopic debridement alone (11) or arthroscopic debridement and thermal shrinkage (12,13). Complete ligament tears with static instability may be treated with arthroscopic debridement alone (14), reduction and temporary SL transarticular pinning (15), ligament repair with or without dorsal capsulodesis (16–21), dorsal capsulodesis alone (22), ligament reconstruction using various tendon weaves or bone-soft tissue-bone constructs (23), tenodeses with various wrist tendons (24–27), limited intercarpal fusions (10,28–32) or RASL (1–3). Each of these procedures has different strategies to reduce and control carpal instability. Some disrupt the normal carpal kinematics more than others, but none completely restore motion and stability.

In the author's opinion, the RASL procedure is indicated in a symptomatic patient without a repairable SL ligament and without significant pancarpal arthritis. A patient may present with chronic dorsal wrist pain after having received a report of normal initial radiographs (predynamic instability) and then over time may develop additional cumulative minor injuries which progresses to a readily apparent dynamic or static instability on subsequent radiographs. Alternatively, initial symptoms may have been mild or resolved shortly after injury and the patient presents for evaluation for the first time

FIGURE 1 Posteroanterior radiograph of a 53-year-old man with two months of wrist pain that began while moving large fertilizer bags by hand. The radiographs demonstrate significant scapholunate diastasis and static instability. The distal scaphoid appears as a circle highlighting the cortical ring sign caused by the flexed scaphoid. The scaphoid appears shortened and the capitate descends proximally.

FIGURE 2 Lateral radiograph of the same patient (Fig. 1). Note, the dorsal intercalated segment instability pattern with lunate extension, an increased capitolunate angle (35°), an increased scapholunate angle (90°), and dorsal translation of the capitate indicated by the offset position of the center of rotation of the lunate and capitate (black circles).

with an acute on chronic unrecognized and asymptomatic injury. In these cases, the SL ligament is often attenuated, fibrotic, with limited vascularity and capacity to hold a suture. Additionally, the repetitive loading on an incompetent SL ligament often leads to secondary intercarpal ligamentous stretching and attenuation in the dorsal intercarpal ligament and leads to wide diastasis and maximal rotatory instability precluding capsulodesis procedures alone. Patients who present after a failed primary surgical reconstruction such as SL ligament repair, SL pinning, or a dorsal capsulodesis, but who have not yet developed arthritis are also candidates for the RASL procedure.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Confirmation of a SL tear is based upon a history with an appropriate mechanism of injury, correlative physical examination signs, and findings on imaging studies. Physical examination consists of observation, palpation, range of motion, and provocative maneuvers on both wrists to elicit asymmetry. The SL ligament can be palpated with deep pressure applied in the interval just distal and ulnar to Lister's tubercle which is the location of the 3–4 portal for wrist arthroscopy. Watson's scaphoid shift test is a provocative maneuver to assess for SL injury (33). The scaphotrapezial joint and the radiocarpal joints are palpated to assess the possibility of associated distal and volar ligamentous injuries.

Complete sectioning of all three regions of the SL ligament in cadavers does not create static SL diastasis as viewed on a standard PA radiograph or DISI deformity on a lateral radiograph, or dynamic changes produced by stress views (7). Associated ligamentous injury may be required to produce abnormal carpal relationships such as the volar extrinsic (radiolunate, radioscaphocapitate) (6,34), the distal intrinsic (scaphotrapezial) (6,35), or the dorsal intercarpal ligaments (36). However, these ligament injuries may be in evolution and are not apparent on routine or stress radiographs until the carpus has experienced sufficient load and time from the injury to produce classic findings.

Plain radiographs are critical and should be obtained as the first imaging study in every patient. The following radiographs should be obtained: PA in neutral rotation, PA in ulnar and

TABLE 1 Normal Lateral Radiographic Angles

Angle	Average (deg)	Range (deg)
Scapholunate (10)	47	35 to 70
Radiolunate (41)	7	−9 to 12
Capitolunate (10)	0	−20 to 15

Negative values indicate dorsiflexion and positive values equal palmar flexion. Pathologic increases in scapholunate (SL) angle or dorsiflexion of the radiolunate or capitolunate angles represent SL instability with the opposite changes suggestive of lunotriquetral instability. *Abbreviations*: SL, scapholunate.

radial deviation, clenched fist PA in pronation, a true lateral in neutral rotation, and two 45° semi-oblique views. Comparison views of the contralateral normal wrist should be obtained as there is a wide range of normal angles. These radiographs may document the instability pattern that confirms the SL injury and grades the extent of arthritis.

On the PA radiograph, several radiographic changes may be noted. A widening of the SL joint space (SL dissociation) that is asymmetric with respect to the contralateral normal wrist is suggestive of a SL ligament injury. The SL distance has been measured at the proximal or mid aspect of the joint space and ranged from 2.5 to 5.0 mm in normal wrist radiographs (37,38). The scaphoid cortical ring sign occurs when excessive palmarflexion of the scaphoid causes the radiographic beam to be parallel with rather than perpendicular to the distal scaphoid (39). Rotation of the scaphoid shortens the distance between its proximal and distal ends. Additionally, with progressive lunate extension, the lunate shape changes from trapezoidal to triangular. The clenched fist and ulnar deviation PA views load the SL joint and may increase the gap. Gilula defined three arciform lines drawn along the proximal surface of the proximal carpal row, the distal surface of the proximal carpal row, and the proximal surface of the distal carpal row (40). A step off in any of these arcs suggests a carpal ligamentous injury, which may be enhanced by applying longitudinal traction to the wrist.

In SL ligament injuries, the scaphoid flexes and the lunate extends leading to abnormal SL angles on the lateral radiograph should be compared to the normal opposite wrist (Table 1). In the normal wrist, the central axis of the distal radius, lunate, and capitate should be aligned. In SL dissociation, these three bones become malaligned as the capitate collapses proximally and translates dorsally, forcing the lunate to rotate into extension (dorsal tilt) which increases the radiolunate (41) and capitolunate angles, decreases carpal height, and creates a DISI pattern.

Other imaging modalities have limited usefulness in current management of suspected SL tears. Since abnormal arthrographic findings have been found in 74% of asymptomatic patients, wrist arthrography is seldom used (42). Magnetic resonance imaging (MRI) also has a limited application because its accuracy is dependent on observer experience, signal sequences, strength of magnet, and use of dedicated wrist coils resulting in variable sensitivities, specificities, and accuracies at a high cost. In a prospective study of arthroscopically confirmed SL tears, MRI was only able to correctly diagnose acute and chronic SL tears in 75% of cases, with no benefit of intravenous contrast (43). The sensitivity was 63% and specificity was 86%. However, in another study using MRI arthrography with a 1.5 T magnet, MRI was able to detect complete tears of the SL ligament with an improved sensitivity of 92%, specificity of 100%, and accuracy of 99% (44). Detection of partial tears had a lower sensitivity of 63%, but specificity and accuracy were still high at 100% and 95%, respectively.

SURGICAL TECHNIQUE FOR THE RASL PROCEDURE

Either regional or general anesthesia can be used, with administration of preoperative prophylactic intravenous antibiotics. The patient is placed supine on the operating room table with the arm on an armboard and a sterile tourniquet is applied and elevated to 250 mm Hg after extremity exsanguination. Using standard techniques described elsewhere in this text, the hand is suspended from a traction tower device and radiocarpal and midcarpal arthroscopy is performed to assess the carpal ligaments, articular cartilage, and degree of instability. If an SL tear is confirmed, no repairable dorsal ligament is observed, and no significant arthritis is present, an arthroscopic or open RASL procedure can be performed. It is recommended that arthroscopic RASL be attempted only after considerable experience with the open procedure. Since the open procedure preserves and anatomically repairs the dorsal capsule, soft tissues are gently manipulated without excessive retraction, no tendons are harvested or split, no bones are fused, only the SL joint and radial styloid tip are exposed, and uninvolved joints are not transfixed with K-wires. We believe the open RASL procedure should be considered a minimally invasive technique.

The hand is removed from the traction tower and a 6 cm midline, longitudinal incision is made on the dorsal wrist just ulnar to Lister's tubercle centered over the radiocarpal joint. The retinaculum is incised through the third dorsal compartment. The extensor pollicis longus is gently retracted radially and the extensor digitorum communis tendons are retracted ulnarly to permit transverse capsular incision to be made over the SL joint between the dorsal intercarpal and dorsal radiotriquetral ligaments. A second longitudinal incision is made centered over the radial styloid. Branches of the dorsal sensory radial nerve and the dorsal radial artery are protected. The first dorsal compartment is incised, the tendons gently retracted, and the capsule is incised. The radial styloid is exposed in a subperiosteally and a limited styloidectomy is performed, preserving the scaphoid fossa and extrinsic ligaments. Styloidectomy provides access to the radial proximal scaphoid for screw placement in the lunate center axis of rotation, removes radioscaphoid impingement, and addresses preexisting radioscaphoid arthritis.

A 0.062 in. K-wire is placed into the most proximal dorsal surface of the extended lunate angled from proximal to distal (Fig. 3). It is important to place the wire proximal to the lunate center on the lateral fluoroscopic image to prevent interference with the insertion of the headless screw. The wire is pushed distally, causing the wire to become perpendicular

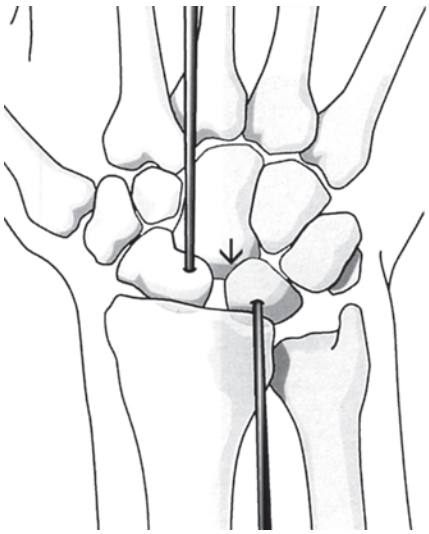

FIGURE 3 Coronal view of the carpus illustrating the orientation of the scaphoid Kirschner (K) wire in a distal to proximal oblique direction and of the lunate K-wire orientation in a proximal to distal oblique direction. Lunate extension causes the capitate head to be abnormally uncovered (*arrow*). Proximal lunate descent causes loss of carpal height and increases scapholunate diastasis. *Source*: Adapted from Ref. 2.

to the dorsal surface of the wrist which causes palmarflexion of the lunate. If this wire is maximally flexed, but the lunate is still not anatomically reduced, it may be necessary to place a second wire into the newly exposed dorsal and proximal part of the lunate, remove the first wire, and then translate the second wire distally until the lunate is fully reduced. When the proximal uncovered capitate articular surface is fully covered by the lunate, reduction of the lunate is anatomic. This can be confirmed fluoroscopically by observing a capitolunate angle of 0° with both bones collinear on the lateral view. A K-wire is also placed into the dorsal scaphoid distal pole at an oblique angle from distal to proximal so that when wire is pushed proximally to extend the palmarflexed scaphoid, the wire becomes perpendicular to the dorsal surface of the wrist (Fig. 4).

With the wires reducing the scaphoid and lunate, the articular cartilage is carefully removed from the opposing scaphoid and lunate surfaces with a mechanical burr until punctuate subchondral bleeding is observed (Fig. 5). This facilitates ingrowth of fibrous connective tissue. If a remnant of the SL ligament is present, it is not debrided but left to add to the fibrous connective tissue at the interface. A Kocher clamp is placed across the joystick K-wires after reduction is confirmed (Fig. 6). A guide wire for the cannulated, Standard Headless Bone Screw (Hand Innovations, Miami, Florida, U.S.A.) is placed into the radial midwaist of the scaphoid exiting the scaphoid at the mid-point of its articular surface opposite the lunate, across the joint, and then into the center of the lunate pointing towards the medial vertex on the coronal image and the middle of the lunate on the lateral image (Figs. 7 and 8). The cannulated drill is placed over the guide wire and the hole is drilled. Then, the screw length is measured with a cannulated guide and the screw is advanced over the guide wire. The length should be slightly less than the length measured from the guide wire to allow countersinking of the screw beneath the scaphoid surface. All K-wires are removed.

The radial capsule and periosteal sleeve are closed with interrupted absorbable sutures. The first dorsal retinaculum is closed over the relocated tendons. The dorsal wrist capsule is closed without imbrication to prevent loss of motion postoperatively. The EPL is left transposed out of its sheath. The wrist is immobilized in a volar splint for two to three weeks to allow for capsular healing; then, early motion in a supervised occupational therapy program is begun. Several weeks later, gradual strengthening is begun with unrestricted activity permitted at four to six months.

The arthroscopic RASL procedure is essentially the same as described above without the use of the dorsal and radial incisions. The radial styloidectomy and decortication of the opposing scaphoid and lunate articular surfaces are performed with arthroscopic burrs through standard portals (see chap. 33 on SLAC wrist for details on styloidectomy). The K-wires for

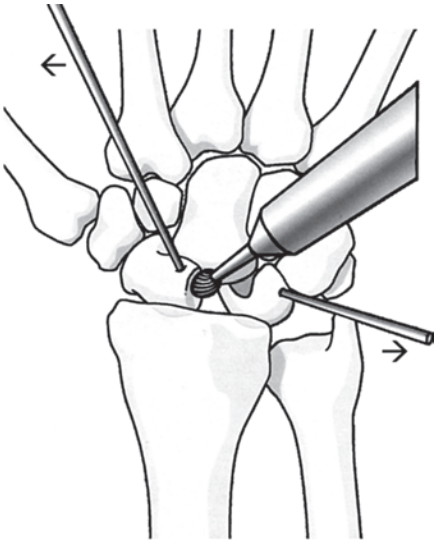

FIGURE 5 Wires can be used to slightly increase scapholunate (SL) diastasis to facilitate insertion of a burr that is used to carefully remove cartilage in the SL interval until punctate bleeding is observed. This stimulates formation of a fibrous neoligament. *Abbreviations*: SL, scapholunate. *Source*: Adapted from Ref. 2.

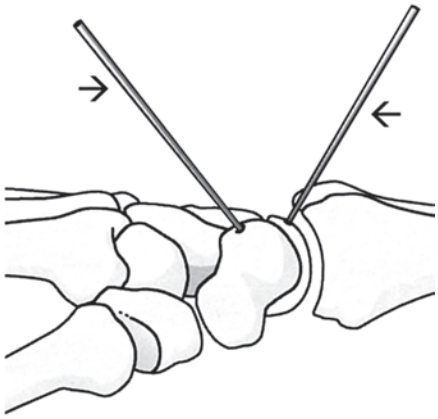

FIGURE 4 Sagittal view of carpal Kirschner-wire orientation. The scaphoid wire is pushed toward the radius (*arrow to right*) to derotate the scaphoid out of palmarflexion and the lunate wire is pushed towards the hand (*arrow to left*) to derotate the lunate out of extension. After reduction, the wires should be roughly parallel rather than divergent. *Source*: Adapted from Ref. 2.

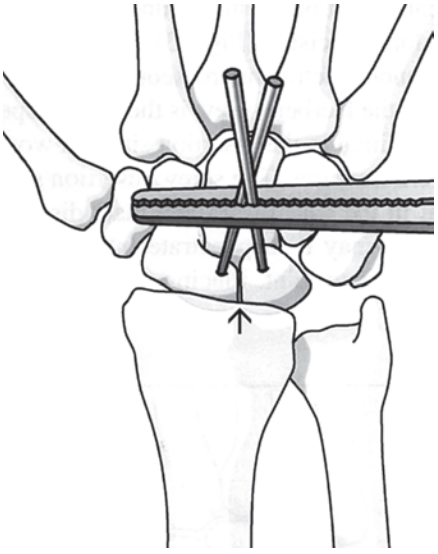

FIGURE 6 A Kocher clamp is used to hold the joysticks that have been used to derotate the scaphoid and lunate into their reduced position. Note, scapholunate diastasis is also corrected (*arrow*). *Source*: Adapted from Ref. 2.

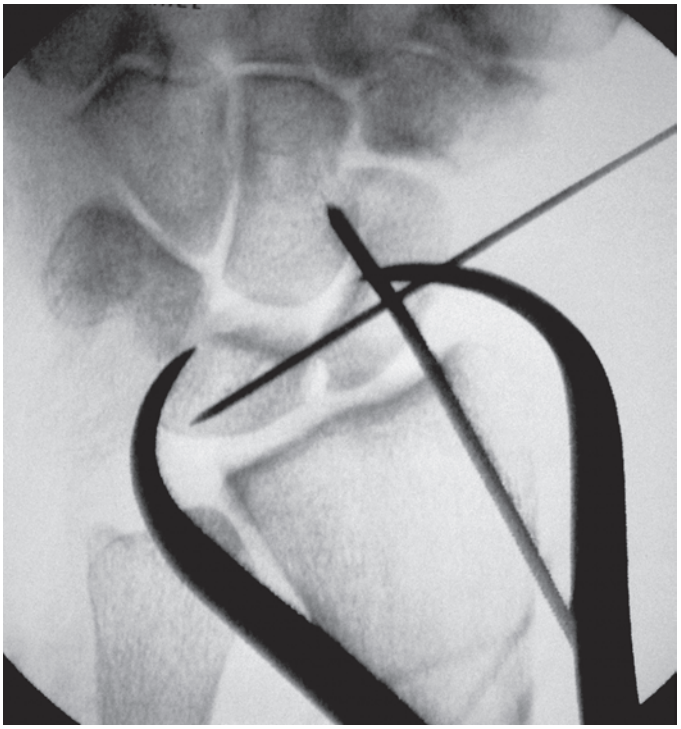

FIGURE 7 Intra-operative fluoroscopic posteroanterior image of guidance wire placement prior to cannulated screw placement. The wire is placed into the midwaist of the scaphoid exiting the scaphoid at the midpoint of its articular surface opposite the lunate, and then into the center of the lunate at the medial vertex on the coronal image.

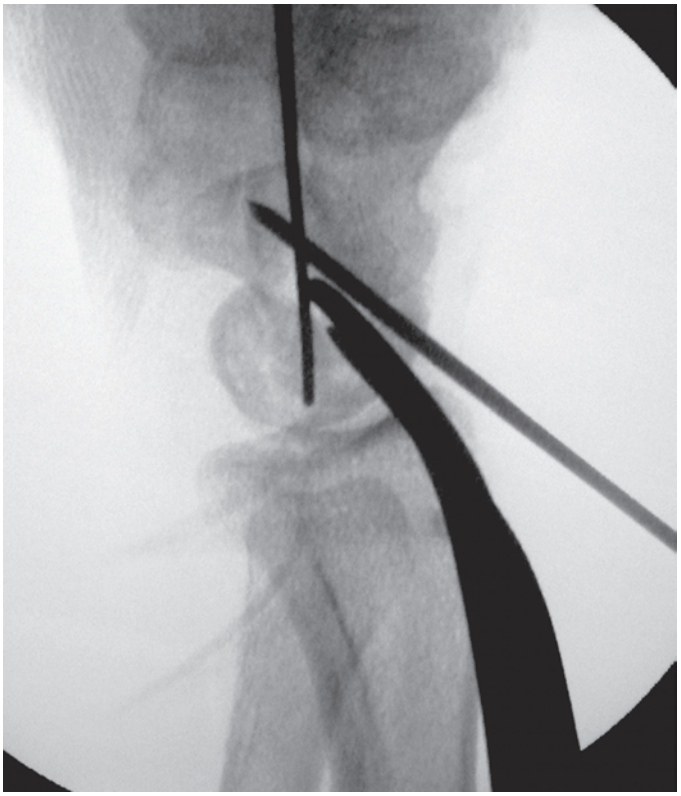

FIGURE 8 Intra-operative fluoroscopic lateral image of wire placement prior to cannulated screw. The wire is appropriately positioned through the scaphoid and into the middle of the lunate on the lateral image.

scaphoid and lunate derotation and for headless bone screw guidance are placed percutaneously by manually pushing the wires down to bone and then advancing them with a wire driver to minimize wrapping up of soft tissues. To drill, measure and place the headless bone screw, a small incision is made radially.

COMPLICATIONS

There have been no occurrences of major intraoperative or post-operative complications consisting of infection, nerve injury, or screw breakage. Accurate measurement of screw length is important with placement of a screw slightly shorter than the measured length of the guide wire so that adequate counter-sinking below the surface of the radial aspect of the scaphoid can be performed. Two out of 24 patients have required screw removal at an average 49 months after surgery due to screw head prominence. One patient maintained carpal alignment and is asymptomatic after screw removal and the second patient has developed instability and progressive arthritis. No headless bone screw threads should cross the SL interval to allow rotation of the scaphoid and lunate with respect to one another. Furthermore, it is critical that the screw be placed through the center of rotation of the scaphoid and the lunate in both the sagittal and coronal planes. Increasing screw obliquity or deviation from the lunate center of rotation may limit motion between the scaphoid and lunate or cause toggling of the bones rather than rotation. It is the obligatory physiologic SL rotation that leads all of the retained screws to show lucency around the lunate threads without migration.

Complete reduction of the scaphoid, lunate, and capitate is essential to restore normal anatomy and allow central placement of the screw. Incomplete SL reduction may predispose to abnormal carpal loading and kinematics that cause screw loosening, progressive carpal instability, or the development of arthritis. This may partially explain why 3 of 24 patients who underwent the RASL procedure needed a subsequent surgical treatment with a proximal row carpectomy or arthrodesis procedure due to recurrent instability and symptoms. Failure to preserve the origins of the radioscaphocapitate, dorsal radiocarpal, and long radiolunate ligaments by aggressive removal of too much of the radial styloid can lead to ulnar and volar carpal translocation (see chap. 33 SLAC wrist for details) (45,46). This was observed in one patient.

OUTCOME OF THE RASL PROCEDURE

In the senior authors' experience, the RASL procedure has been used to treat patients with irreparable, chronic (an average of 16 months post-injury) SL tears, with 22 static and two dynamic patterns of instability. At an average of 62 months after surgery, the average Visual Analog Score for pain was 1 and the average disabilities of the arm, shoulder and hand (DASH) score was 23. The RASL procedure provides continued improvement in wrist function as the DASH continues to decrease with time and patient wrist use. The average Physical Component Score and Mental Component Score on the SF-36 were 45.8 and 52.1, respectively, with 50 being the average score for the general population (47). The average flexion/extension arc was 103° and radial/ulnar deviation was 43°. Grip strength was 79% of the uninvolved wrist. The SL gap was significantly reduced at final radiographic follow-up of 18 months from 5.1 to 1.6 mm ($p < 0.05$). The RASL effectively restores and maintains carpal alignment, as measured by significant reduction of the SL angle

from 81° to 53° at final follow-up in patients with preoperative static instability (Figs. 9–12).

Soft tissue procedures that do not involve intercarpal fusion preserve SL motion, but they have not been as successful in maintaining an improved SL angle at final follow-up evaluations, even with lesser degrees of preoperative static instability ranging from 53° to 78° (17,19,20,48). This may be due to the lack of effective control of lunate extension by solely scaphoid-based reconstructions such as dorsal capsulodesis.

SUMMARY

From cadaver studies, we know that normal wrist ligaments maintain the carpal height and alignment through balanced tension that results in stored potential energy. When one or more ligaments is compromised, the potential energy is released as kinetic energy, as the carpal bones rotate, translate, and collapse into a more stable configuration (49). The first part of the RASL procedure is *reduction* of the scaphoid and lunate back to stable alignment with the lunate colinear with the radius and capitate and the scaphoid in a mid-flexed posture with respect to the radius. Simultaneously, the critical midcarpal lunatocapitate relationship is restored when the proximal pole of the capitate is captured by the concave distal articular surface of the lunate and the ulnar aspect of the scaphoid.

FIGURE 9 Posteroanterior clenched fist radiograph of the patient seen in Figure 1 after a reduction and association of the scaphoid and lunate procedure at 40 months follow-up. The Visual Analog Scale for pain was 1 (0=best, 10=worst), grip strength was symmetric, and disabilities of the arm, shoulder and hand score was 2 (0=best, 100=worst). Note the central placement of the screw from the scaphoid waist to the lunate vertex. Radiocarpal and midcarpal joint spaces are preserved without evidence of arthritic progression in the capitolunate and radioscaphoid joints. Radiolucency is seen at both ends of the screw without screw migration, indicating expected, persistent carpal bone rotation around the screw.

FIGURE 10 Lateral radiograph of the same patient (Fig. 1) after a reduction and association of the scaphoid and lunate procedure at 40 months follow-up demonstrating a slightly volar placement of the screw with radiolucency appreciated.

FIGURE 11 Posteroanterior radiograph with wrist in radial deviation of the same patient (Fig. 1) after a reduction and association of the scaphoid and lunate procedure at 40 months follow-up. Note the foreshortened scaphoid indicating scaphoid palmarflexion during radial deviation.

FIGURE 12 Posteroanterior radiograph with wrist in ulnar deviation of the same patient (Fig. 1) after a reduction and association of the scaphoid and lunate procedure at 40 months follow-up. Scaphoid is in a normal, extended position compared to its flexed posture on the radial deviation view, indicating rotation is occurring between scaphoid and lunate. The lunate also changes position relative to the radial deviation view indicating that it also rotates during wrist motion.

The second part of the procedure is the *association* of the scaphoid and lunate with a headless bone screw while a fibrous neoligament forms, both of which establish long-term carpal stability. Permanent, planned retention of the screw distinguishes this technique from the one described by Herbert (50). This is critical to allow for adequate remodeling of the fibrous neoligament and to prevent the capitate from forming a wedge between the scaphoid and lunate if it is allowed to descend proximally. The prevention of carpal collapse may prevent or slow SLAC arthritis. Planned motion between the scaphoid and lunate around the screw and neoligament allows more normal kinematics and load transmission than limited intercarpal fusions. Thus, the RASL procedure nearly recapitulates carpal kinematics when soft tissue reconstruction alone may be inadequate or a limited arthrodesis is not desired.

SL ligament tears are common causes of chronic wrist pain and can lead to progressive patterns of arthritis. A thorough understanding of wrist anatomy and kinematics is necessary to select the appropriate treatment. The RASL procedure is an effective technique to restore carpal alignment, preserve motion, and improve symptoms without limiting future surgical treatments including intercarpal fusions, proximal row carpectomy, or wrist arthrodesis, should fixation fail or arthritis progress.

SUMMATION POINTS

Indications
Initial treatment or after a failed alternative surgical treatment for an irreparable, symptomatic SL ligament tear with any degree of instability.

Contraindications
Significant pancarpal arthritis.

Outcomes
Excellent pain relief, improved function, maintenance of functional wrist motion, and maintenance of carpal alignment at five years.

Complications
Occurred primarily in initial cases and decreased as experience with the technique increased

- Screw backout/prominence 8% (2/24)
- Screw placement off center axis 12% (3/24)
- Excessive styloidectomy 4% (1/24)
- Inadequate carpal bone derotation.

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Prosthetic Arthroplasty of Proximal Pole Scaphoid Nonunions

Christophe L. Mathoulin
Institut de la Main, Clinique Jouvenet, Paris, France

INTRODUCTION

Pseudarthrosis and necrosis of the proximal pole of the scaphoid are difficult to treat and the outcome is uncertain, particularly in elderly people. Eventually, this problem leads to radioscaphoid arthritis, which progressively spreads to the entire wrist and causes carpal collapse, in a typical pattern: scaphoid nonunion advanced collapse (wrist). In the same way, scapholunate dislocation rapidly leads to styloscaphoid arthritis in which the capitate collapses into the scapholunate space: scapholunate advanced collapse (wrist). Several authors have previously advocated the replacement of the proximal pole of the scaphoid. The silicon spacer promoted by Michon (1) then by Zemel (2) is no longer used and has been replaced by autologous biological materials proposed by Eaton (3). Jones (4) proposed a spherical vitallium implant, whereby the prosthesis was put into a cage with the risk of dislocation.

A novel implant which adapts to the kinematics of the carpus has recently been proposed (5). The adaptive proximal scaphoid implant (APSI; Bioprofile, Grenoble, France) is made of pyrolitic carbon. The total biocompatibility of this material has been previously proven (6,7). Hard wearing and chemically inert, it does not wear away the bone. Its friction coefficient is low when rubbing against bone and cartilage and allows it to slide between the cartilage and the surrounding ligaments to find the position of least resistance against the deformable walls of its biologic cage. Because it does not adhere to the surrounding walls, it does not apply pressure to the surrounding bones and does not initiate a dislocation.

Its module of elasticity is almost identical to that of bone, allowing it to be tolerated fully (Young's module: bone = 20, APSI = 25). This absence of difference between the elasticity modules avoids wear and tear on the bone.

This implant is distinctive in that its ovoid shape allows its "adaptive" mobility when the first row of carpal bones moves (6).

Frontally, the small radius corresponds to the scaphoid area of the radius, and from the side view the large radius forms an ovoid, of which the large curve is anteroposterior and the small curve is frontal (Fig. 1). By rotating on these axes during frontal deviation and flexion–extension movements, the APSI copies the movements of the proximal scaphoid exactly and becomes integrated in a corroborating and synchronous way with the kinematics of the carpal bones. Because of this three-dimensional reorientation during the movements of the wrist, the implant remains stable in the physiological amplitudes and does not require any form of fixation to the distal scaphoid or periprosthetic encapsulation (Fig. 2).

In view of the quality of the reported results with an open procedure, we decided to try placing the implant by arthroscopy. This report details our experience positioning this implant by using wrist arthroscopy.

INDICATIONS

This technique is only reserved for replacement of the proximal pole of the scaphoid in which reconstruction is not possible (excessively small fragment, an osseous fragment separated into several small pieces). The surrounding cartilage surfaces are generally intact without arthrosis. The use of this implant is a very good salvage procedure in elderly people but could be a "waiting" therapeutic option in young patients.

The contraindications include too large of a proximal fragment of the scaphoid (waist fracture) and significant chondral changes of the surrounding bones. The presence of styloid arthritis is not a contraindication because one can perform a radial styloidectomy during the same operative procedure. Furthermore, the minimally invasive technique is better than open surgery, because with the use of wrist arthroscopy the surgeon avoids a large approach and the normal risk of internal joint fibrosis.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Preoperative Physical Examination

The examination is the same as for all scaphoid nonunions: the surgeon should document the location of pain, range of motion, strength, and functional status. The examination is done comparatively to the opposite side.

Preoperative Imaging

Simple radiographies (frontal, lateral, and specific scaphoid view) are most often sufficient. Comparative X rays of opposite side are required. CT scan and MRI can be added in order to check the viability of the proximal fragments and the importance of chondral changes. Because the wrist continues to challenge clinicians with its array of potential diagnoses and treatments and multiple cartilaginous surfaces, combined with the intrinsic and extrinsic ligaments, wrist arthroscopy has proven to be a useful adjunct in the diagnosis and planning of scaphoid nonunions, and is a real part of the treatment.

SURGICAL TECHNIQUE

All patients in our series were operated on as outpatients under local–regional anesthesia using a pneumatic tourniquet (8). The arm is laid flat on an arm table, and axial traction is applied to the forearm and wrist using a wrist tower. The strength of

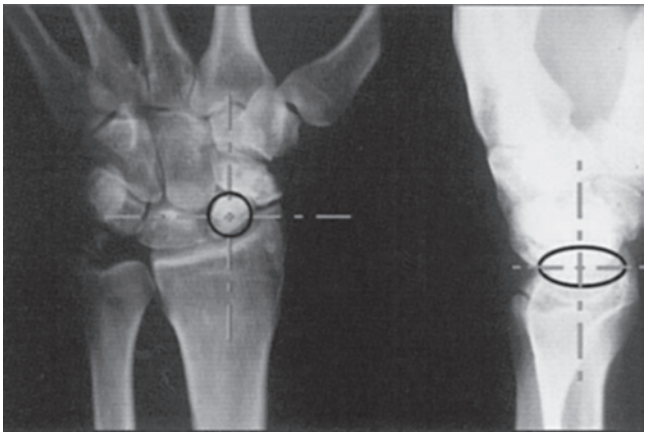


FIGURE 1 Position of the APSI in front and side view X-rays. *Abbreviation*: APSI, adaptive proximal scaphoid implant.

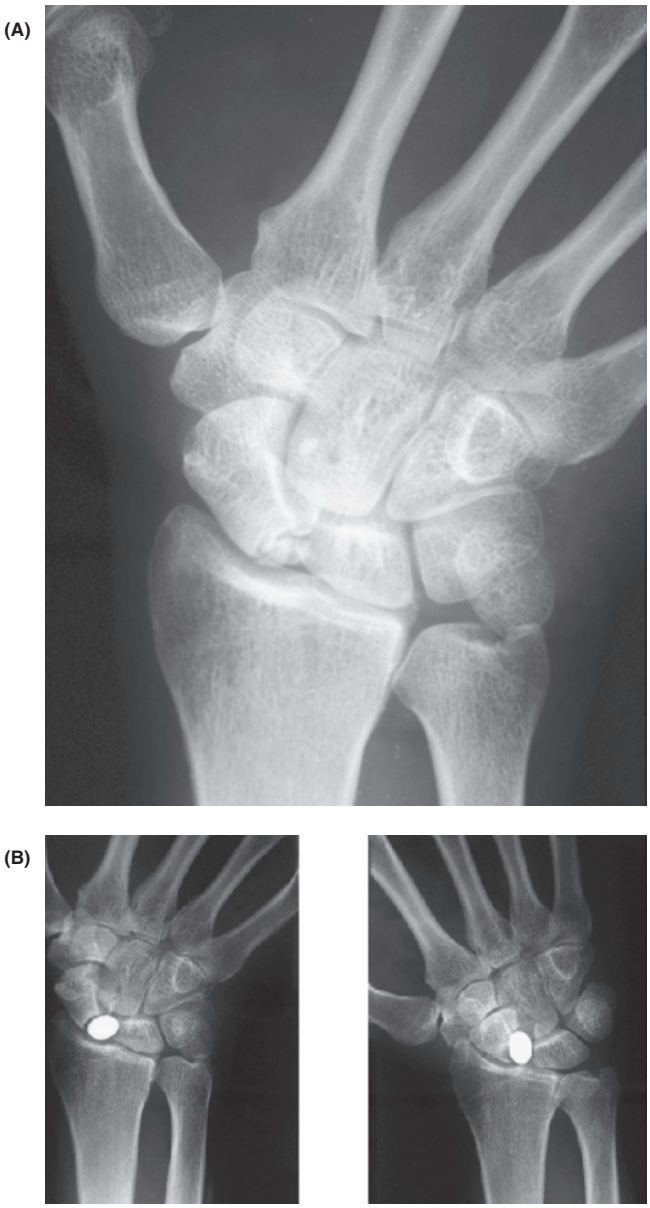


FIGURE 2 (**A**) X-ray of a case with untreatable necrotic proximal pole. (**B**) X-ray in ulnar and radial deviation showing the mobility and three-dimensional adaptability of the implant.

FIGURE 3 Radiocarpal joint filling.

the traction is usually 5 to 7 kgf. After drawing the different bone parts on the carpus, the wrist is filled with saline solution (Fig. 3).

At first, the arthroscopic guide and the arthroscope are positioned in the radiocarpal joint using 4–5 or 6-R radiocarpal portal. Exploration of the joint is performed, locating any possible associated lesions. After locating the proximal pole, a 3–4 radiocarpal portal is performed. This surgical approach is slightly larger than usual, about 1.5 cm, so that the proximal pole can be withdrawn and the implant put in place. The arthroscope can easily be positioned in this surgical approach, allowing direct access to the area of nonunion. A radial midcarpal surgical approach is used to analyze cartilage and to monitor the positioning of the implant.

After examining the proximal pole, the remaining cartilage is analyzed. First, the luno–radial area is analyzed in order to check that the cartilage between the lunate and radius is sound (Fig. 4A,B). Second, the quality of the cartilage between the distal scaphoid and the capitate is evaluated. It is often surprising to see good articular cartilage at this interval, especially in elderly people whereas considering the age of the lesions one would expect to see much more extensive cartilage degeneration. Finally, the state of the cartilage between the head of the capitate and the distal face of the lunate is analyzed.

Resection of the Proximal Part of the Scaphoid

Proximal pole resection is a relatively easy procedure, depending on how old the lesion is. In certain cases, it is necessary to use a burr to resect the proximal pole (Fig. 5). Sometimes we are faced with a small, necrosed proximal pole, weakly attached to the lunate by a few ligament fibers. The attachments are divided under arthroscopic control using instruments such as a surgical blade and small scissors (Figs. 6 and 7A,B). The detached proximal pole is easily withdrawn with forceps (Fig. 8). A radial styloid osteotomy is sometimes recommended to remove a painful contact between the styloid and the remaining distal part of the scaphoid.

Placing the Implant

First, the test implant is tried. There are three sizes:

- Small: length 16 mm and width 8 mm.

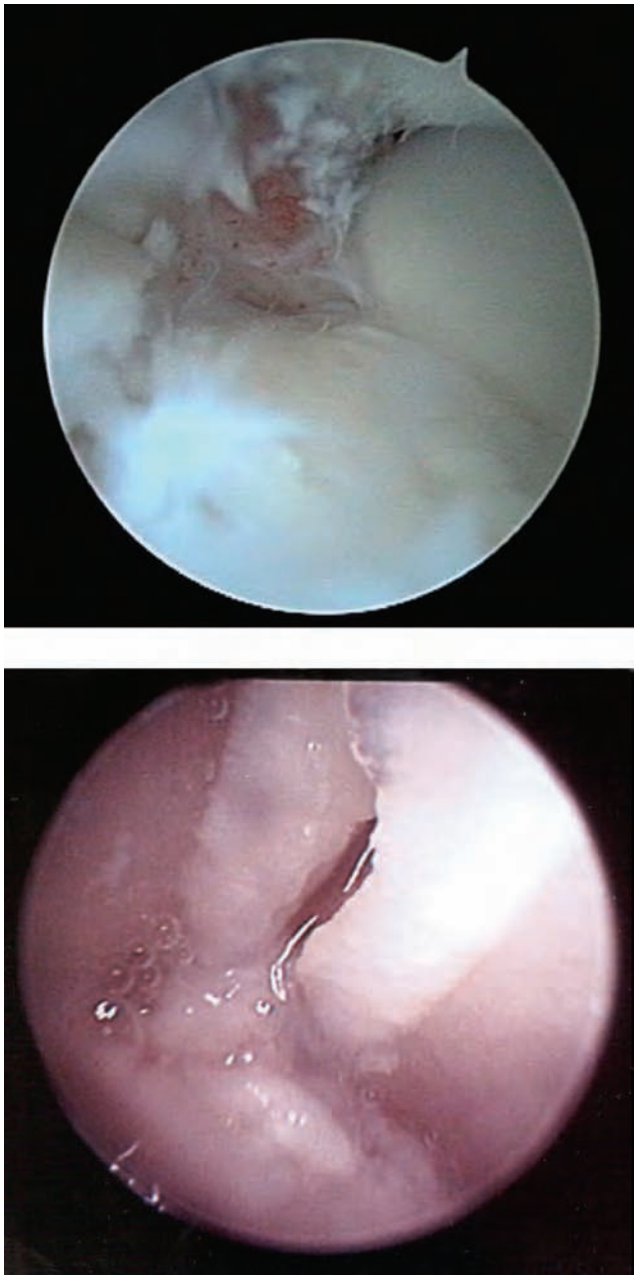


FIGURE 4 (**A**) Arthroscopic midcarpal view showing arthritis the position of necrotic proximal pole between the distal scaphoid on the left and the lunate on the right. (**B**) Arthoscopic view showing the chondral change of the capitate. The cartilage between the lateral side of the capitate and the medial side of the distal scaphoid is sound.

- Medium: length 17 mm and width 9.1 mm.
- Large: length 18 mm and width 10 mm.

The size is chosen on the operating table by positioning the test implants next to the resected proximal pole (Fig. 9). The test implant is then put into the radiocarpal joint in place of the proximal pole, and it is very satisfying to see how well this implant fits itself into the correct position (Fig. 10). After checking the correct congruence of the test implant by arthroscopy (Fig. 11A,B), it must be taken out. This is not always easy and is evidence of the good natural stability of the implant. It is replaced very easily by the definitive prosthesis, still under

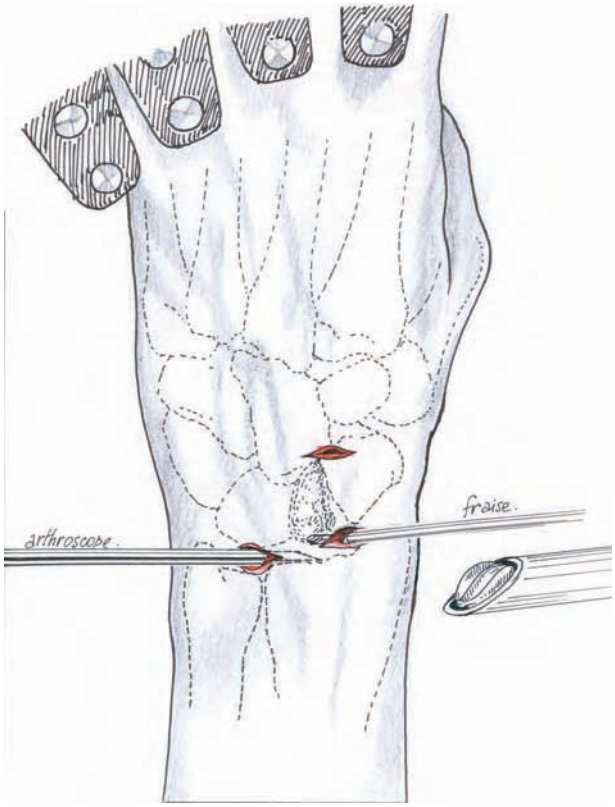


FIGURE 5 Diagram showing the 4–5 radiocarpal portal for the arthroscope and the possibility of proximal pole resection through the 3–4 radiocarpal portal using a burr.

arthroscopic control (Fig. 12). After removing the arthroscope, forced wrist movements are carried out to confirm that there is no dislocation of the implant. A representative case with pre- and postoperative X-rays is seen in Figure 13.

Postoperative Care

Only the 3–4 radiocarpal portal is closed by one or two stitches. As for normal wrist arthroscopy, it is not necessary to close the

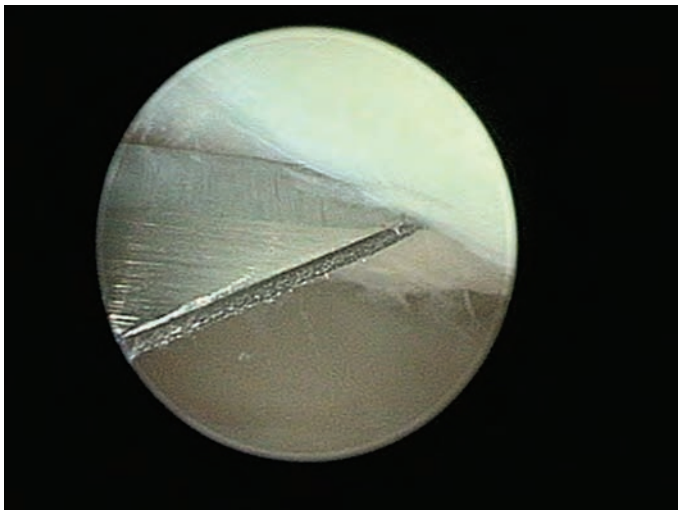


FIGURE 6 Radiocarpal arthroscopic view showing the use of a surgical blade to perforate the sacpholunate ligament.

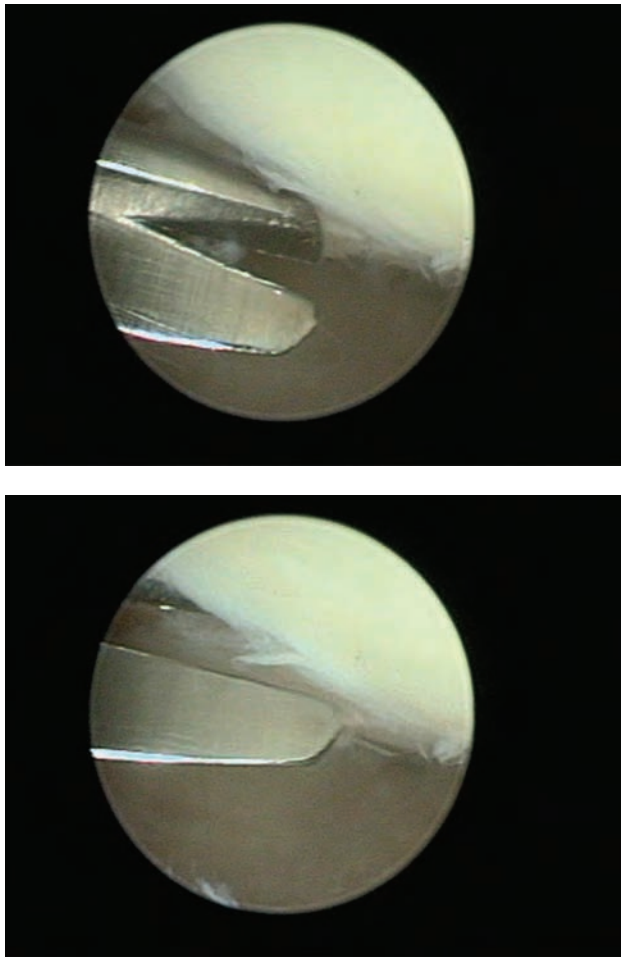


FIGURE 7 (**A**,**B**) Radiocarpal arthroscopic view showing the use of a scissors to separate the proximal pole and the lunate.

other portals. A protective dressing is put in place for eight days. Mobility is started immediately, letting the patient choose, themselves, the movements he or she wishes to make depending on postoperative pain. If necessary, rehabilitation can start after the third week.

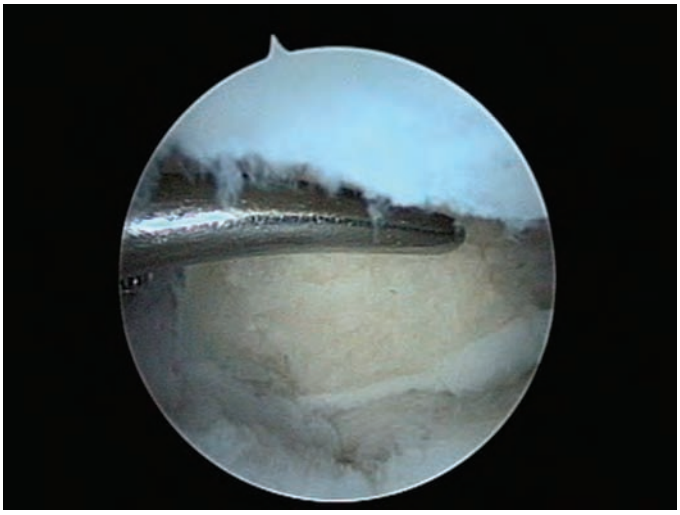


FIGURE 8 Radiocarpal arthroscopic view showing the proximal pole removal.

FIGURE 9 The resected proximal part of the scaphoid compared to the test and actual implants in order to choose the right size.

■ COMPLICATIONS

The most important technical point is to remove all fragments of proximal pole of the scaphoid. It is necessary to separate completely the scapholunate ligament attachment in order to easily remove the several pieces of bone, especially when they

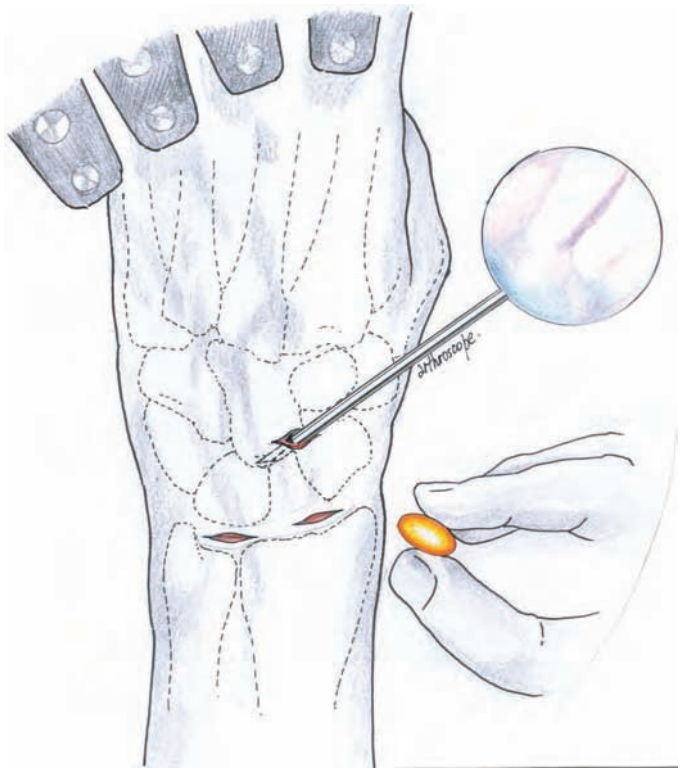
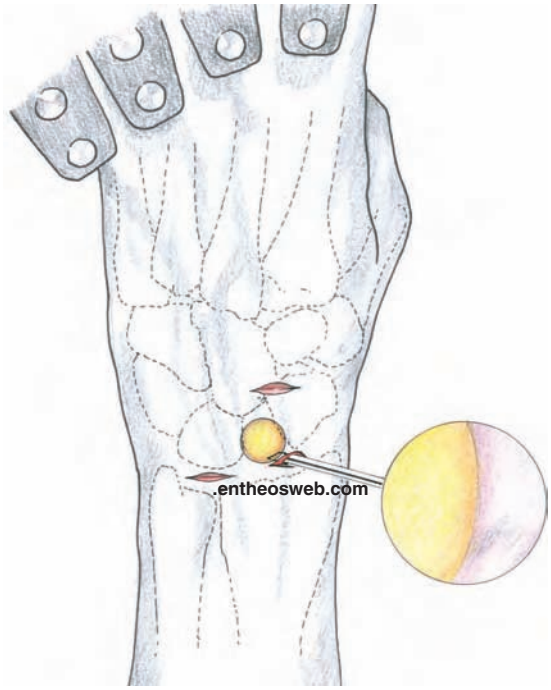


FIGURE 10 Diagram showing a radial midcarpal portal for the arthroscope before placing the test implant.

(A)



(B)

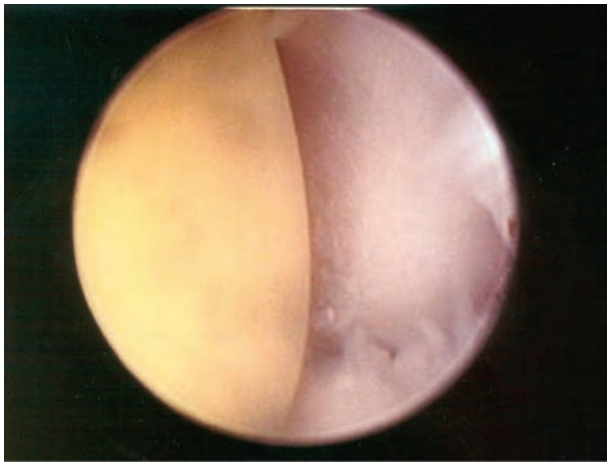


FIGURE 11 (**A**) Diagram showing a 3–4 radiocarpal portal for the arthroscope to check the correct position of the test implant. (**B**) Radiocarpal arthroscopic view showing the correct position of the test implant and the distal part of the distal scaphoid.

are small. Nevertheless, we have to take care not to damage the volar capsule to avoid volar dislocation of the implant in normal dorsal extension.

We had a case of volar dislocation of the implant postoperatively. It appeared that we created a little hole with scissors when we separated the attached proximal pole to the lunate. The implant passed by this hole and stayed in volar soft tissue. We had to replace the implant by a classic open volar approach and close the volar capsule perforation but had no further problems.

■ OUTCOME

We have operated on 18 patients during the period from the year 2000 to 2004. All were operated on as outpatients under

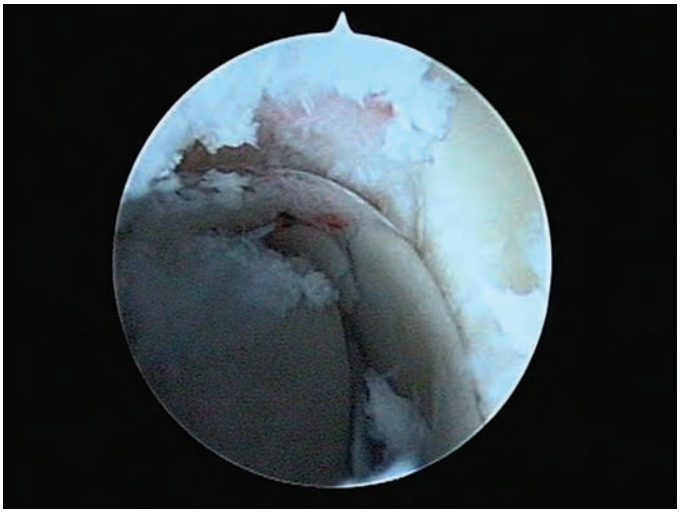


FIGURE 12 Midcarpal arthroscopic view showing the correct position of the implant. It is interesting to compare this view to the preoperative one (Fig. 4A) in order to see how the implant fits itself in the right position.

local–regional anesthesia using a pneumatic tourniquet. The average age was 49 years (range 40–81 years). There were 14 men and 4 women. All 18 patients were available for follow-up examination and radiographs.

The average follow-up time was 28 months (range 12–63 months). In younger people, we needed to place a volar splint in half of the cases. There were no immediate postoperative complications. We had one case of volar implant dislocation in the youngest patient, surely in connection with a lesion of volar capsule at the time of proximal pole removal. After intra-articular replacement, suture of the capsule, and cast immobilization for six weeks, the patient finally had a very good result.

We can separate these patients into two separate subgroups. The first series consisted of only elderly people: six patients. The average age was 76 years (range 72–81 years). All presented extensive arthritis with complete necrosis of proximal pole of the scaphoid and disabling pain. None of our six elderly patients had postoperative immobilization. The average follow-up was 39 months (range 25–63 months). The range of motion increased in all the cases from an average of 45° to 75° of active flexion–extension. None of these patients had pain at the longest follow-up. We did not have any complications.

The second series consisted of the youngest patients, 10 men and two women. The average age was 44 years (range 40–61 years). They all had necrotic proximal poles of the scaphoid in which the reconstruction and/or revascularization was impossible due to the small necrotic pieces of scaphoid. All had no adjacent chondral changes except in front of the proximal pole. The average follow-up was 23 months (range 12–49 months).

The major complication in this series was the one case of volar implant dislocation. We had two failures in poor indications (nonunion of the waist scaphoid). This technique should be reserved only for the proximal pole nonunions because the size of the implant is not adapted for replacement of a large part of the scaphoid. We performed palliative treatment in these cases (one four-bone arthrodesis and one proximal row carpectomy).

Except these two cases, all the other cases had excellent to good result without significant pain based on a modified Mayo Wrist scoring system and were completely satisfied. Pain disappeared completely after three months. In all the cases,

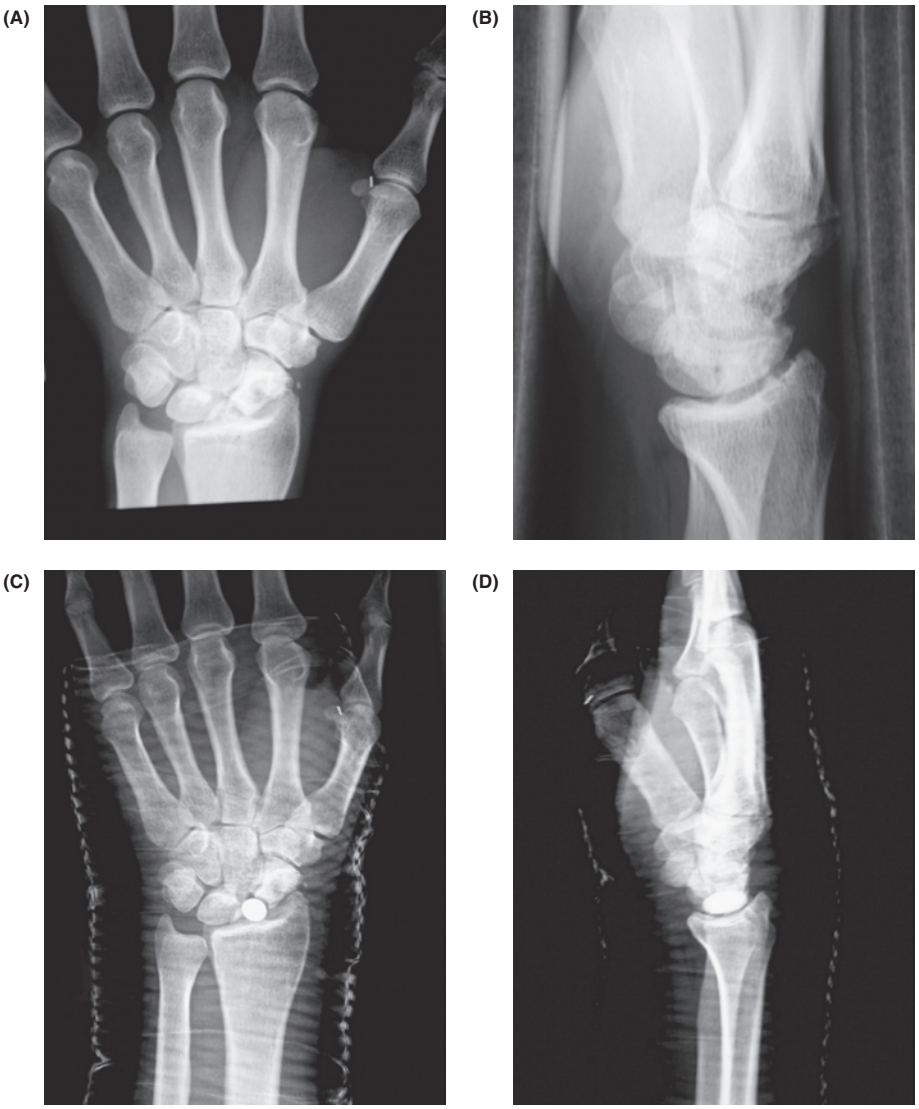


FIGURE 13 (**A**,**B**) Case 1: Front and side view X-rays of a necrotic proximal pole of the scaphoid. (**C**,**D**) Case 1: Side and front view X-rays showing the perfect position of the implant postoperatively.

the wrist range of motion improved in the flexion–extension arc from an average of 50° before surgery to an average of 100° after surgery. The incisions all healed well with very minimal scarring (Fig. 14). The parameters of radial–ulnar deviation and grip strength improved markedly after surgery.

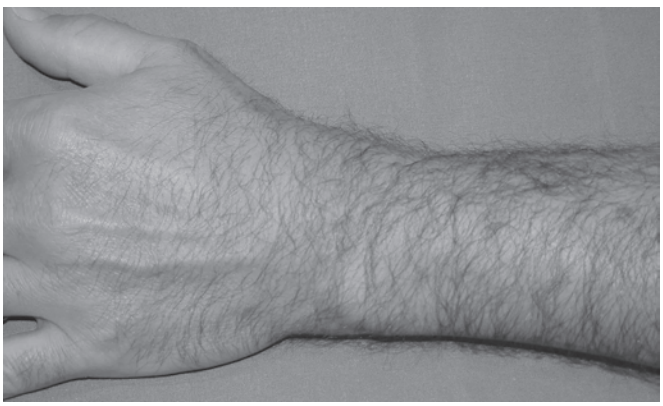


FIGURE 14 Cosmetic appearance without scar.

■ SUMMARY

The indications are rare and reserved only for necrotic proximal pole, but when the rules of placement are respected, arthroscopic arthroplasty for proximal pole scaphoid nonunion is a safe and reliable procedure. It is a simple salvage procedure in elderly people but could be a "waiting" therapeutic option in young patients with necrotic proximal pole of the scaphoid.

Brief Indications

Replacement of necrotic, unreconstructable proximal pole of the scaphoid.

Outcomes

- Good increase in range of motion.
- Excellent reduction in pain.

Complications

- One case of volar implant dislocations.
- Two failures in bad indications (nonunion of the waist scaphoid). These cases required palliative treatment (one four-bone arthrodesis and one proximal row carpectomy).

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Augmented External Fixation for Distal Radius Fractures

John T. Capo, Kenneth G. Swan, Jr., and Virak Tan
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Distal radius fractures are extremely common injuries that are most frequently seen in children and again later in life in elderly osteopenic women (1). The majority of distal radius fractures are simple fractures resulting from a fall and impact on an outstretched hand, and may be treated nonoperatively. High-energy distal radius fractures are more common in younger adults, and in these patients, the need for operative stabilization is more likely. In addition, some of the osteoporotic low-energy fractures may be unstable injuries that require operative stabilization. The demands of the elderly patient are increasing as they become more active and physiologically healthier. The use of external fixators, augmented with pins, screws, or small plates inserted through percutaneous or minimally invasive means, is a useful technique in the treatment of distal radius fractures.

INDICATIONS

A typical injury is a bending fracture that is usually seen in an elderly female. The fracture line is in the metaphysis and may be comminuted, while the articular surface is often intact. These fractures are often amenable to external fixation combined with percutaneous pinning. More high-energy fractures usually combine metaphyseal and articular comminution. These fractures demand more extensive methods of fixation and can be stabilized with a combination of external fixation and limited open reduction and internal fixation (ORIF) with pins, screws, or small plates. Also, open fractures are particularly suited to external fixation, as the wound is exposed and easily examined for postoperative care.

Some fractures can be deemed unstable at presentation. An unstable distal radius fracture can be defined by several criteria. These include articular step-off >2 mm, comminution $>50\%$ (extending from dorsal to volar), dorsal angulation $>20^\circ$, shortening >10 mm, a shearing Barton-type fracture pattern, and a fracture combined with a radiocarpal dislocation. When any of these criteria are met, the fracture is usually best treated operatively. Closed treatment of these injuries has shown poor results with a tendency to redisplace (2). Other indications for operative treatment are: those patients with lower extremity injuries who need to weight bear through their upper extremity and need rigid fixation; other fractures of the ipsilateral upper extremity that require stable fixation of the radius to rehabilitate the arm to achieve functional range of motion (ROM); and often open fractures combined with soft-tissue injury. In addition, when combined with ORIF, external fixators are an excellent method of unloading the carpus to allow small articular fragments and osteopenic metaphyseal bone to heal completely (3,4).

PREOPERATIVE PLANNING

Physical Exam

A distal radius fracture typically presents with tenderness, ecchymosis, and a variable amount of swelling dorsally over the distal radius. There is often a deformity at the wrist, and it may assume a position of apex–volar angulation. Neuorvascular status must be completely examined. Median nerve function is critical as distal radius fractures may induce swelling that may create acute carpal tunnel syndrome or, in severe cases, a true compartment syndrome. Tendon function needs to be examined, with attention to the extensor pollicis longus. The carpus must be examined for tenderness that may indicate carpal fractures or ligamentous injuries.

Imaging

Anterior–posterior (AP) and lateral plain radiographs are usually sufficient to characterize the distal radius fracture. Oblique films with 30° pronation and supination often detect subtle distal radius fractures. If there is severe shortening or displacement of the radius or ulna, then an elbow radiograph should be obtained to evaluate for longitudinal forearm instability or associated elbow fractures. Computed tomography scans of the radius are occasionally helpful to learn more about the articular involvement of the radius. Axial cuts with two-dimensional reconstructions in the frontal and sagittal planes are helpful to detect fragment size and displacement. This information may help in planning operative approaches to achieve better access to the most displaced and unstable fragments. Triangular fibrocartilage injury may manifest as distal radial–ulnar joint (DRUJ) subluxation, by showing displacement of the ulna dorsally or volarly. In a true lateral X ray, the pisiform sits between the volar limits of the scaphoid and volar cortex of the capitate. With this true lateral X ray, the distal ulna sits in the dorsal half of the radius, with the dorsal cortices colinear (5).

SURGICAL TECHNIQUE

Goals and Principles

The goals of treatment of distal radius fractures include: (*i*) restoration of the articular surface, (*ii*) realignment of the

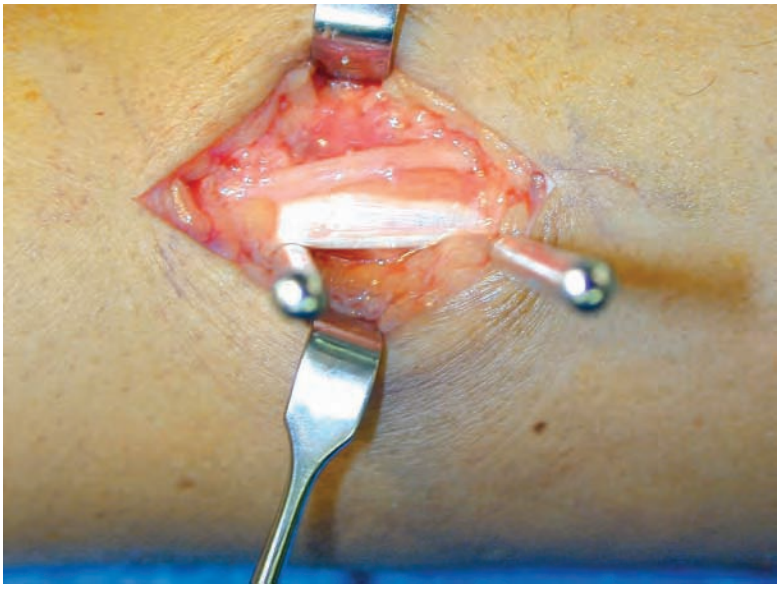

FIGURE 1 The proximal fixator pins are placed through one open incision. The pins are placed between the tendons of the radial wrist extensors. The superficial radial nerve can be seen volar to this interval. *Source*: Courtesy of John T. Capo, MD.

articular platform in space, with appropriate volar tilt and radial inclination, (*iii*) promote adequate healing, (*iv*) ensure a stable and reduced DRUJ, and (*v*) to maintain adequate finger and elbow ROM. It also must be remembered that the distal radius has two chondral surfaces that must be aligned: the radiocarpal joint with the scaphoid and lunate facets, and the sigmoid notch that articulates with the distal ulna.

External fixator frames function by inducing ligamentotaxis across the fracture site and thereby reducing fracture fragments. Distraction alone can maintain length, neutralize forces, and reduce larger peripheral fracture fragments. However, external fixation alone is often ineffective in reducing impacted central articular fragments. Flexion alone cannot restore volar tilt, as the dorsal capsular ligaments are more expansile than the volar ligaments. Indeed, excessive flexion

FIGURE 2 Half pins with a 2.5-mm thread diameter are placed in the second metacarpal. The proximal pin is placed at the metaphyseal flare and the distal pin is placed in the shaft. *Source*: Courtesy of John T. Capo, MD.

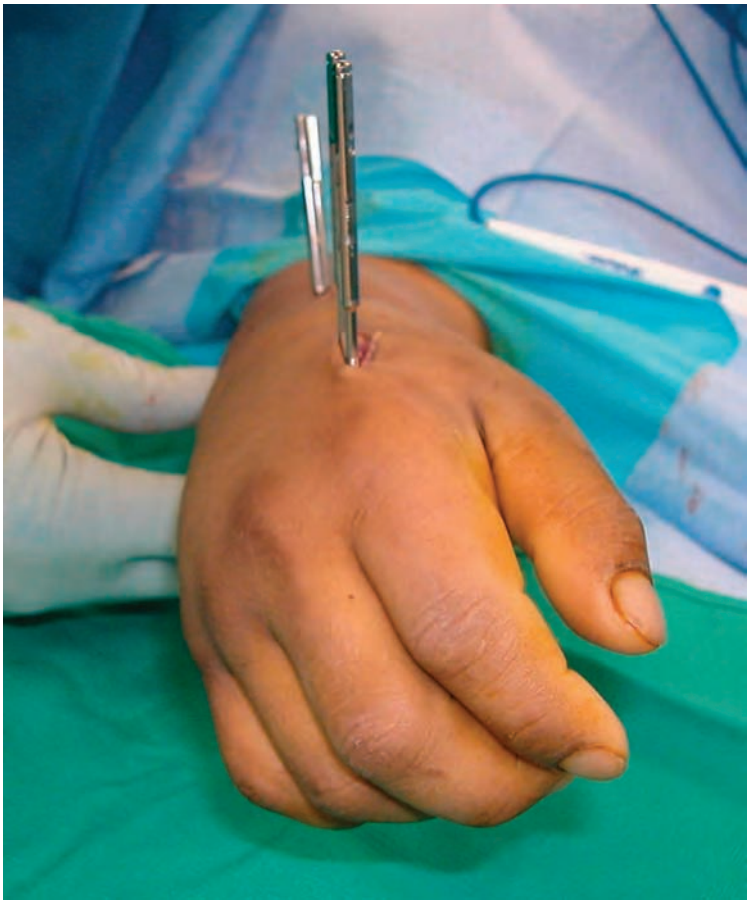

FIGURE 3 Placement of proximal and distal half pins in a 45° dorsal–radial plane. *Source*: Courtesy of John T. Capo, MD.

and ulnar deviation can cause acute carpal tunnel syndrome and make postoperative rehabilitation difficult, as this position severely limits finger ROM.

Operative Technique

Proximal threaded half pins, 3.0 to 4.0 mm, are placed approximately one hand's breadth proximal to the radial styloid, in a relatively uncovered area of the radial shaft. This area is largely devoid of tendons and is just proximal to the muscles of the first and third compartments (the extensor pollicis longus, extensor pollicis brevis, and abductor pollicis longus). A single 2- to 3-cm incision should be used for both proximal pins, and care taken to identify and protect the tendons and the superficial branch of the radial nerve. Percutaneous incisions should be avoided as this places these structures at risk. The extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis interval is

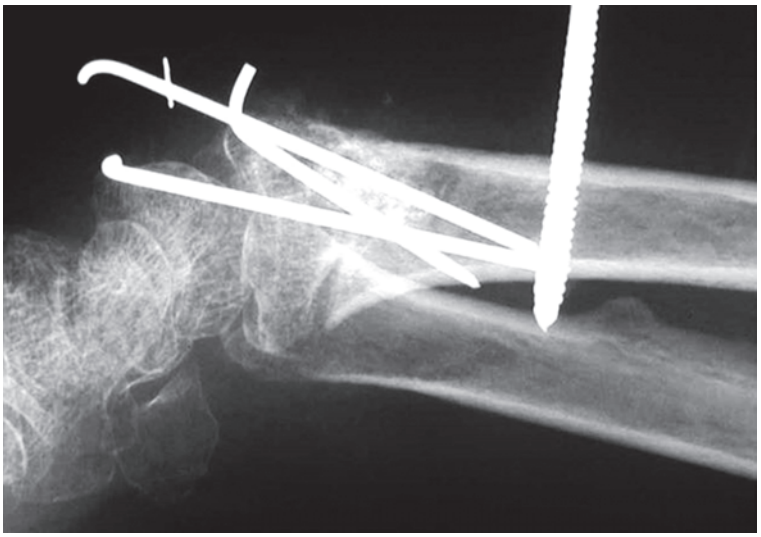

FIGURE 4 Excessive wrist flexion is inappropriately placed in this distal radius fracture case. The wrist should be placed in neutral alignment to promote finger ROM and rehabilitation. *Abbreviation*: ROM, range of motion. *Source*: Courtesy of John T. Capo, MD.

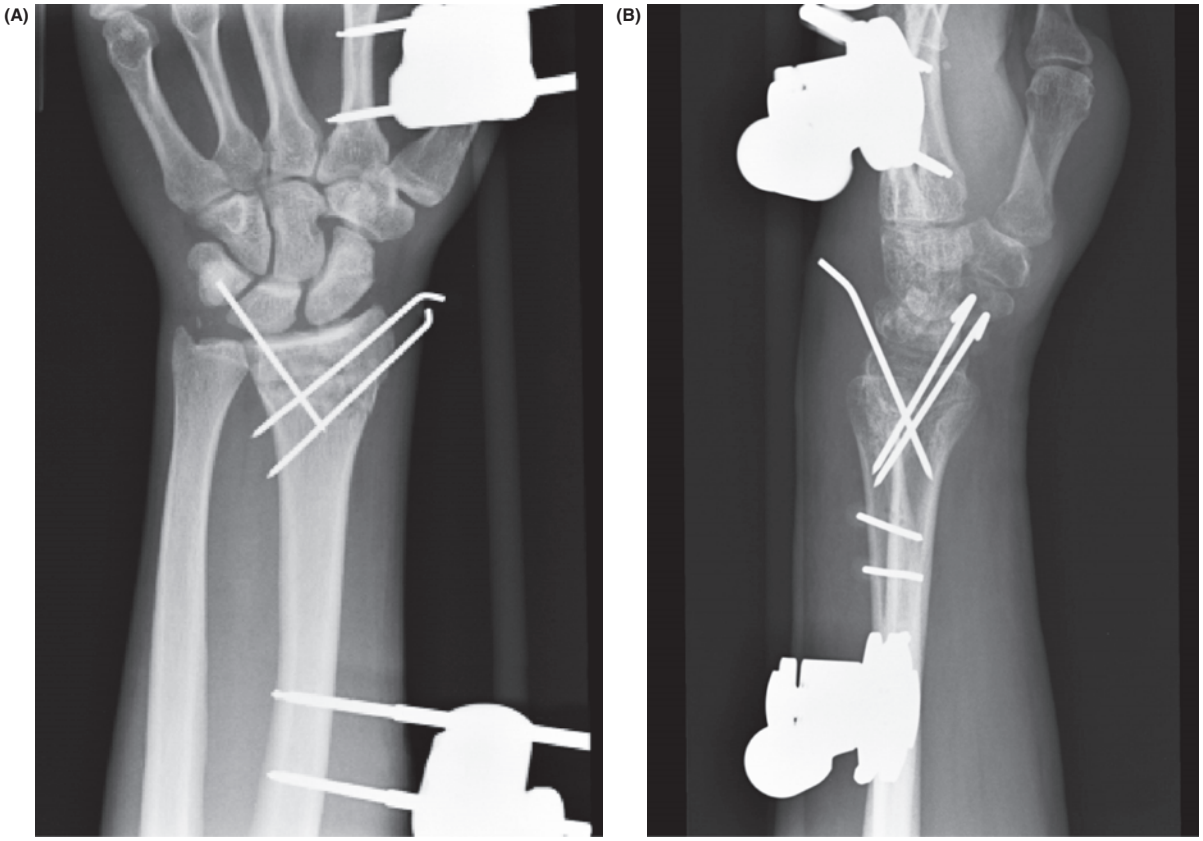

FIGURE 5 (**A**) AP view of distal radius fracture treated with augmented external fixation. The carpus is reduced on the distal radius and there is no over-distraction at the radiocarpal or midcarpal joints. (**B**) Lateral view of another distal radius fracture showing neutral alignment of the wrist and hand. *Abbreviation*: AP, anterior–posterior. *Source*: Courtesy of John T. Capo, MD.

FIGURE 6 Over-distraction of the carpus in this distal radius fracture demonstrates distal translation of the scaphoid which indicates an associated scapho-lunate ligament tear. *Source*: Courtesy of John T. Capo, MD.

utilized. This is slightly more dorsal than the brachioradialis–ECRL interval, and thus lies further away from the superficial branch of the radial nerve. Also this interval provides a tendon buffer on either side of the pins and provokes less nerve irritation (Fig. 1). The wrist extensors are immobilized by the frame and thus there is little tendon excursion in this interval.

Distal pins placed in the hand should have a smaller thread diameter (2.5 mm) to help avoid fracturing the metacarpal. These are placed in the proximal metaphyseal flare and shaft of the second metacarpal (Fig. 2). Open pin placement is again used to avoid injuring the first dorsal interosseous muscle and terminal branches of the superficial radial nerve. In addition, pins should not be transfixed into the third metacarpal as this may damage the motor branch of the ulnar nerve. Both sets of pins should be bicortical and placed 45° in the radial–dorsal plane. Placing the frame in this plane allows full retropulsion of the thumb and aids in achieving unobstructed lateral X rays (Fig. 3).

Next, all the skin incisions at the pin sites are closed with nylon sutures. This is easier now than at the close of the procedure where spanning bars and other exposed hardware make closure tedious. The pin clamps are next placed on the half pins at an appropriate level and tightened. The fracture must next be reduced. It is tempting to apply excessive volar flexion and ulnar deviation in an attempt to reduce the fracture deformity (Fig. 4). However, this extreme degree of positioning does not effectively induce flexion of the distal fragment and may result in elevated carpal tunnel pressures (6,7). It is more effective to induce traction and palmar translation of the carpus. In addition, ulnar deviation

FIGURE 7 (**A**) AP and (**B**) lateral views of an open, severely comminuted and displaced distal radius fracture. (**C**) AP and (**D**) lateral X rays showing initial stabilization of an external fixator. The distal most proximal pin is near the fracture site which may interfere with future plate placement. *Abbreviations*: AP, anterior–posterior. *Source*: Courtesy of John T. Capo, MD.

should not exceed 20°, as this may place excessive strain on the triangular fibrocartilage complex.

Distal radius fractures often require additional fixation methods after placement of the external fixator. The addition of Kirschner (K)-wires to an external fixation construct has been proven in the lab to have significantly increased rigidity (8). This may be required if fracture reduction cannot be obtained by ligamentotaxis alone, or if an excessive, nonphysiologic position of the wrist is needed for fracture reduction. In this latter case, the fixator can be utilized as a provisional reduction tool. Often the fracture requires hyperflexion, ulnar deviation, and significant palmar translation. After this is achieved the reduction can be held with crossed K-wires (0.062″, 0.054″, or 0.045″), one or two placed in the radial styloid and an additional pin placed in the ulnar corner of the radius. This configuration with 0.062″ K-wires has been shown to provide optimal rigidity (9). The radial-sided pins pass from straight radial to ulnar or slightly volar to dorsal, while the ulnar corner pin is placed obliquely from dorsal to volar. The radial styloid pins should be placed through a small open incision while the dorsal ulnar pins can be placed percutaneously. Once the pins are placed, the external fixator is adjusted back to a more neutral and physiologic alignment (Fig. 5). Supplemental K-wires may also be utilized as reduction joysticks to move articular fragments into anatomic position prior to final pin positioning.

At the close of the procedure, the position of the wrist and degree of distraction must be critically assessed. Flexion should not be more than 10° as this prevents power grip of the hand and can induce median nerve compression. Full passive flexion of the fingers into the palm should be easily achieved. If this is impossible or has significant rebound then the distraction is excessive and needs to be reduced. This inhibition of passive flexion is caused by tension on the external finger extensors and will seriously jeopardize final finger ROM. Examination of the final fluoroscopy shot should show even distraction across all the carpal joints. There should be equal distraction seen at the midcarpal and radiocarpal joints. Excessive distraction can be displayed as distraction of

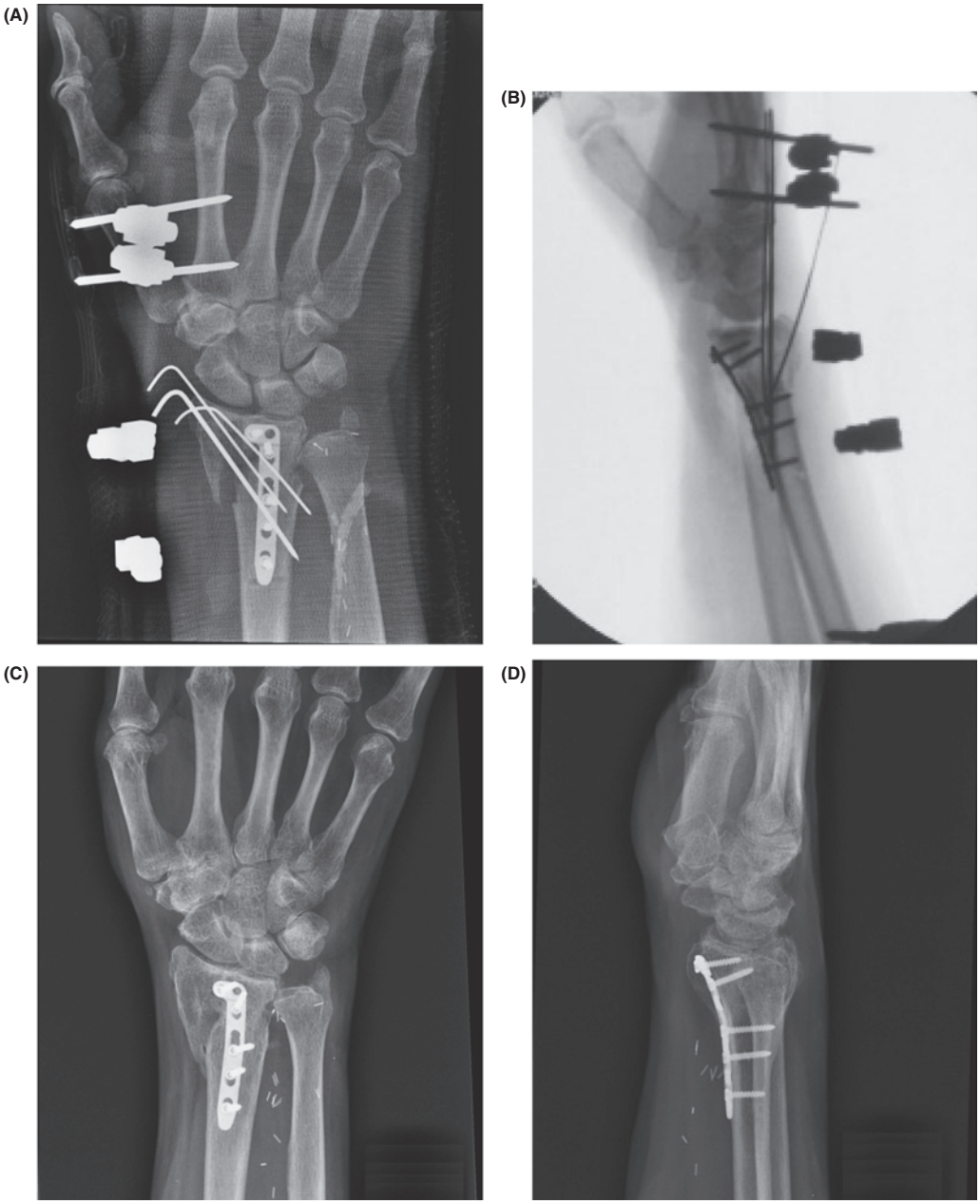

FIGURE 8 (**A**) Intra-operative AP and (**B**) lateral X rays demonstrating restoration of the joint surface with a small volar plate and additional percutaneous wires placed in the styloid. (**C**,**D**) Radiographs at follow-up showing healing of the fracture, reduction of the carpus, and articular congruity at the distal radius. *Abbreviations*: AP, anterior–posterior. *Source*: Courtesy of John T. Capo, MD.

the scaphoid in relation to the lunate, signifying a scapholunate tear (Fig. 6). In both the AP and lateral views, the carpus should be concentrically reduced, with the lunate and scaphoid in there respective fossa.

■ COMBINED ORIF TECHNIQUES

An external fixator can be used as one of several components in the fracture fixation hardware of a distal radius fracture. This is ideal for severe high-energy fractures that have metaphyseal and articular comminution. The external fixator is used to neutralize the metaphyseal fragmentation while small plates or percutaneously placed wires are used to align and fix the articular fragments. Ideally, the fixator should be placed in the standard 45° dorsal–radial position. This orientation allows access for either a dorsal, volar, or radial approach. Initially, excessive traction and angulation can be applied to help align fragments provisionally. A large radial styloid fragment may be approached by a volar Henry approach or a straight lateral approach. Lunate facet fragments can be addressed through a volar–ulnar approach between the ulnar neurovascular bundle and the carpal tunnel contents, or dorsally through the third or fourth dorsal compartments. First, the articular fragments are secured, then the articular segment is attached to the shaft. At this point, the fixator can be backed off to a physiologic position, while still maintaining mild distraction to unload the

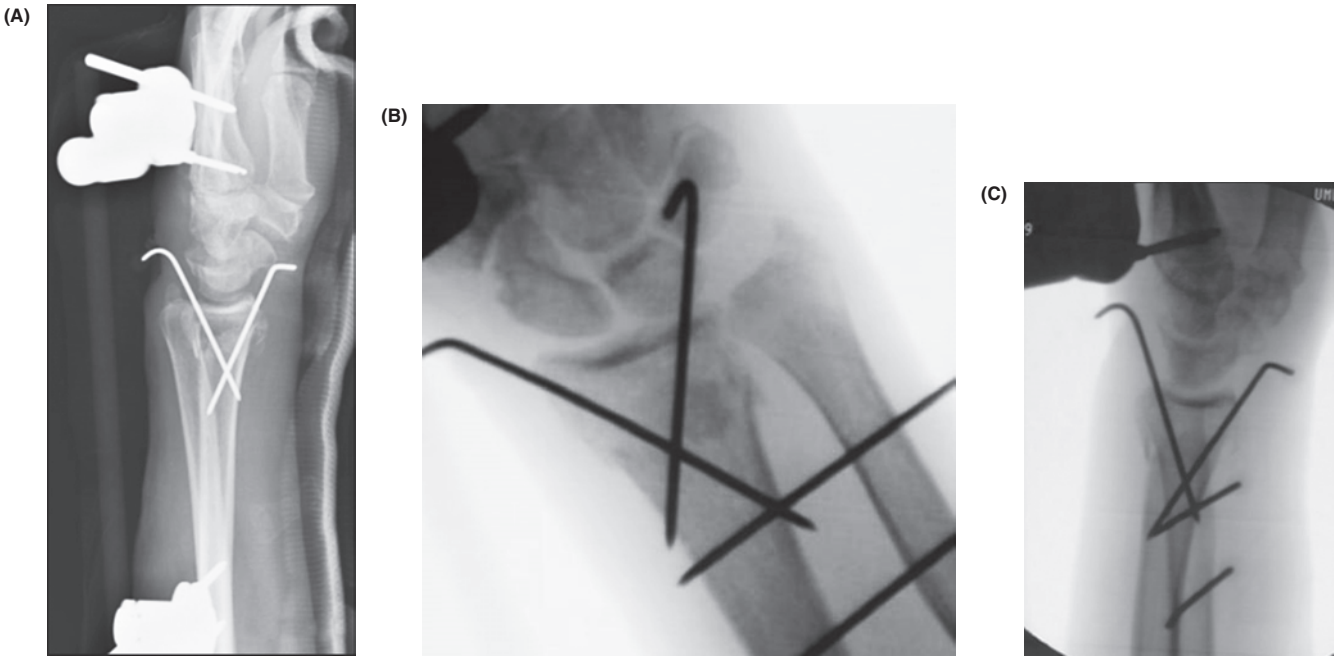

FIGURE 9 (**A**) Lateral postoperative X ray of distal radius stabilized with an external fixator demonstrating dorsal subluxations of the ulna. The patient had a prominent distal ulna and difficulty with forearm rotation. (**B**) AP X ray showing two 0.062″ K-wires holding the reduced DRUJ. (**C**) Lateral view demonstrating reduction of DRUJ. *Abbreviations*: AP, anterior–posterior; DRUJ, distal radial–ulnar joint; K-wires, Kirschner wires. *Source*: Courtesy of John T. Capo, MD.

carpus from the distal radius (Figs. 7 and 8). The fixator can be removed at four to five weeks for early wrist ROM with the other hardware providing adequate stability.

STABLIZATION OF DRUJ

The stability of the DRUJ should be evaluated at the close of operative fixation of all wrist injuries. DRUJ instability injury occurs in up to 10% of patients with distal radius fractures and is a major source of disability following successful healing of these fractures (10). The DRUJ is assessed with the elbow placed on the hand table and flexed at 90°. The radius and hand are stabilized and the ulna is stressed volarly and dorsally. This maneuver is done in neutral rotation and again in full pronation and supination. If there is abnormal translation or a significant click or sense of subluxation, the DRUJ must be stabilized. If the DRUJ can easily be reduced it can be stabilized in several ways. It can be fixed with percutaneous ulnoradial pins (Fig. 9) or by inclusion of the ulna in the external fixator construct with an extension bar (Fig. 10). A large associated ulnar styloid can be fixed with a screw or tension band technique. If radioulnar instability is not treated at initial injury, chronic subluxations ensues and usually requires open reduction and ligament reconstruction for treatment (10).

AFTERCARE

Pin track irritation and infection may occur. The importance of daily pin care must be reinforced to patients. Caregivers responsible for elderly or infirmed patients must also understand the importance of compliance with pin care. After the first post-op dressing change, twice daily cleaning with one-half strength hydrogen peroxide is initiated. Daily ROM exercises are also important. Occupational therapy is used in approximately two-thirds of our patients. The decision for therapy is usually made in the first two weeks after fixation. External fixation across the wrist should allow for complete finger ROM. Digital stiffness must be avoided as this is very difficult to treat chronically. Elbow flexion and extension and limited forearm rotation should also be initiated if there is no associated instability of the elbow or DRUJ (Fig. 11). The functional goal is to have complete digital and elbow ROM at the time of fixator removal.

Augmented fixation can also be beneficial during the postoperative course. With the presence of dual fixation, either the fixator or K-wires can be removed earlier if they become problematic. This can be especially helpful in the presence of a pin tract infection or in order to initiate early ROM therapy.

COMPLICATIONS

The complication rate associated with external fixation of distal radius fractures can be quite high, ranging from 20% to 85% (11–15). The majority of complications are minor pin track infections and transient neuropraxias. Wrist stiffness is often associated with external fixation, but usually is a function of the injury and not the fixator. However, more serious complications can occur. These primarily consist of tendon irritation and rupture, loss of fracture reduction, and complex regional pain–like syndromes (CRPS).

Most superficial pin track infections can be treated with meticulous pin care and oral antibiotics. However, occasionally pin tract infections require debridement or pin removal. In such cases, the presence of augmentation such as K-wires can be very valuable for maintaining the reduction. The rate of pin track infections, both superficial and deep, is about 20% (11,15,16). Some have advocated delaying surgery 7 to 10 days prior to pin placement to allow swelling to subside and potentially decrease the rate of pin tract infections (4).

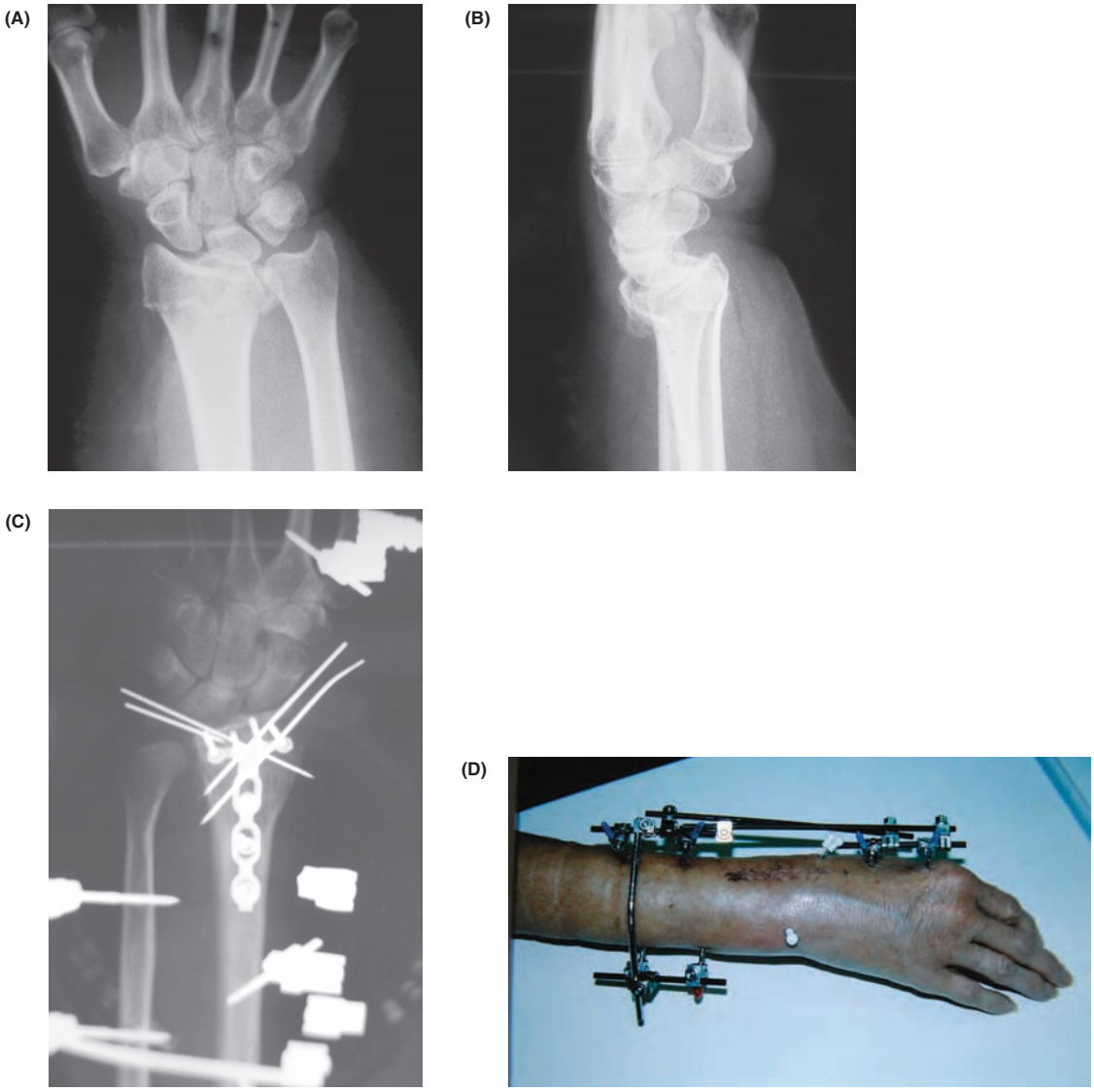

FIGURE 10 (**A**) AP and (**B**) lateral view of a comminuted distal radius fracture. (**C**) Postoperative X ray showing stabilization of fracture with volar plating, dorsal pin fixation, and an external fixator. (**D**) The external fixator construct is extended to the ulnar shaft with an outrigger bar to stabilize the DRUJ. *Abbreviations*: AP, anterior–posterior; DRUJ, distal radial–ulnar joint. *Source*: Courtesy of John T. Capo, MD.

Rates of neuritis and CRPS of 10% to 22% have been reported (11,12,14). It is unclear if these nerve injuries are from the initial trauma, or a complication of the treatment. It seems the incidence of nerve irritation may be significant (14) but the occurrence of a true CRPS is rare. Open half pin placement is helpful in minimizing iatrogenic nerve injury. Kaempffe and Walker (17) have suggested a causal relationship between fixator carpal distraction and postoperative ROM deficits. This often quoted study, however, did not demonstrate a statistically significant effect of distraction on outcome. Only duration of external fixation was statistically correlated with decreased wrist ROM.

We have analyzed 21 patients, two years after external fixation for moderate and severe distal radius fractures. The clinical results demonstrated 10 excellent, 7 good, 4 fair, and no poor outcomes according to the Gartland and Werley classification. Grip strength averaged 83% of the contralateral side, and ROM showed flexion of 62°, extension of 56°, and a 154° arc of rotation. The amount of distraction, as measured by the carpal height index was assessed and related to final clinical outcome. We found no adverse effects on wrist flexion extension or rotation with fixator distraction. It appears that stiffness in injuries treated by external fixation is more a function of the injury rather than the distraction induced by the fixator.

OUTCOMES

The biomechanics of augmented external fixation has been studied by Wolfe (8). These authors compared osteotomized distal radii stabilized with an external fixator alone or combined with various K-wire configurations. Both standard fracture transfixion wires combined with an external fixator, and a fixator with and an "outrigger" wire placed into the distal fragment and secured to the external fixator were superior to external fixation alone in reducing fracture motion. A single wire across the fracture site was enough to gain appreciable stability, and additional wires did not improve stability further.

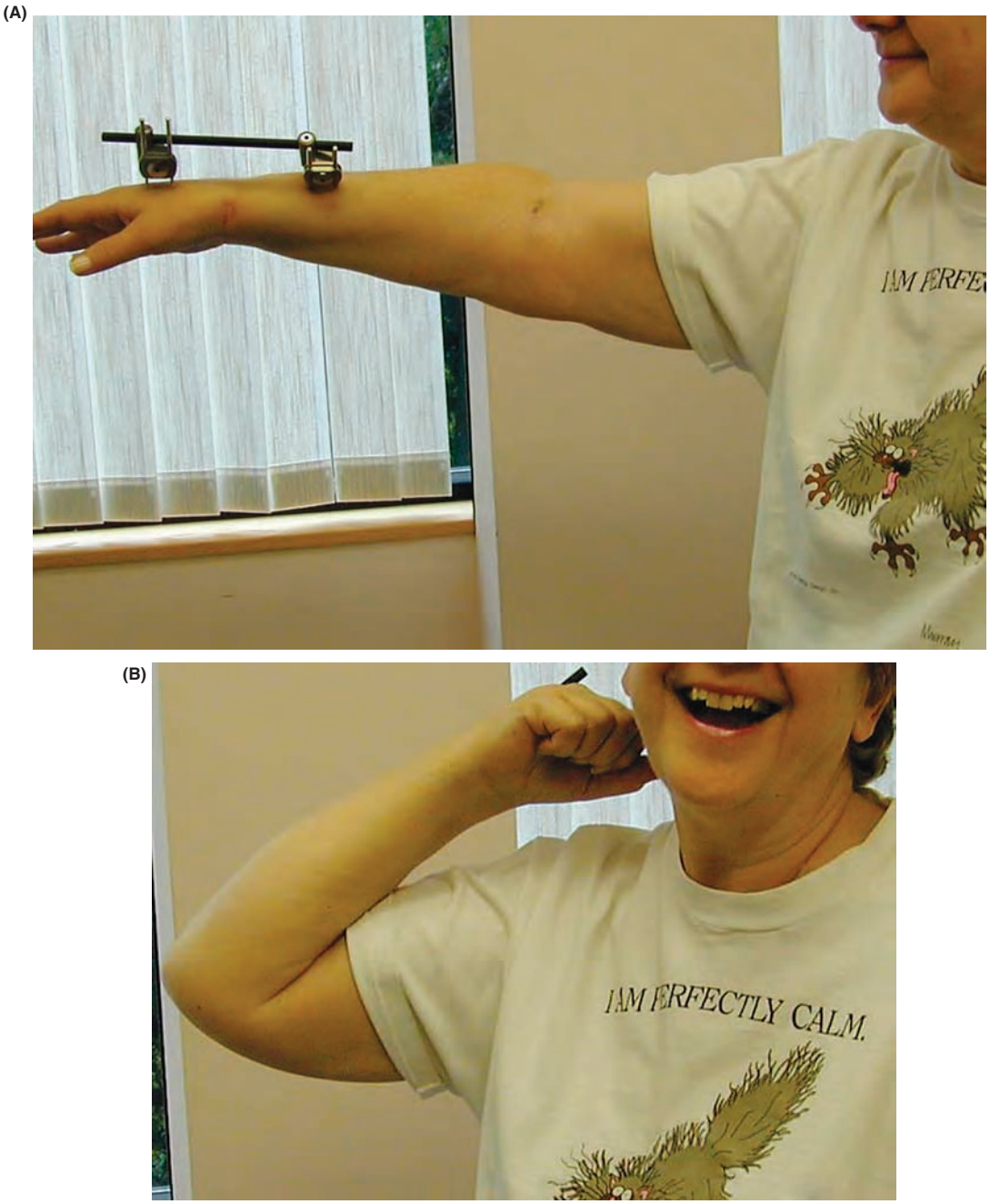

FIGURE 11 (**A**) Clinical photograph demonstrating full elbow extension and (**B**) flexion of patient with a distal radius fracture treated with an external fixator. *Source*: Courtesy of John T. Capo, MD.

Dunning et al. (18) studied augmented external fixation in distal radius fractures by generating simulated finger and forearm motions in cadavers. The extremeties were stabilized using spanning external fixation with or without radial styloid pins, or with a dorsal distal radius plate. The results demonstrated that supplemental K-wires significantly reduce fracture fragment motion when compared with external fixation alone. The stability imparted by the augmented ex-fix construct approached that reached with the dorsal plating technique.

Harley et al. (14) performed a prospective randomized study comparing augmented external fixation versus casting combined with percutaneous pinning for unstable distal radius fractures. Forty-one patients were followed for six months. The authors noted no difference in clinical outcome between the two groups, although they did note percutaneous pins and casting were more likely to result in articular gaps and defects. There was also a definite trend toward more frequent pin tract infections, CRPS, and nerve injuries in the external fixator group. The external fixator group had no significant difference in postoperative ROM.

Werber et al. (12) performed a randomized, prospective study comparing external fixation of distal radius fractures using the standard four-pin technique to a five-pin external fixator that included an additional pin placed in the radial styloid and attached to the fixator. Fifty patients were evaluated at least six months postoperatively. The authors found that the five-pin fixator was significantly better at

reduction of the fracture and in maintenance of the anatomic parameters. There was no difference in articular step-off between the groups. The five-pin group had a better clinical outcome with better ROM, and grip strength when compared with the four-pin group.

SUMMARY

Distal radius fractures are ubiquitous and are seen in all age groups from children to the elderly. Today, the choice of options for surgical treatment of distal radius fractures is wide ranging. With the popularity of locked plating, typically through a volar approach, the external fixator is now used less frequently. However with the advent of newer low profile designs in combination with supplementary pins, screws, or small plates, the utility of external fixators has increased. The principles of anatomic articular reduction, minimal soft-tissue trauma, and early ROM must be strictly adhered to ensure optimal results (19).

SUMMATION POINTS

Indications

- Extra-articular distal radius fractures with significant displacement.
- Intra-articular fractures with large fragments that can be reduced with percutaneous or limited open means.
- Open fractures with complex open wounds and soft-tissue injury.

Complications

- Pin sight irritation and infection.
- Inadequate reduction of articular surface.
- Over-distraction resulting in digital stiffness and median nerve irritation.

Outcomes

- Stable fixation with early return to function.
- Limited soft-tissue injury with surgery.
- Excellent and good results in $>85\%$ of patients.

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18

Non-Bridging External Fixation of the Distal Radius

Margaret M. McQueen
Royal Infirmary of Edinburgh, Edinburgh, Scotland, U.K.

INTRODUCTION

Distal radius fractures are extremely common injuries occurring mostly as low-energy extra-articular or minimal articular fractures in middle-aged to elderly women but with a small peak of incidence also in young men with higher energy injuries that tend to be intra-articular (1).

Most stable distal radial fractures can be treated in a cast. Instability of the distal radius, defined as either demonstrated or predicted inability to retain the reduced radiological position in a cast or articular displacement, are considered indications for surgical treatment of distal radial fractures in independent patients regardless of age. A number of surgical techniques are possible in this situation, including nonbridging external fixation. This method employs pins in the distal fragment and radius proximal to the fracture, thus not bridging either the radiocarpal, intercarpal, or carpometacarpal joints.

The first recorded use of external fixation in the wrist was reported by Ombrédanne who used a nonbridging technique for fractures and osteotomies of the forearm in children in 1929. Ombrédanne concluded that "temporary osteosynthesis with external connection allows a mathematical adjustment of the surgical correction … and guarantees further retention with ample and sufficient precision" (2).

For about 60 years, this sensible conclusion was largely ignored with surgeons concentrating on bridging external fixation first introduced by Anderson and O'Neil in 1944 (3). At that time, external fixation was generally used for severely comminuted intra-articular fractures of the distal radius in young men in whom nonbridging external fixation may not have been an option. Interest in the technique did not revive until the 1990s, possibly because of increasing numbers of healthier, elderly patients with low-energy fractures, who unlike previous generations, were not prepared to accept malunion and possible functional deficit and in whom nonbridging external fixation was a feasible option.

INDICATIONS

It is now generally agreed that malunion of a fracture of the distal radius, whether metaphyseal or intra-articular, is likely to lead to functional deficit leading to difficulty with the normal activities of daily living (4–7). Metaphyseal instability of the distal radius, whether demonstrated or predicted, in the fit patient is the most common indication for treatment with nonbridging external fixation to prevent malunion. Nonbridging external fixation should be used in preference to bridging external fixation whenever possible because of the improved radiological and functional results that have been demonstrated (8–10).

Nonbridging techniques are indicated for extra-articular dorsally displaced fractures with metaphyseal instability. The technique is not suitable for the treatment of volar displaced fractures. Most unstable fractures of the distal radius with minimal or undisplaced articular extension can also be successfully treated using this technique. Fewer cases with displaced articular extensions are suitable for nonbridging ex fix as after fixation of the joint surface they may lack the necessary space in the distal fragment for the distal pins. However, the use of multiplanar wires both to reduce and hold the articular fragments and to hold the metaphyseal alignment in a hybrid-type construct of nonbridging external fixation was recently reported as a good treatment option for articular fractures (11). Nonbridging external fixation is also indicated as a minimally invasive technique for corrective osteotomy of the distal radius for the treatment of symptomatic malunion.

The main contraindications for the technique of nonbridging external fixation is lack of space for pins in the distal fragment: approximately 1 cm of intact volar cortex is required to allow purchase for the pins. Dorsal comminution is not a contraindication for the technique as the pins achieve their grip on the volar cortex but severe articular comminution may preclude pin placement in the distal fragment.

As in any other technique for the management of unstable distal radius fracture, nonbridging external fixation is not recommended for the frail elderly dependent patient. With such patients, the fracture should be managed in a cast and malunion accepted (12). However, osteoporosis in the fit patient is not a contraindication as fixation failure is rare (8,11,13,14). As with any external fixation technique, insertion of pins through areas of possible skin infection is also contraindicated.

The indications for nonbridging external fixation of the distal radius do not differ significantly from the indications for the comparable open technique of either dorsal or volar plating. However, plating techniques frequently require a second operation for implant removal, which may be a relative contraindication in patients with significant comorbidities.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

The technique of nonbridging external fixation for fracture of the distal radius is simple and requires minimal preoperative planning. Physical examination should include assessment of neurological function in the hand, since in the presence of carpal tunnel syndrome decompression should be added to the surgical procedure. Evidence of complex regional pain syndrome type I should be noted but is not a contraindication for the technique. Examination of the skin in the area is required to exclude local infection.

The mainstay of preoperative imaging is a good series of preoperative films with true anteroposterior (AP) and lateral views of the wrist. This should allow assessment of the size of the distal fragment. On the lateral view, the volar cortex should be seen clearly: 1 cm of intact volar cortex is required. The AP view also allows assessment of the size of the fragment. Beware of the distal fragment that narrows toward the distal radioulnar

joint on the AP view forming a triangle with the radial styloid at its apex. This configuration may not allow sufficient purchase for an ulnar-sided pin.

Unless the fracture has redisplaced after initial closed reduction, the likelihood of instability should also be assessed on the preoperative plain films to establish the indication for stabilization. Radiological factors increasing the risk of instability are the presence of metaphyseal comminution, increasing radial shortening, and increasing initial dorsal angulation (15).

No special preoperative planning is required for the use of nonbridging external fixation in distal radial osteotomy. In this situation, the size of the distal fragment is determined by the placement of the osteotomy cut. The desired angle of correction may be estimated preoperatively but can easily be adjusted perioperatively by using the pins as a joystick. More advanced imaging is not usually necessary unless the nonbridging technique is to be used for severe articular fractures when computed tomography scanning may be required to visualize the articular fracture pattern and to plan placement of hybrid-type pins.

SURGICAL TECHNIQUE

Axillary or supraclavicular regional block is recommended as there is some evidence that the use of this technique will reduce the incidence of complex regional pain syndrome type I (16). The patient is placed supine with the affected arm extended on the hand table and the wrist in neutral rotation. A tourniquet is applied to the upper arm. The surgeon is seated on the cephalic side of the arm table and the C-arm is positioned on the opposite side. Fracture reduction prior to insertion of the pins is not necessary.

Acute Fractures

The distal pins are inserted first from dorsal to volar, midway between the fracture site and the radiocarpal joint, and on either side of Lister's tubercle. If there is an undisplaced sagittal, articular fracture pins should be placed on both the radial and ulnar sides of the articular extension. Lister's tubercle may be palpable in cases with minimal swelling and gives a good indication of the approximate level of pin entry. The exact placing will be determined by the type of fixator used, but in those with two parallel distal pins, the ulnar-sided pin should be inserted first into the ulnar corner of the distal radius. A marker is placed on the skin and its position in relation to the entry point on bone confirmed on a lateral and AP view of the wrist (Figs. 1 and 2). A 1-cm longitudinal incision is made at this point and the extensor retinaculum visualized. A longitudinal incision is made in the retinaculum under direct vision with care taken not to damage any underlying tendons. The

FIGURE 1 An anteroposterior view of the distal radius showing the ideal placement of a fixator pin in the ulnar corner of the distal radius. The patient had a concomitant scaphoid fracture fixed with a screw.

FIGURE 2 A lateral view of the distal radius demonstrating the starting point for a fixator pin, midway between the fracture and the joint.

underlying bone is then exposed. A fixator pin is placed on the bone and the position confirmed on the image intensifier. The pin is then adjusted so that its projected course is parallel to the radiocarpal joint on the lateral view. The pin is then inserted by hand until its tip penetrates the volar cortex (Fig. 3). Predrilling is not necessary. Further pins may then be inserted using the same technique; the spacing and relationship of the pins will be determined by the fixator used.

Pins are then placed in the radial diaphysis proximal to the fracture. These should be as close as possible to the fracture to allow as small a fixator construct as possible. Open pin placement is mandatory to avoid damage to the dorsal branch of the radial nerve. A longitudinal skin incision is used over the dorsum of the radius followed by blunt dissection to expose the tendons of extensor carpi radialis longus and extensor carpi radialis brevis. The natural interval between these tendons is developed to expose the radius. The proximal pins are then inserted by hand with or without predrilling and should engage both cortices of the radius. The fixator should then be assembled but not tightened. Reduction of the fracture is then achieved using the distal pins as "joysticks" (Fig. 4). In a fresh fracture, this requires very little force. Where reduction has been delayed, forcible reduction should not be attempted as this may cause pin loosening. In late cases, gradual reduction should be employed and is usually possible up to around three weeks after fracture. Should reduction not be possible without undue force a small incision should be made over the dorsum of the fracture and a lever inserted to reduce the fracture by direct means. The fixator is then tightened and the reduction confirmed using the image intensifier.

Distal Radial Osteotomies

Use of a nonbridging external fixator for distal radial osteotomy allows minimal soft tissue dissection. A 2.5-cm transverse skin incision is made over the site of deformity. The extensor retinaculum is then divided longitudinally and the radius exposed between the third and fourth extensor compartments. The level of the osteotomy is identified. Distal pins are then inserted through two separate incisions using the same technique as described for acute fractures and are placed between the level of the planned osteotomy site and the radiocarpal joint. An osteotomy cut is then made with a small saw parallel to the pins and as far as but not through the volar cortex. An osteotome is then inserted into the osteotomy cut and the volar cortex cracked by creating an open wedge dorsally.

Proximal pin insertion is performed using the same technique as for acute fractures. The distal pins can then be used to allow accurate positioning of the distal fragment. The wedge-shaped defect in the distal radius is filled with cancellous bone

FIGURE 3 The pin has been inserted by hand. Note that the pin penetrates the volar cortex.

harvested from the iliac crest (Fig. 5). The transverse incision is closed but the pin track incisions are left open.

Postoperative management is the same for both fractures and osteotomies. Pin tracks are not closed but are treated with dressings that are initially changed daily, but then twice weekly, provided the pin tracks are satisfactory. Hand and wrist movements are encouraged and no form of immobilization is used. The fixator is removed in the majority of cases at five to six weeks. Occasionally, in the presence of associated diaphyseal comminution, a longer period is required until diaphyseal healing is evident radiologically.

COMPLICATIONS

There are few perioperative pitfalls. One which may be encountered per-operatively is over-reduction of the fracture (Fig. 6), especially if there is bayoneting of the volar cortex. This should be easily recognized on the image intensifier views and is therefore a preventable complication. If insertion of distal pins proves unsuccessful because of insufficient intact volar cortex, then it is simple to convert the construct to a bridging construct with or without augmentation.

Aseptic pin track loosening or pullout is rare even in osteoporotic bone. However, the most common complication of nonbridging external fixation of the distal radius is pin track infection, which is reported to occur in 9% to 33% of cases (8,11,13,14,17). Fortunately, the vast majority are minor infections that are treated with antibiotics and increased frequency of dressings.

Extensor pollicis longus rupture or irritation occurs in less than 5% of cases (8,11,13,18). This is a similar rate to distal radial fractures treated by different methods (1), but much less than the more invasive technique of dorsal plating in which high rates of extensor tendon rupture or irritation are reported (19,20). Rates of other fracture-related complications are not affected by the use of nonbridging external fixation.

OUTCOMES

Fractures

Radiological outcomes of nonbridging external fixation for extra-articular or minimal articular fractures are uniformly good (Table 1). The first report of nonbridging external fixation with anatomical results was a comparison of plaster versus nonbridging external fixation in patients under 60 years of age with displaced distal radial fractures. The quality of the reduction was good in both groups, but the reduced position

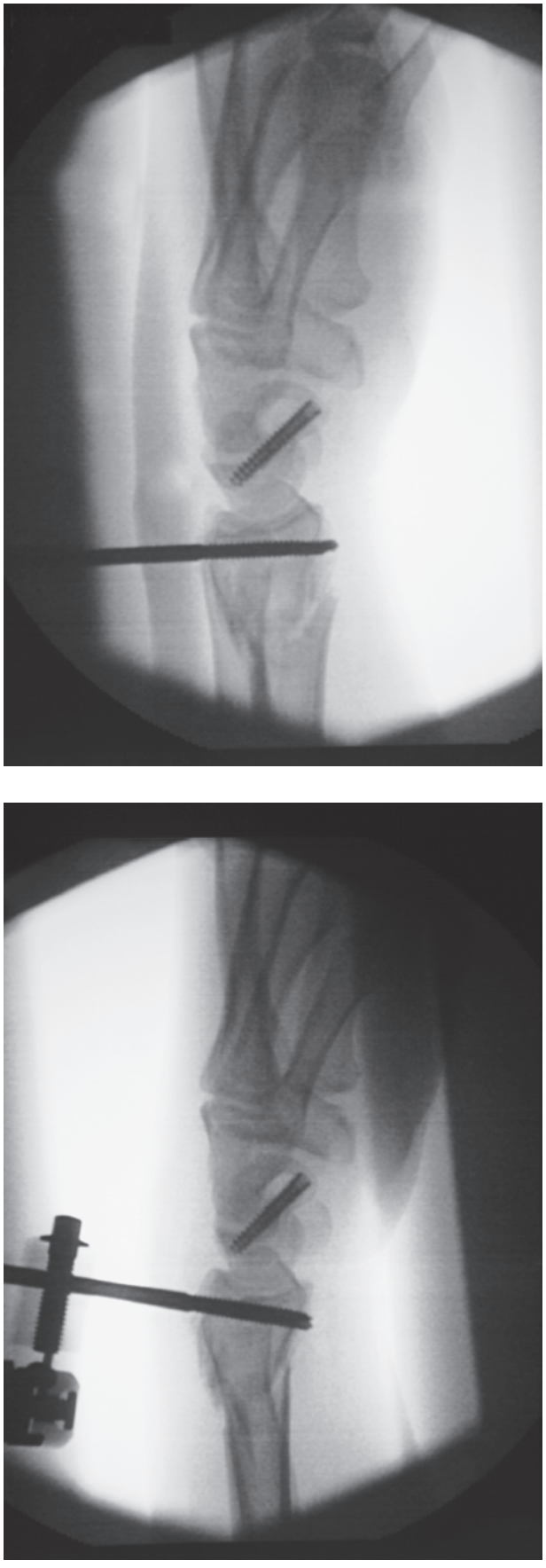

FIGURE 4 (**A**) Two pins have been inserted. The fracture is unreduced. (**B**) The fracture has been reduced using the joystick technique.

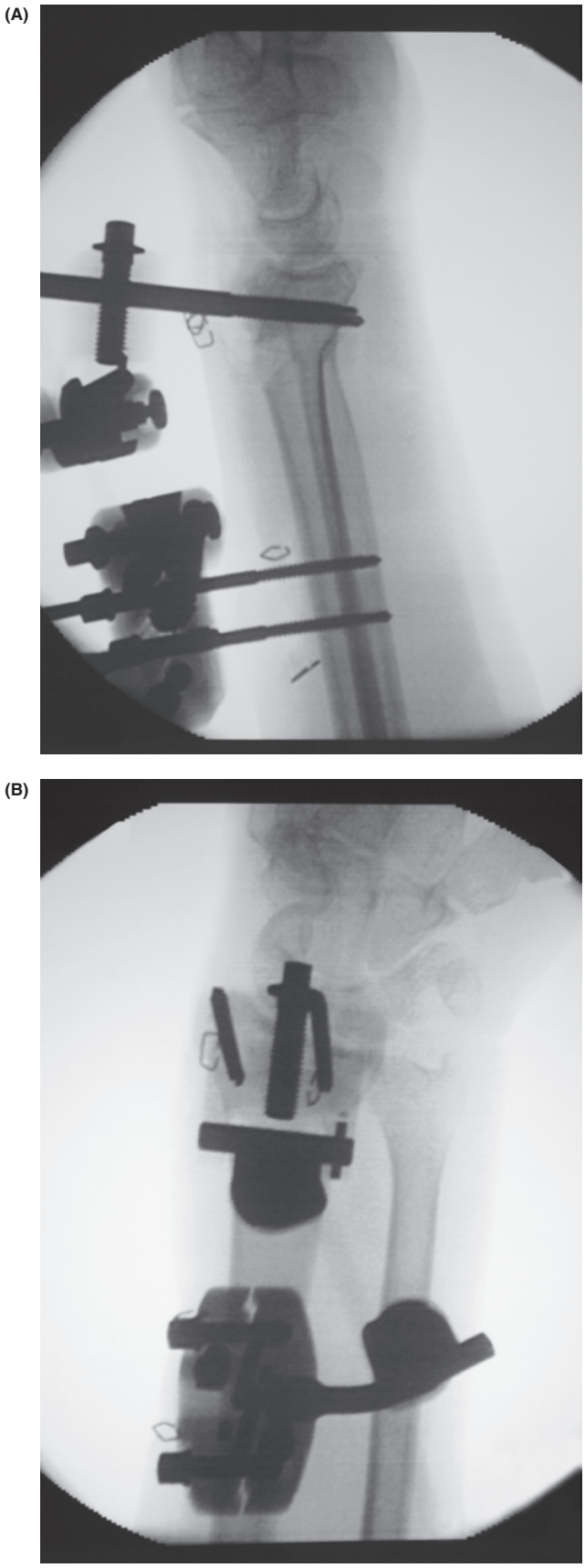

FIGURE 5 A postoperative anteroposterior (**A**) and lateral (**B**) view following corrective osteotomy of the distal radius using nonbridging external fixation. Note the bone graft in the defect which is clearly seen on the lateral view.

FIGURE 6 A lateral view of the distal radius showing over-reduction of the same fracture as in Figures 1–4. There is excessive volar tilt.

was maintained better ($p < 0.01$) by the external fixation group (21).

The first randomized study of nonbridging external fixation was a comparison with bridging external fixation. Sixty patients with redisplaced distal radial fractures and an average age of 61 years were included. Nonbridging external fixation showed statistically significant improvement in both dorsal angle and radial shortening at all stages of review, successfully maintaining volar tilt until final review at one year (8). There were no malunions in the nonbridging group in this study.

Thus, the main radiological advantage of nonbridging external fixation is restoration and maintenance of the normal volar tilt of the distal radius. In bridging external fixation, reduction of the fracture depends on ligamentotaxis. Volar tilt may not be restored because the volar ligaments are shorter and stronger than the dorsal ligaments and prevent full reduction (23). With nonbridging external fixation, the reduction is performed using the distal pins as joysticks, allowing the surgeon direct control of the distal fragment and obviating the need for ligamentotaxis.

Superior functional outcomes are also reported in nonbridging external fixation for acute fractures of the distal radius compared to bridging techniques (8). In this study, the nonbridging group grip strength was restored to 87% of the opposite normal side, allowing for appropriate hand dominance. Other indices of function also showed superior results in the nonbridging group.

The outcomes when nonbridging external fixation is used for multifragmentary articular fractures are less optimal. Table 1 shows a summary of the reports available in the literature on nonbridging external fixation. In extra-articular and minimal articular fractures, functional results are excellent. The only exception to that rule is when the technique is used for severe articular fractures when it is likely that the severity of the injury dictates the outcome (22).

There have as yet been no randomized studies comparing nonbridging external fixation with the more invasive technique of plating for the management of unstable distal radius fractures. Volar locked plating has been introduced recently for unstable distal radius fractures in the hope that fixed angle devices would confer more stability in osteoporotic bone, and that compared to dorsal plating there would be less soft tissue irritation and therefore less need for implant removal. The technique is more invasive than nonbridging external fixation and has been widely used with very limited data available on its outcome.

One of the first reports of the technique was on 50 fractures treated with a volar locked plate in patients with a mean age of 62 years (24). In 21 of their fractures, the postoperative reduction

TABLE 1 Published Outcomes of Nonbridging External Fixation for Fracture of the Distal Radius

	Fracture type	Malunion	Function	Major PTI	EPL rupture
Jenkins (1987) (21) *n*=32	Extra-articular/nonarticular	2	N/A	0	0
McQueen (1998) (8) *n*=30	Extra-articular/non articular	0	Grip strength 87%	0	2
Krishnan et al. (1998) (17) *n*=22	Intra-articular	0	29/30 excellent/good	2	0
McQueen et al. (1999) (13) *n*=20	Extra-articular/non articular	1	Grip strength 88%	1	0
Krishnan et al. (2003) (22) *n*=30	Intra-articular	N/R	Grip strength 45%	0	3
Flinkkila et al. (2003) (18) *n*=52	Extra-articular/non articular	2	Grip strength 90%	1	0
Gradl et al. (2005) (11) *n*=25	Extra-articular Severe articular	1	96% excellent	2	0

Abbreviations: EPL, extensor pollicis longus; N/R, not reported; PTI, pin track infection.

deteriorated by the final review, and in four there was sufficient collapse of the fracture to allow penetration of the radiocarpal joint by the distal screws. The authors suggested that in patients with significant osteoporosis bone grafting may be required to augment the fixation, thus increasing the invasive nature of the technique. A more recent study has also shown a concerning rate of fracture collapse (10%), especially in patients with severe comminution (25). There also remains a significant rate of secondary surgery for implant removal due to either flexor tendon problems from the plate or extensor tendon irritation or rupture due to screw penetration dorsally (24,25). Randomized studies are required to compare this technique with established techniques including nonbridging external fixation.

Osteotomy

Little is reported on the use of nonbridging external fixation for distal radial osteotomy. A series of 23 patients were treated in the author's institution with nonbridging external fixators for symptomatic malunion of the distal radius. There were statistically significant improvements in both dorsal angulation and radial shortening, with dorsal angulation improving from a mean of 18.6° to a mean volar tilt of 6.5° at final review. All functional measures were statistically significantly improved at final review compared with preoperative levels except wrist extension and key grip strength. The only major complications were two patients with extensor pollicis longus ruptures. Radial osteotomy with nonbridging external fixation provides a minimally invasive technique for distal radial osteotomy with reliable radiological and functional results.

SUMMARY

Nonbridging external fixation of the distal radius for metaphyseal unstable fractures is a simple minimally invasive technique that allows the surgeon to obtain and maintain an excellent reduction. Functional results are generally very satisfactory with a rapid return to function and good long-term function. Nonbridging external fixation has been shown to be superior to bridging external fixation in the treatment of unstable distal radius fractures. The technique has not been directly compared to either dorsal or volar plating but is likely to have less fracture collapse, fewer tendon problems, and therefore less secondary surgery.

FUTURE DIRECTION

Prospective randomized studies are required to compare nonbridging external fixation with plating, especially locked volar plating, for unstable extra and minimal articular fractures of the distal radius. The use of the technique in severe articular fractures should be defined more clearly. There is also the opportunity to develop lighter and lower profile components that are fully radiolucent in order to maximize function for the patient while the fixator is in place.

SUMMATION POINTS

Indications

- Unstable extra-articular and minimal intra-articular fractures of the distal radius
- Severe articular fractures of the distal radius (using multiplanar K-wires)
- Minimally invasive technique for distal radial osteotomy for symptomatic malunion of the distal radius

Outcomes

- Few malunions
- Rapid rehabilitation and excellent long-term function

Complications

- Minor pin track infections
- Iatrogenic volar malunion

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19

Spanning Plating for Distal Radius Fractures

Anthony J. Lauder
Department of Orthopedic Surgery and Rehabilitation, University of Nebraska Medical Center, Omaha, Nebraska, U.S.A.

David S. Ruch
Department of Orthopedics, Duke University Medical Center, Durham, North Carolina, U.S.A.

Douglas P. Hanel
Section of Hand and Microvascular Surgery, Department of Orthopedics and Sports Medicine, University of Washington, Seattle, Washington, U.S.A.

INTRODUCTION

Initially, as described by Colles in 1814, distal radius fractures were considered entities that had universally good outcomes, deserving only benign neglect as treatment (1). Although this may occur for nondisplaced distal radius fractures that heal uneventfully, many authors have demonstrated high complication rates with conservative management of more complicated fractures (2,3). More recently, surgeons have become more aggressive in their treatment of distal radius fractures due to the recognition that good outcomes depend on the restoration of normal anatomy (4–8). Even though distal radius fractures are exceedingly common injuries, it is this restoration of normal anatomy, specifically the articular surface, which can present a significant challenge for the treating surgeon.

Furthermore, certain subsets of injuries including high-energy fractures and fractures occurring in osteoporotic bone pose particular problems. High-energy fractures with severe comminution extending into the metaphyseal–diaphyseal region and osteoporotic fractures also with comminution and poor structural support make articular surface reconstruction through open techniques a daunting task (Fig. 1). Adding to the difficulty with surgical treatment for these types of distal radius fractures is the fact that many of these patients present with multiple injuries. Multiple injured patients, who often need maximum use of their upper extremities to change assist with mobilization, require rigid fracture fixation that dissipates weight-bearing forces while providing enough stability to allow fracture healing. Ideally, a method to treat distal radius fractures in the face of polytraumatized patients or poor bone stock would provide rigid fixation, help maintain fracture reduction, require minimal postoperative nursing or patient care, be easily applied, and allow for early weight bearing.

A relatively facile technique that provides the support necessary to allow early weight bearing is the spanning or internal distraction plating of the distal radius (Fig. 2). Originally described by Burke and Singer in 1998 (9), this method bypasses the injured segment with a bridge plate from the distal shaft of the radius to the shaft of the second or third metacarpals. Advantages of this technique include the following: (*i*) it effectively eliminates the compressive forces at the distal radius articular surface seen when non-spanning devices are utilized; (*ii*) it can be much cheaper than external fixators applied for similar fractures; (*iii*) it allows for early weight bearing and patient mobilization; (*iv*) it eliminates the need for pin site care and the complications that can stem from infected tracts; (*v*) it is indicated in severely comminuted or osteoporotic bone where proximal migration of the distal fragments would be expected with weight-bearing and non-spanning devices; and (*vi*) it implements indirect reduction techniques through ligamentotaxis that reduces the devascularization of fragments, which can occur with open techniques. Important disadvantages of this technique include the following: (*i*) it entails prolonged immobilization of the wrist during fracture healing; (*ii*) it requires distraction to afford a reduction that has been associated with complications (10–13); and (*iii*) it requires a second surgery for plate removal.

Certainly many other techniques, each with advantages and disadvantages, exist for definitively treating distal radius fractures that occur in osteoporotic bone or that stem from high-energy insults. Closed reduction and percutaneous pinning, a minimally invasive technique that can be performed rapidly, provides some added stability compared to closed reduction alone. The stability added using percutaneous wires is not enough to allow for early weight-bearing or aggressive range of motion, however. External fixation, another option that can be used as a supplement to Kirschner (K)-wires or by itself to treat wrist fractures, has traditionally been implemented for severely comminuted distal radius fractures. It bypasses the injured segment and can provide a very rigid construct that may allow for early weight bearing (11,14–-16). However, the use of external fixation can be the source for many patient care problems and complications. Weber and Szabo noted complication rates ranging from 52% to 63% in comminuted wrist fractures treated with external fixation (17). Furthermore, the external pins not only add to the nursing burden by requiring multiple cleanings each day, but also increase the risk of local infection and fixator loosening (18,19). Pin tract infections and loosening may necessitate early removal of the external fixator, making difficult any long-term immobilization that may be desired for some high-energy injuries.

Most recently, the treatment of distal radius fractures has advanced rapidly with alternative implants and techniques devised specifically for comminuted wrist fractures in single extremity injuries. These innovative designs and techniques include fixed-angle plates and small plates and/or wire forms intended for fragment specific fixation (20,21). These new

FIGURE 1 (**A**) Anteroposterior radiograph demonstrating high-energy fracture to distal radius with severe comminution extending into the metaphyseal–diaphyseal region. (**B**) Lateral radiograph of the same injury.

implants are designed to be of low profile and to allow multiple points of fixation to help restore a stable, congruent articular surface. The thinness of the implants and the fact that many are designed for volar placement alleviate the problems with extensor tendon irritation and rupture seen frequently with bulkier implants placed dorsally (22,23). They are not without complications, however. Implant breakage, tendon irritation/rupture, loss of fixation, temporary paresthesias, and screw perforation into the articular surface are noted problems (20,24,25). Furthermore, these implants are not ideal for the multiple injured patients or the highly comminuted fractures with extension into the radial diaphysis. At this time, there is no evidence that these newer plates and/or wire forms can support the loads seen through the wrist in patients who require their upper extremities for transfers. Additionally, although the low-profile volar locking plates with multiple screw options are excellent for articular reconstruction, they are not designed to provide the compression or rigidity required to adequately treat a radial diaphyseal fracture (26,27). Severely comminuted osteoporotic fractures can also be problematic for these new devices. This stems from the fact that these implants cannot neutralize the compressive forces seen at the radiocarpal joint, which can quickly lead to collapse of the weakened subchondral bone around a screw, peg, or wire form.

The bridge plate, serving as an "internal fixator," has many biomechanical advantages that overcome the problems seen with other implants. In a study analyzing different external fixator configurations, Behrens et al. noted that the rigidity of a construct was directly proportional to the proximity of the longitudinal fixator bar to the bone and fracture site (28). Based on these findings, the bridge plate, with its direct contact to the radius and metacarpals, is the strongest possible fixator construct. Additionally, while eliminating the compressive forces seen at the radiocarpal joint, the bridge plate also serves as a dorsal buttress through its direct contact with the dorsal cortex. The importance of the dorsal contact between the plate and distal radius is underscored by a study from Bartosh and Saldana, showing that ligamentotaxis by itself was not a sufficient means for restoring palmar tilt (29).

INDICATIONS

There are many situations in which the bridge plate for the distal radius might be considered ideal. Current indications include (*i*) high-energy injuries in polytraumatized patients where early weight bearing on the upper extremities might be necessary for transfers; (*ii*) osteoporotic fractures with significant comminution that might lead to early collapse if the compressive forces at the wrist are not neutralized; (*iii*) high-energy fractures with extension into the metaphyseal–diaphyseal region of the distal radius; and (*iv*) fractures that would best be treated by bridging techniques in patients who simply refuse to accept external fixation as an option. Importantly, internal distraction or bridge plating of the distal radius is not merely a substitute for external fixators. Certainly, external fixators should still have a place in the wrist surgeon's repertoire, especially when there is significant soft tissue destruction and/or loss.

CONTRAINDICATIONS

The only true contraindication to bridge plating a distal radius is a patient who, because of other injuries, cannot safely tolerate the procedure. Two relative contraindications include (*i*) the presence of volar fracture fragments that do not reduce with

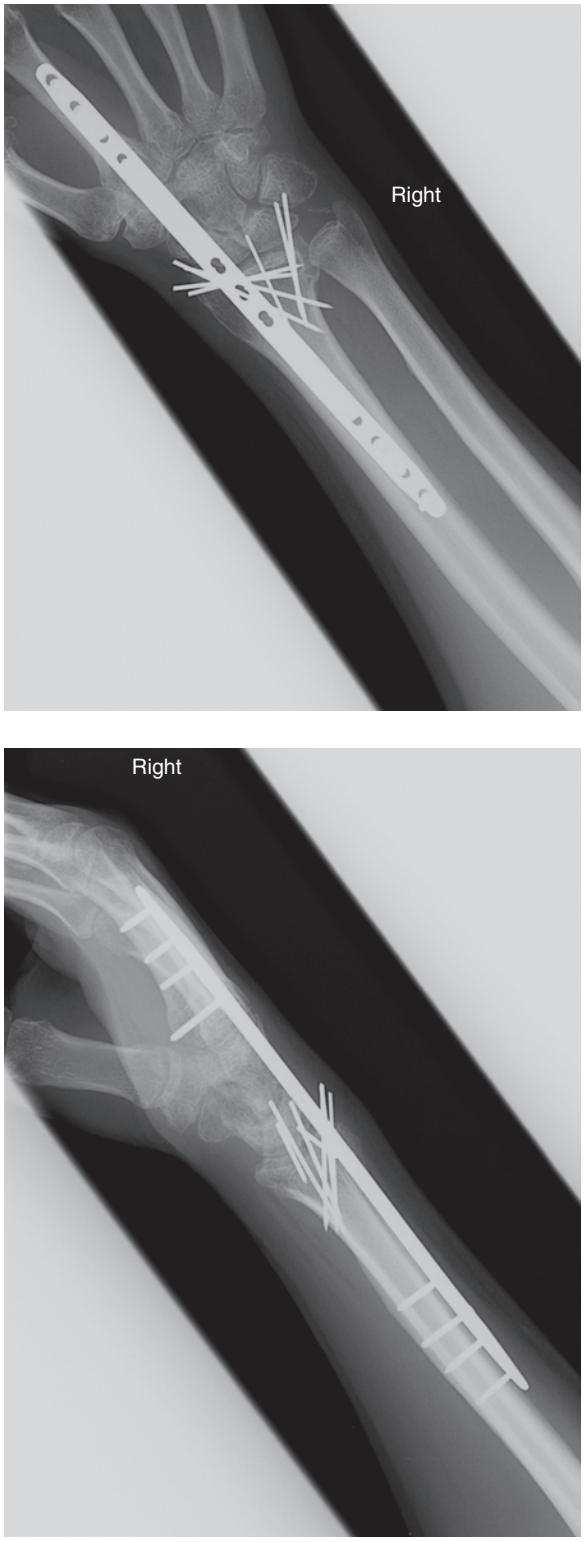

FIGURE 2 (**A**) Anteroposterior and (**B**) lateral X-rays demonstrating a comminuted distal radius fracture in a patient that sustained injuries to multiple extremities. Note the supplemental Kirschner wires providing subchondral support and stabilization for smaller fragments.

distraction (these types of injuries may be better served with a volar approach and plating techniques to secure the free fragments) and (*ii*) injuries that result in soft tissue loss that would leave the plate exposed.

PREOPERATIVE EVALUATION

As with any fracture of the distal radius, preoperative radiographic evaluation should include posteroanterior (PA), oblique, and lateral views. The PA view should be taken with the shoulder in neutral rotation and abducted 90°, elbow flexed 90°, and the forearm flat on the radiographic cassette. A true PA view is noted when the ulnar and radial styloids make up the far lateral and medial borders of the wrist on the X-ray (Fig. 3). The lateral view should be taken with the beam perpendicular to the long axis of the radial shaft. The quality of the lateral view can be assessed by the position of the pisiform relative to the distal pole of the scaphoid. In a true lateral view, the pisiform should overlap with the distal pole of the scaphoid. Any deviation from this suggests too much pronation or supination of the wrist (Fig. 4) (30). A computed tomography (CT) scan may be a useful adjunct in fractures where there is a suspected free intra-articular fragment. Typically, these fragments will not reduce with ligamentotaxis alone, and the CT can provide helpful information of fracture location, which can direct limited operative approaches to help restore joint congruity. With the fragment reduced, a spanning plate could be applied. Finally, any preoperative evaluation of a person with a high-energy fracture should include the person as a whole, realizing that the distal radius fracture may be a relatively minor part of the entire picture.

FIGURE 3 A true anteroposterior view of the wrist with the ulnar and radial styloids making up the outermost ulnar and radial portions on the radiograph.

FIGURE 4 A true lateral of the wrist with the pisiform overlying the distal pole of the scaphoid (*arrow*).

SURGICAL TECHNIQUE

3.5 mm ASIF Compression Plate

The patient is kept in the supine position and the affected arm is placed on a radiolucent arm board. A tourniquet is placed as high as possible on the arm. This technique, as first described by Ruch et al. (31), requires three incisions. The first incision, measuring approximately 4 cm in length, is made over the midshaft of the long finger metacarpal. The metacarpal is cleared of soft tissues while the extensor tendon is retracted and protected. A second incision, again measuring approximately 4 cm, is made over the dorsum of the distal aspect of the radius. Under fluoroscopic guidance, this incision should be placed at least 4 cm proximal to the proximal most aspect of the fracture. Blunt dissection should be carried down to the distal radius and care must be taken to avoid injury to the superficial branch of the radial nerve. After preparing the first two incisions, palpate Lister's tubercle and make a 2-cm incision directly over the bony landmark. Fully release the extensor pollicis longus (EPL) and retract it radially. Mobilizing the EPL facilitates both plate insertion and the application of bone graft for filling voids at the subchondral surface of the distal radius.

Plate selection should be based on the size of the patient and the proximal extent of the comminution of the distal radius fracture. Lay a 12-, 14-, 16-, or 20-hole 3.5-mm Association for the Study of Internal Fixation (ASIF) compression plate (Synthes, Paoli, Pennsylvania, U.S.A.) on the overlying skin of the wrist and use the C-arm to ensure that a minimum of three cortical screws can be placed proximal to the fracture. Starting at the distal incision direct the plate toward the proximal incisions over the distal radius. Ensure that the plate is applied beneath the extensor tendons but extra-articular to the carpus by visualizing the plate through the incision over Lister's tubercle. Once passed to the proximal most incision, recheck, through the middle incision, that impingement has not occurred between the plate and the EPL or digital extensors. At this time, the plate should be secured distally with a screw placed in the midline of the shaft of the metacarpal. Midline placement of screw ensures that the hand will not rotate in relation to the forearm when the plate is eventually secured to the radius.

Next, the radial length must be restored. Using manual traction under fluoroscopic guidance, apply a serrated clamp through the proximal incision to secure the plate to the radius once an appropriate length has been obtained. Prior to securing the proximal plate with screws, full rotation of the forearm should be confirmed. Furthermore, full passive motion of all the digits should be possible. If full flexion is not possible, then plate impingement on the extensor tendons is likely and extrinsic extensor tightness will occur if this is not resolved. Once the surgeon is assured of full motion, the plate can be secured proximally with screws. The remaining holes overlying the metacarpal can also be filled at this time.

With the plate in its final position and radial length restored, the surgeon can now direct attention to reducing the articular surface and restoring joint congruity. Any metaphyseal defects can be bone grafted through the incision made over Lister's tubercle. The bone graft will help elevate and buttress any articular fragments overlying the defects. Due to an increased risk of infection, bone grafting should not be performed in a grossly contaminated fracture or in injuries with soft tissue defects that preclude primary wound closure. Further buttressing of the lunate fossa can be provided with a 3.5-mm screw inserted through the mid-portion of the plate just under the subchondral bone of the lunate facet. Some fragments that require reduction may be too small for screw purchase. In this instance, 0.45 or 0.62 in. K-wires should be implemented to reduce and stabilize these fragments. This is often the case with the radial styloid and fragments from the intermediate column. Once satisfied with the placement of the plate and joint reduction, the surgeon needs to address the distal radioulnar joint (DRUJ). DRUJ stability should be checked in pronation, neutral, and supination, and compared with the contralateral side. If instability of the DRUJ is evident, then any large fractures of the ulnar styloid should be repaired and the forearm splinted in supination with some type of long-arm splint.

2.4 mm Mandibular Reconstruction Plate or Distal Radius Bridge Plate

Another technique, as described by Hanel et al. (32), utilizes either a 22-hole 2.4-mm mandibular reconstruction plate (Synthes) or a 2.4-mm distal radius bridge (DRB) plate (Synthes) (Fig. 5). In this method, the plate is applied under the second dorsal compartment and secured to the index finger metacarpal distally.

Similar to the prior technique, the patient is kept in the supine position and the affected extremity is centered on

a radiolucent arm board. Tourniquets can be used but are not necessary and are not currently implemented by the senior author (D.P.H.). Sterile mesh finger traps are applied to the index and middle fingers after the completion of prepping and draping. Using a rope and pulley system, 4.5 kg of longitudinal traction should be applied and an initial closed reduction performed (Fig. 6). After the initial setup is complete, a plate should be selected. Both plate systems allow for the placement of locked screws effectively making them fixed-angle devices. The mandibular plate has only threaded screw holes, while the DRB plate provides combination holes with both locked and non-locked options. The mandibular reconstruction plate is titanium, has scalloped edges, squared-off ends, and comes in a 12- or 20-hole size. The DRB plate is stainless steel and has tapered edges. It comes in one size, which is equivalent to the length of a 20-hole mandibular reconstruction plate.

Superimpose the chosen plate over the dorsal skin of the wrist in a line from the distal metaphyseal flare of the index metacarpal to the diaphysis of the radius (Fig. 7). Using fluoroscopic guidance, mark out incisions that are centered over the proximal and distal most four screw holes (Fig. 8). The plate should be of sufficient length to allow a minimum of three screws both distally and proximally. Depending on one's preference, the arm can be exsanguinated and the tourniquet inflated at this time or the skin can be infiltrated with 0.25% bupivicaine with epinephrine for hemostasis. The distal incision is made over the base of the second metacarpal and extends distally over the shaft for approximately 5 cm. The extensor tendons to the index finger should be retracted ulnarly and the insertions of the extensor carpi radialis longus (ECRL) and extensor carpi radialis brevis (ECRB) should be identified at their insertion points on the bases of the second and third metacarpals, respectively. A second incision is made proximal to the outcropper muscles (abductor pollicis longus, extensor pollicis brevis) of the forearm in line with the second dorsal compartment. Care must be taken to avoid injury to the superficial branch of the radial nerve as it pierces the fascia and traverses dorsally. The plate is inserted between the ECRL and ECRB tendons and gently passed under the outcroppers. Remaining extra-articular, the plate should be advanced until it is visualized in the distal incision. Occasionally, because of dorsal fracture fragments or soft tissue obstruction, it will be difficult to advance the plate past the carpus. In this case, a third incision can be made over Lister's tubercle to ease passage of the plate under direct vision. This incision can also be helpful with joint reduction and application of bone graft later in the case.

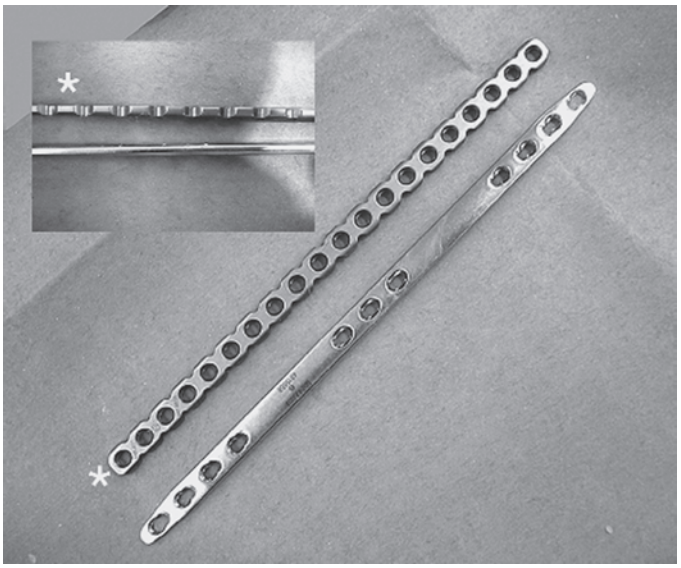

FIGURE 5 Two examples of available bridge plates for distal radius fractures. The titanium Arbeitsgemeinschaft für Osteosynthesefragen (AO) mandibular reconstruction plate (*) has blunted ends with scalloped edges. The AO distal radius bridge plate has tapered ends and beveled edges.

Once the plate is through to the distal incision, secure it to the shaft of the index metacarpal with a non-locking screw. Proper placement of a non-locked screw will effectively draw the plate to the bone, eliminating any gap formation that may occur between the plate and the bone if a locked screw is placed first (Fig. 9). Using the C-arm, confirm that radial length has been restored with the previously applied traction. If length has not been restored, the proximal aspect of the plate can be pushed distally in-line with the second metacarpal. With the length appropriately restored, clamp the plate to the radial shaft to secure its position. As with the metacarpal, insert a non-locked screw into the proximal most hole of the plate. The remaining holes are filled with fully threaded, 2.4 mm bicortical locking screws.

Frequently, the combination of traction and dorsal plate placement restores radial length, volar tilt, and radial inclination. However, there are times when supplemental fracture work must be undertaken after the spanning plate is applied. In these cases, articular fragments can be elevated and defects bone grafted through the incision located over Lister's tubercle (Fig. 10). Most intercarpal injuries can also be addressed through this same incision. Percutaneous K-wires along with screws placed through the mid-portion of the plate overlying the distal radius can be implemented to augment fracture fixation and stability. Any unstable volar shear or volar medial fragments must be buttressed through a separate volar incision.

Prior to completion of the surgery, the DRUJ should be inspected for any signs of instability. Volar and dorsal excursion of the distal ulna in relation to the distal radius should be checked in neutral, pronated, and supinated positions. Attempts at reconstructing the triangular fibrocartilage complex or stabilizing ulnar styloid fractures should be undertaken if the DRUJ is indeed found to be unstable and the patient's condition allows. Patients who cannot tolerate prolonged procedures should have the ulna pinned directly to the radius just proximal to the DRUJ with two 0.62 in. K-wires.

■ POSTOPERATIVE PROTOCOL/REHABILITATION

Patients without DRUJ instability should be splinted postoperatively for approximately 10 to 14 days to allow soft tissue healing. Our standard protocol is to place the patient in a long-arm plaster splint, but a forearm-based splint is acceptable for the compliant patient. Immediately postoperatively, both active and passive finger range of motion is started. Furthermore, the patient is allowed to bear weight through the forearm and elbow as needed for transfers and ambulation with a platform crutch. Lifting and carrying is allowed in the immediate postoperative period but is limited to 4.5 kg until the fracture has healed radiographically.

At the 10- to 14-day mark, forearm rotation and DRUJ stability are once again assessed. Splints are discontinued altogether if forearm rotation is achieved with little effort and the DRUJ is stable. Patients are allowed to begin gentle axial loading of the wrist at this time. This axial loading is advanced at the one-month mark and patients are permitted to

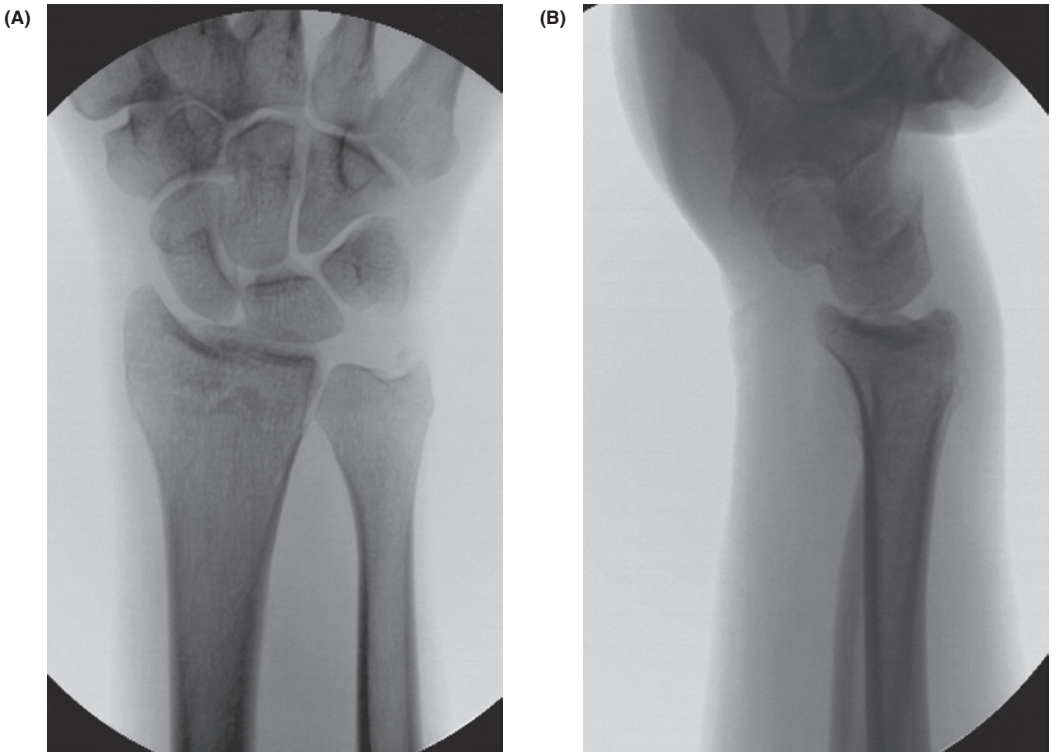

FIGURE 6 (**A**) Anteroposterior and (**B**) lateral intraoperative radiographs demonstrating the initial reduction obtained for a comminuted intra-articular distal radius fracture utilizing traction and ligamentotaxis.

discontinue the platform attachment and begin weight bearing through the handgrip of their crutch.

If at the 10- to 14-day mark, the patient has difficulty with supination or the DRUJ was repaired at the time of the initial surgery, the patient is placed in a removable long-arm splint. This splint is fabricated in our occupational therapy department. The splint holds the forearm supinated and can be removed for showering and range of motion exercises. The splint is continued for an additional three weeks or until five weeks postoperatively. Patients who required pins across their DRUJ have the pins removed at the three- to six-week mark and are kept in a removable long-arm splint for an additional two weeks. The timing for pin removal is based on the amount of DRUJ instability noted at the time of the index procedure.

If supplemental K-wires were left outside of the skin, they should be removed at six weeks postoperatively. If the K-wires have been cut short and left under the skin, they can be removed at the time the spanning plate is removed assuming that they are not irritating the patient excessively. Generally, the spanning plate can be removed between three and four months postoperatively when the fracture has healed both clinically and radiographically. After plate removal, hand therapy should focus on strengthening and regaining wrist flexion and extension.

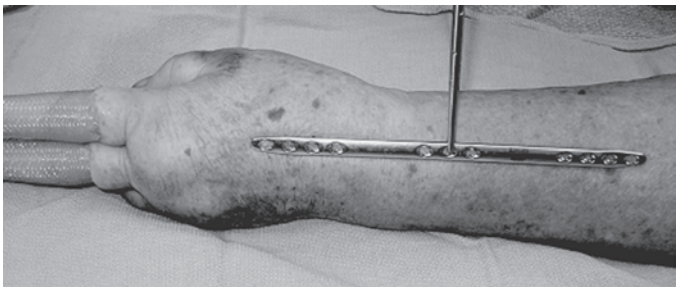

FIGURE 7 Intraoperative photograph demonstrating how a bridge plate can be superimposed over the wrist to help mark out incisions. Note the sterile finger traps on the index and middle fingers.

■ COMPLICATIONS AND THEIR MANAGEMENT

Complications with this technique are generally few. As with any surgery, infection is always a concern. However, up to this point, reported infections have only been superficial and responsive to antibiotics. There have been no cases of osteomyelitis. Three patients reportedly had an extension lag of 15° in the long finger after plate placement (31). Ultimately, in every case, the extension lag improved to less than 10° after plate removal. Two other reported complications include a broken plate and rupture of an ECRL (32). Both complications occurred in a commercial fisherman who did not return to have his plate removed in a timely manner. The patient returned at 19 months after his initial surgery with broken hardware. At the time of plate removal, the ECRL rupture was noted and treated with a tenodesis to the ECRB. Anecdotally, we have seen a fracture in the second metacarpal just distal to a bridge plate. The fracture occurred in a very osteoporotic female who fell approximately two months after plate placement. The minimally displaced fracture was treated with splinting and went on to heal uneventfully.

■ OUTCOMES

Several studies have validated internal distraction plating as an excellent tool in the armamentarium for treatment of distal

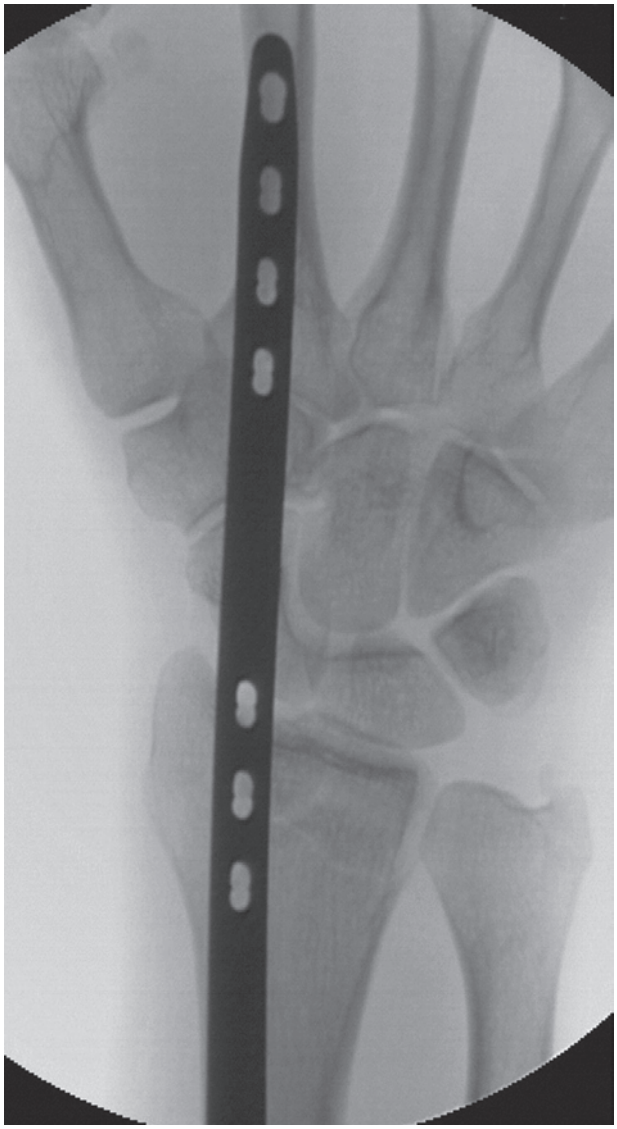

FIGURE 8 X-ray demonstrating the use of fluoroscopy and the superimposed bridge plate to help with incision placement.

FIGURE 9 Intraoperative X-ray illustrating the use of a non-locked screw to secure the plate distally. Using a non-locked screw helps draw the bone to the plate. Once locked screws are placed the plate is essentially fixed in space.

radius fractures. Shortly after Burke and Singer (9) demonstrated the technique of bridge plating, Becton et al. described their own method implementing a specialized plate designed to simplify extra-articular insertion (33). Their technique involved application of the plate under the second dorsal compartment from the distal radius to the index metacarpal. Although their plate cannot be converted into a fixed-angle device and it is too short for use in fractures with meta-diaphyseal extension, they reported good results in 35 patients. All fractures united by eight weeks and they had no extensor tendon ruptures or chronic regional pain syndromes (CRPS). Their two complications included loosening of metacarpal-sided screws and an index finger metacarpal fracture through a screw hole. The radius fractures in these two patients went on to heal uneventfully.

In 2005 Ruch et al. reported on their technique for spanning distal radius fractures with a 3.5-mm ASIF compression plate (31). The study included 22 patients with high-energy injuries that had extension into the metaphyseal–diaphyseal portion of the distal radius. Plates were applied under the fourth dorsal compartment from the distal radius to the metacarpal of the long finger. The average time to fracture healing was 110 days and there were no nonunions. At six months, patients averaged 57°/65° of flexion and extension and 77°/76° of pronation and supination, respectively. At the one-year follow-up, 14 patients were rated as excellent, 6 as good, and 2 as fair according to the Gartland and Werley rating system for distal radius fractures (34). At an average of 24.8 months from surgery, DASH scores averaged 11.5 (35). Complications were few and included three postoperative infections in patients with open fractures and three mild extensor lags of the long finger that were noted to be less than 10° at the final follow-up. There were no tendon ruptures, loss of reduction, or refracture after plate removal.

Utilizing either 2.4 mm titanium mandibular reconstruction plates (Synthes) or 2.4 mm stainless steel DRB plates, Hanel et al. reported their results for 62 patients who required spanning of their distal radius fractures (32). Plates in this study were passed under the second dorsal compartment and affixed to the shaft of the distal third of the radius and second

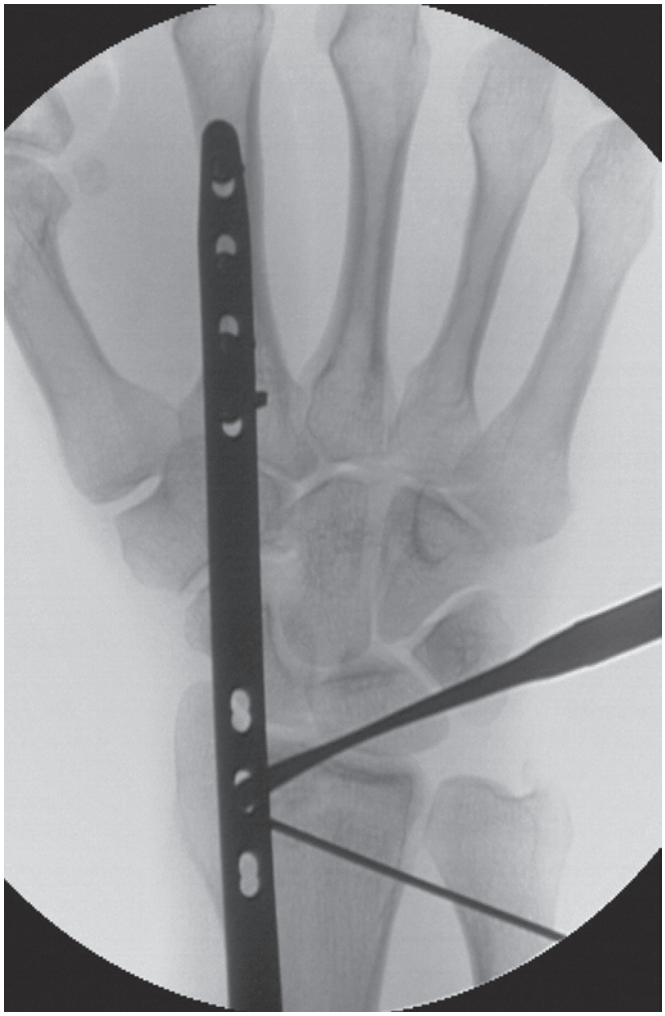

FIGURE 10 X-ray demonstrating elevation of articular fragments through a dorsal incision located over Lister's tubercle. After the fragments are elevated bone graft should be used for support. The bone graft can be supplemented with screws and/or Kirschner wires and/or small plates.

metacarpal utilizing locking screw technology. All the fractures went on to heal prior to plate removal, which averaged 112 days postoperatively. One patient broke his plate 16 months after implantation. He was a commercial fisherman in Alaska who returned to work with his plate in place. He returned at 19 months postoperatively for plate removal and has since returned to work. Of the 62 patients, 41 returned to their previous occupation. It should be noted that 8 of the remaining 21 patients were unemployed prior to their injuries. Of the 21 patients, who did not return to their prior employment, 13 sustained multiple injuries necessitating drastic lifestyle changes. No cases of postoperative CRPS or finger stiffness were noted in this study.

In unpublished data, Wolf et al. (36) assessed the rigidity of locking bridge plates in a cadaver model of unstable distal radius fractures. They also compared this information to the biomechanical stability of external fixators in the same fracture model. The authors utilized 2.4 mm spanning plates on 10 specimens with 1 cm of the distal radius removed to simulate an unstable situation. Importantly, it was noted that locking internal bridge plates with either four or three screws both distally and proximally were significantly more rigid than standard external fixation ($p < 0.05$). Furthermore, there was no statistical difference in stability between those osteotomies stabilized with four screws both proximally and distally versus those secured with a three screws on either side of the simulated fracture.

SUMMARY

The spanning internal distraction plate is a useful tool for many distal radius fractures and it should have a role in any wrist surgeon's armamentarium. As an internal fixator this method has many biomechanical and practical advantages to a standard external fixator. Furthermore, bridge plating with its ease of application, inherent stability, and need for minimal postoperative care, make it an ideal method of distal radius fixation in patients with multiple extremity injuries and/or poor bone stock.

SUMMATION POINTS

Indications

- High-energy injuries in polytraumatized patients who require weight bearing through the upper extremities for transfers.
- Osteoporotic fractures, with comminution, that require neutralization of the forces across the wrist.
- High-energy injuries with extension into the metadiaphyseal region.
- Fractures requiring bridging techniques in patients who refuse external fixation.

Contraindications (Relative)

- Volar fracture fragments that will not reduce with ligamentotaxis.
- Dorsal soft tissue loss that would result in plate exposure.

Outcomes

- Average fracture healing times ranged from 60 to 110 days.
- Majority of patients are able to return to previous work: 41 of 62 in one study.
- Average motion at six months postoperatively was 57°/65° of flexion/extension and 77°/76° of pronation/supination.

Complications

- Infrequent
- Extension lag of long finger
- Broken hardware
- Superficial infection
- ECRL rupture

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Minimally Invasive Treatment of Distal Radius Fractures with the MICRONAIL

Virak Tan and John T. Capo
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Fractures of the distal radius are common injuries. The extensive varieties of fracture patterns and patient populations in which they occur have led to the development of numerous treatment strategies. The treatment options include cast immobilization, percutaneous pinning (1), external fixation (2–4), internal fixation with plates (5–16), and a combination thereof (17,18). Management is based on the fracture pattern, degree of displacement, other associated injuries, and the individual patient's needs and demands. Internal fixation of these fractures has grown in popularity with the recognition of the importance of stable fixation and early motion of the involved extremity (19).

Although open reduction and internal fixation with metal implants on the surface of the distal radius has allowed better reduction of the fracture fragments and in many cases offer more secure fixation (5–16), it demands more extensive surgical exposure and soft-tissue stripping. Furthermore, hardware problems such as hardware prominence and tendon irritation, can occur in times which often lead to removal of the implant (7,8,11,12,15,16,19). The MICRONAIL (Wright Medical Technology, Inc., Arlington, Tennessee, U.S.A.) is an intramedullary (IM) device that was designed specifically to provide stable support of distal radius fractures while minimizing soft-tissue complications that can occur with internal and external fixation implants (Fig. 1). The implant utilizes the principles of load sharing, subchondral screw divergence, and locked fixed-angle fixation. It is inserted through a small skin incision at the radial styloid and does not further devascularize the fracture fragments. The limited surgical dissection and rigid fracture fixation allow for minimal postoperative immobilization and an early return of function.

INDICATIONS

Overall, the indications for MICRONAIL use are generally the same as for other distal radius fixation methods. Specific indications for the MICRONAIL include distal radial metaphyseal fractures (*i*) where casting or external fixation is not tolerated by the patient, (*ii*) when reduction cannot be maintained by closed means, or (*iii*) where early motion and return to function is essential. Fracture patterns that are amenable to this form of fixation include extra-articular fractures (AO Types 1B, 1C) (20), intra-articular fractures with large fragments that can be adequately reduced with closed or percutaneous methods (AO Types B2, B3, C1, and C2), and distal radial metaphyseal malunions.

Fractures with multiple comminuted articular fragments (AO Type C3) may not be suitable for MICRONAIL stabilization alone and may require supplemental fragment-specific fixation. Other contraindications may include medical comorbidities, patient refusal to undergo surgery, and active local infection.

PREOPERATIVE PLANNING

The evaluation of a distal radius fracture is straightforward and is based on the history, physical examination, and imaging studies. Important considerations in the history include age, hand-dominance, occupation/vocation, and mechanism of injury. Associated injuries in other areas of the body should be ruled out when there is a high-energy mechanism. Examination of the injured arm should include the elbow and forearm in addition to the carpus, distal radius, and distal radioulnar joint (DRUJ). Palpation may elicit tenderness about the scaphoid, scapholunate interval, or distal ulna. Careful neurovascular examination must be performed with attention to the median nerve, as acute carpal tunnel syndrome may develop with displaced distal radius fractures (21–23). If there is an associated operative injury about the wrist, it may need to be addressed at the same time of the distal radius fixation.

Initial imaging studies should include orthogonal radiographs of all involved areas. For isolated injuries of the distal radius, the index radiographs should consist of posterior–anterior, lateral, and oblique views centered over the wrist. Additional studies such as post-reduction radiographs and computed tomography scans may be obtained for better visualization of comminution or articular involvement. Traction X-rays are useful to determine the stability of the fracture pattern and whether it is amendable to MICRONAIL fixation.

SURGICAL TECHNIQUE

The surgical technique starts with a standard preparation of the arm for wrist for surgery (24). An image intensifier is used to confirm that a near-anatomic reduction is achievable by closed manipulation. After the tourniquet is inflated, a 2 to 3 cm longitudinal incision centered over the radial styloid is made in the skin (Fig. 2). Blunt dissection is performed through the subcutaneous tissue and branches of the radial sensory nerve are retracted from the surgical field. Dissection is then carried down to the periosteum between the first and second dorsal extensor compartments. The periosteum is elevated and retracted. The fracture is provisionally reduced and stabilized with Kirschner wires (K-wires) as needed (Fig. 3). In cases where there are large articular fragments, especially on the ulnar corner, temporary placement of K-wires may help maintain the reduction. Using a cannulated drill, cortical window is made at the tip of the radial styloid 2 to 3 mm proximal to the radioscaphoid joint line (Fig. 4). The starter awl is then introduced into the radial styloid in a retrograde fashion under fluoroscopic guidance (Fig. 5). The fracture should be held in a reduced position as the awl is advanced into the metaphysis.

The awl is removed and broaching of the bone is begun. With the aid of an image intensifier, the broach is guided across the fracture site and advanced proximally into the

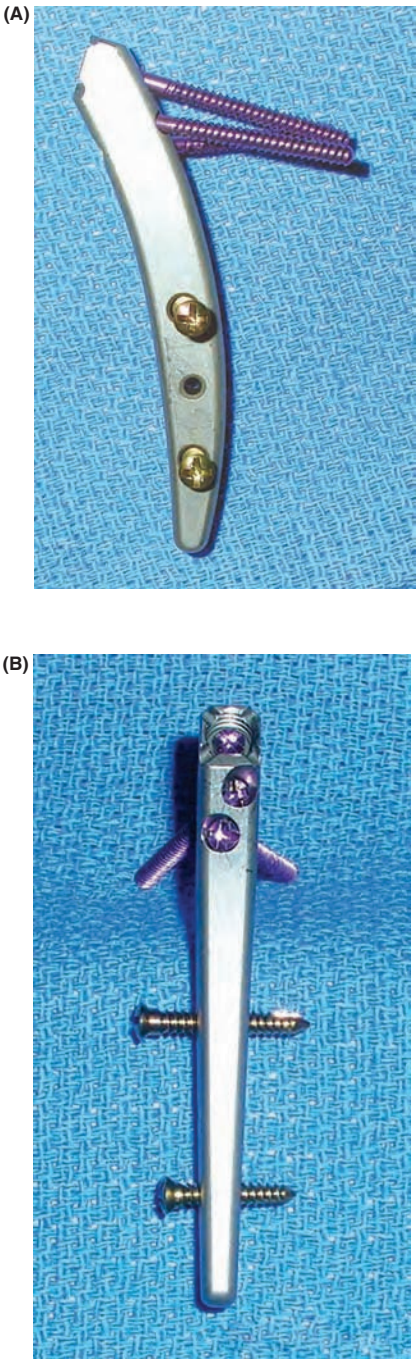

FIGURE 1 Photographs of the MICRONAIL. (**A**) Frontal view and (**B**) side view. *Source*: Courtesy of Virak Tan, MD.

metaphyseal–diaphyseal bone (Fig. 6) by gently tapping the end with a small mallet. It is critical at this step to stay radial in the canal in order to avoid penetrating the ulnar cortex of the radial shaft. Sequential broaching is then done to the point where the broach does not spin within the medullary canal, using 2-finger pressure. Care should be taken to avoid "over-rotating" during the broaching. The broach should be inserted to the level of the shoulder of the broach, to ensure proper depth below the radial cortex. Once the bone has been broached to the appropriate size, the actual implant, attached to the insertion jig, is advanced into the bone until it is countersunk within the radial styloid. Position of the MICRONAIL should be confirmed with the image

FIGURE 2 Marking for incision over radial styloid (*arrow*), between the first and second dorsal compartments, for the entry point. The other marking (*dorsal*) is for placement of the proximal interlocking screws. *Source*: Courtesy of Virak Tan, MD.

intensifier. Satisfactory depth of insertion can be determined by inserting a K-wire through the most distal hole of the device. The wire should pass within the subchondral bone, approximately 2 mm proximal to the articular surface. The distal locking buttress screws are now inserted after drilling through the guides on the jig, thereby locking the distal bone fragment to the nail. These screws also lock into the nail, creating a fixed-angle device.

Attention is turned to placement of the proximal interlocking screws. Minor adjustments in radial length and inclination can be done at this time. Temporary K-wires can be

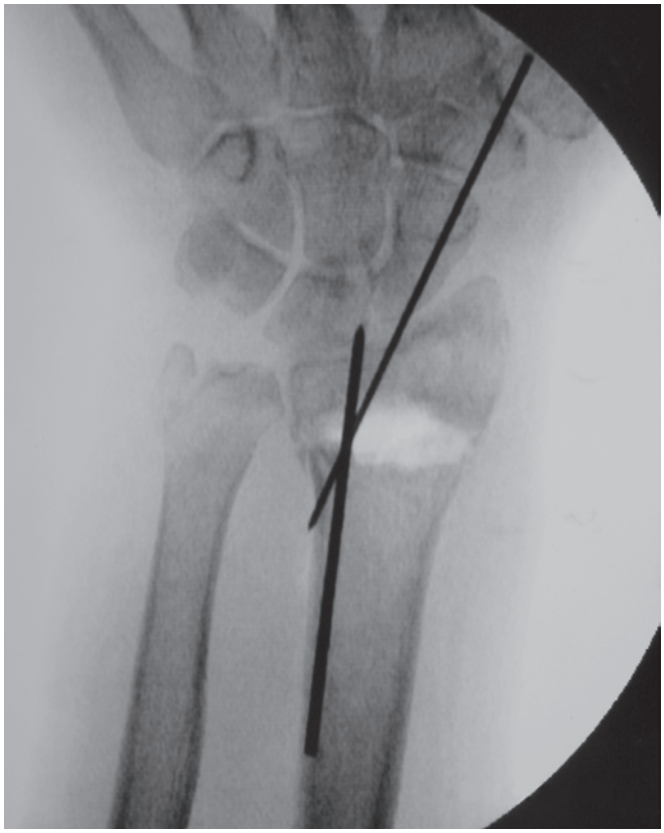

FIGURE 3 Intraoperative posteroanterior fluoroscopic view of provisional stabilization of a distal radius fracture with K-wires wires. The K-wires are placed so that there is no obstruction to the path of the MICRONAIL. *Abbreviations*: K-wires, Kirschner-wires. *Source*: Courtesy of Virak Tan, MD.

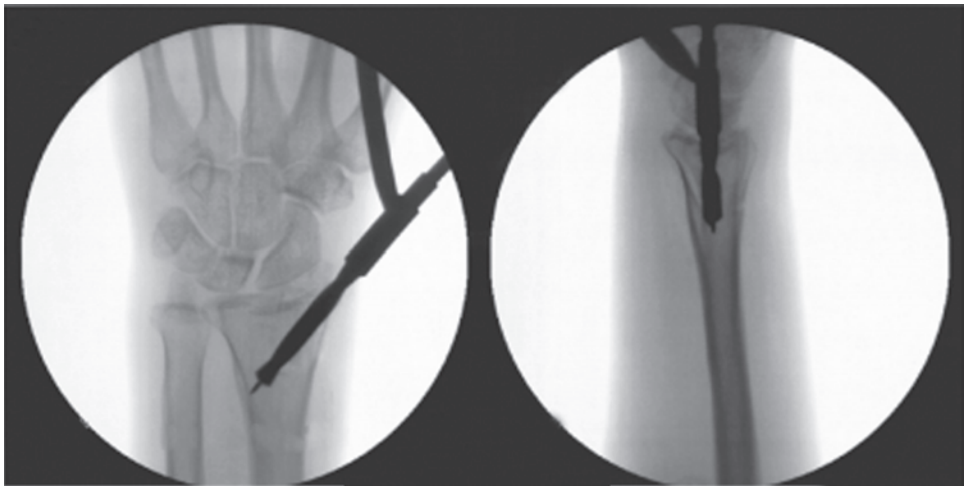

FIGURE 4 Intraoperative posteroanterior and lateral fluoroscopic views of a cannulated drill that is used to create a cortical window at the radial styloid, 2 to 3 mm proximal to the radioscaphoid joint line. This can be done under hand power. *Source*: Courtesy of Virak Tan, MD.

inserted through the jig and into the proximal fracture fragment to maintain the final reduction. The proximal interlocking screws are placed through a single 2 to 3 cm longitudinal incision on the dorsum of the wrist, using the guide and sleeve provided. These bicortical interlocking screws secure the distal fragment-nail construct to the shaft fragment. After the jig is disassembled, final fluoroscopic images confirm the position of the implant and the alignment of the fracture. The tourniquet is deflated, the wounds are irrigated, and the skin is closed.

Postoperatively, for AO fracture types A2, A3, B2, B3, and C1 no splinting is necessary; For AO types C2 and C3, the wrist is splinted for two to four weeks. Finger motion is started immediately. Patients may perform home exercises with active finger (and wrist motion if not splinted) as tolerated. At two to four weeks, any splint use is discontinued and home therapy is progressed. The decision for formal supervised hand therapy is individualized and based on the patient's progress.

Case Example

The patient is an 82-year-old right hand dominant female with a history of poor vision and difficulty ambulating, who fell on her outstretched right hand. She was found to have a displaced intra-articular AO Type C2 fracture with an associated ulnar styloid fracture (Fig. 7). Closed reduction was performed in the emergency room and a sugar-tong splint applied. Post-reduction X-rays showed incomplete restoration of the radial length and dorsal comminution in the metaphyseal bone. A decision was made to perform operative stabilization of the fracture in order to minimize her dysfunction and disability.

After medical clearance, she underwent MICRONAIL fixation of the distal radius three days after her injury (Fig. 8). The ulnar-sided dorsal fragment was percutaneously reduced and provisional stabilized with a K-wire before instrumenting for the MICRONAIL. After fixation, testing of the DRUJ showed

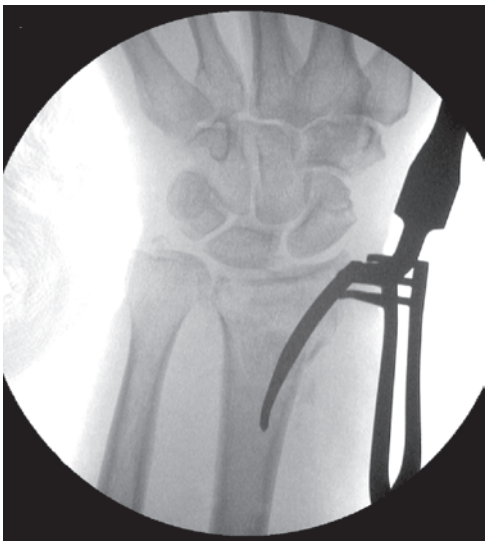

FIGURE 5 The starter awl is introduced through the cortical window at the radial styloid in a retrograde fashion under fluoroscopic guidance. It is guided across the fracture site with the fracture in a reduced position. *Source*: Courtesy of Virak Tan, MD.

FIGURE 6 The broaching of the canal is done by gently tapping the end with a small mallet. Adequate broaching is achieved when the broach is fully seated within the canal and it does not toggle with "2-finger pressure". *Source*: Courtesy of Virak Tan, MD.

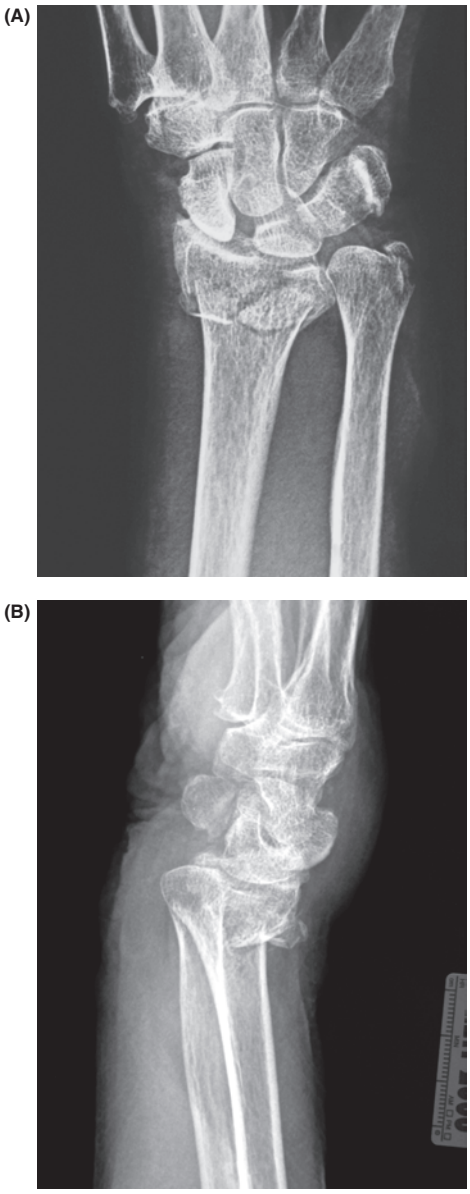

FIGURE 7 Injury radiographs, (**A**) posteroanterior view and (**B**) lateral views of a displaced intra-articular AO Type C2 fracture with an associated ulnar styloid fracture in an 82-year-old woman. *Source*: Courtesy of Virak Tan, MD.

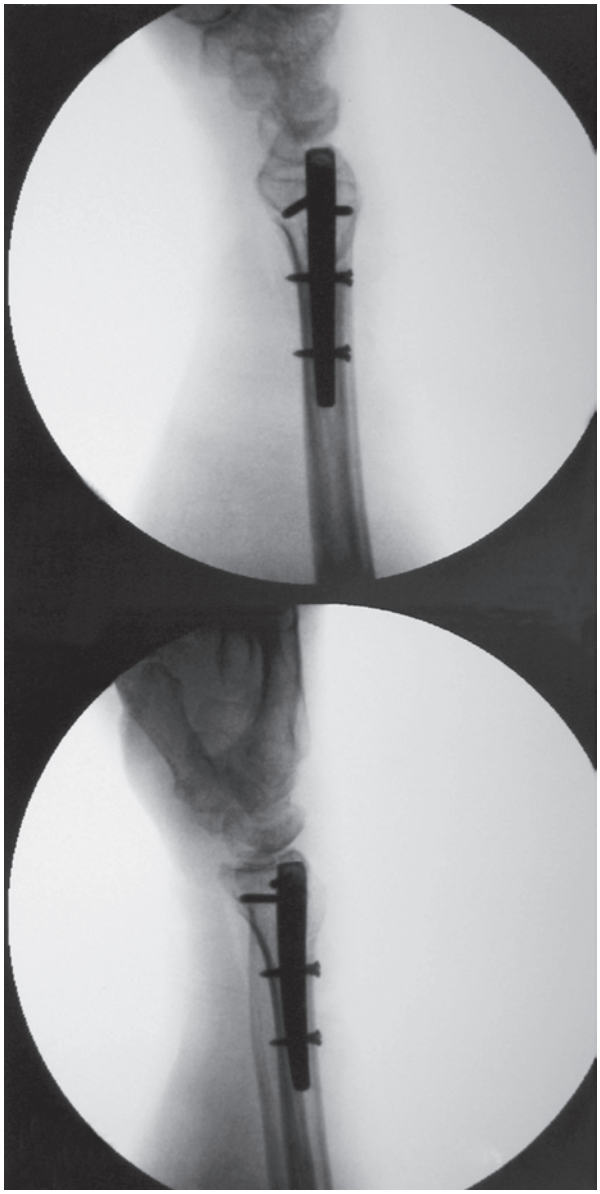

FIGURE 8 (*Top*) Intraoperative image intensifier lateral view and (*Bottom*) fossa lateral views, showing restoration of the volar tilt and establishment of articular congruity. *Source*: Courtesy of Virak Tan, MD.

no instability and the ulnar styloid was not displaced; therefore, the ulnar styloid was left alone. The incidental finding of a scapholunate interval widening was left alone because of the patient's advanced age and no prior history of wrist pain. Postoperatively, a splint was not used and the patient was discharged home the same day.

The patient did not require (or desire) formal therapy. At eight weeks postoperation, she had no wrist pain and reported being back to her baseline level of function. Radiographs showed a healed distal radius fracture with no intra-articular step-off (Fig. 9). Examination showed an active wrist range of motion of 45° of flexion to 75° of extension; 20° and 30° of radial and ulnar deviation, respectively and full forearm rotation (Fig. 10). Her grip strength was 25 lb (76% of the uninjured side) and she was able to lift a 5-lb dumbbell. She was pleased with the outcome.

■ COMPLICATIONS

Similar to other methods of distal radius fracture fixation, one of the complications that can occur is loss of reduction. There are two reasons why this can happen with the MICRONAIL. First, it has been too far proximally and the distal locking buttress screws are more than 2 mm from the joint line. In such an instance, distal fragment can settle until the subchondral bone come to rest against the screws. The second reason is inadequate fixation of an intra-articular fragment, which can redisplace in the postoperative period. This potential pitfall must be recognized during the operative procedure so that K-wire(s) or small buttress plate(s) may be used as supplemental fixation.

Transient dorsal radial sensory nerve irritation has been reported with the MICRONAIL. Because this sensory nerve courses within the operative field at the radial styloid, excessive retraction or inadvertent surgical trauma can result in sensory

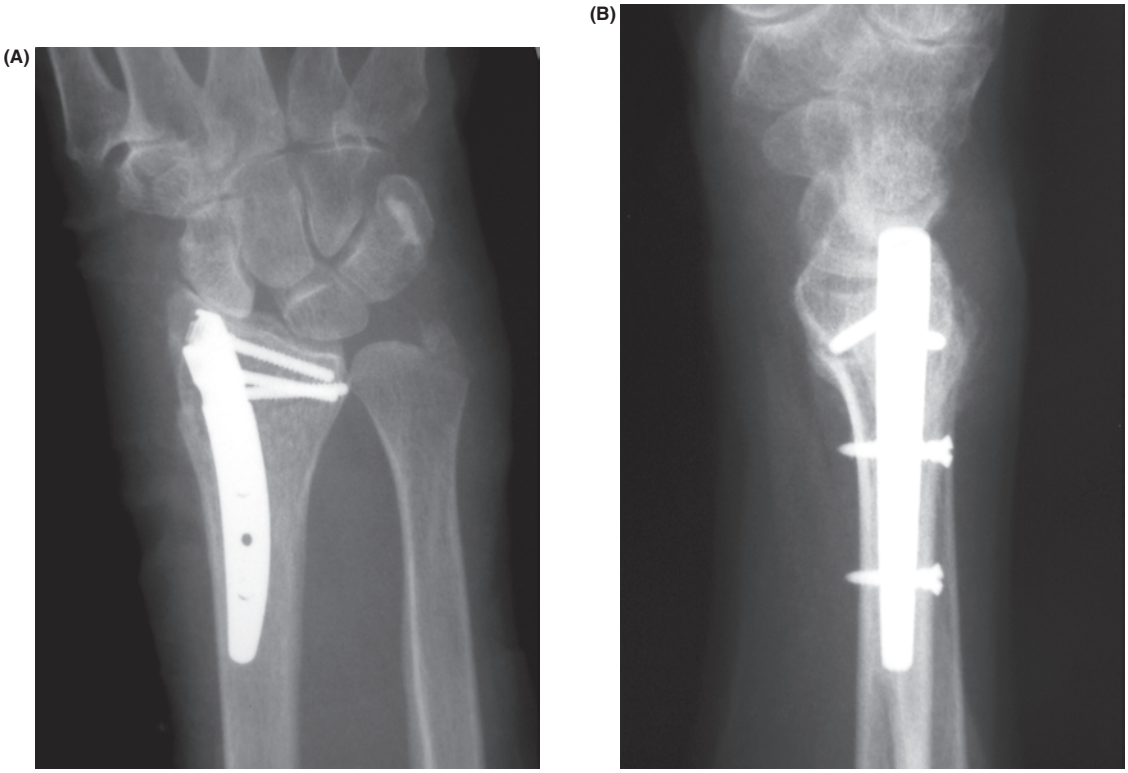

FIGURE 9 Postoperative radiographs (**A**) PA view and (**B**) lateral views at eight weeks status/post MICRONAIL fixation. *Source*: Courtesy of Virak Tan, MD.

disturbance in the hand. The surgeon should be comfortable with the anatomy and mobilization of nerve, which can be bluntly dissected and gently retracted dorsally.

A complication that has not been reported but has the potential to cause problems is placement of excessively long screws, especially distally. Screw penetration into the DRUJ and radiocarpal joint is avoided by fluoroscopic confirmation of screw length and position. If the most distal screw enters the radiocarpal joint, the implant can be seated more proximally.

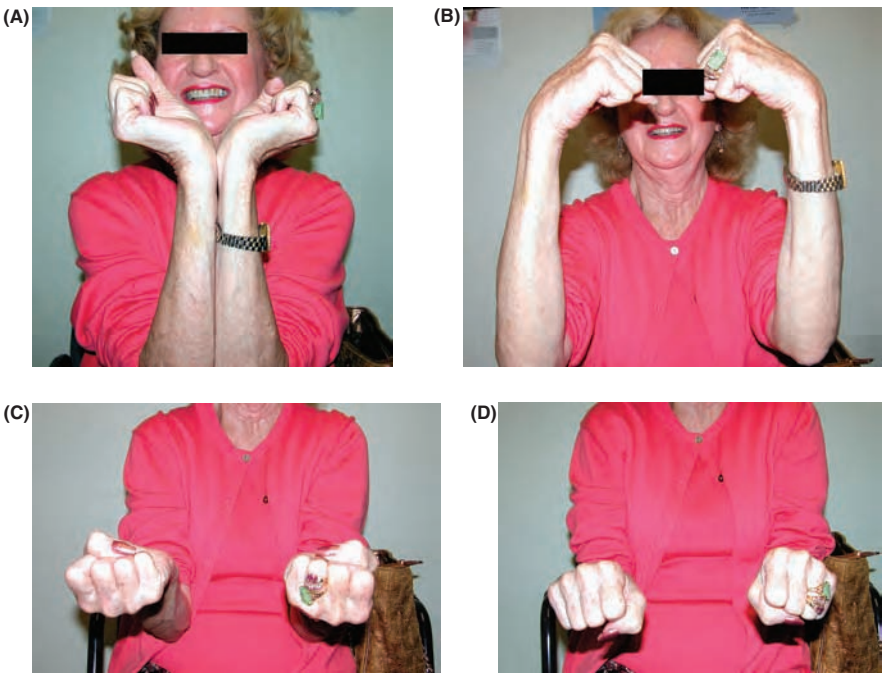

FIGURE 10 Clinical photographs of the patient in Figure 7 at eight weeks after fixation with the MICRONAIL. *Source*: Courtesy of Virak Tan, MD.

OUTCOMES

In 2005, we reported our early experience with the MICRONAIL (25). A prospective analysis of 23 consecutive patients was performed. The mean age of the group was 59 years (range 31–83). Overall outcome regarding patient satisfaction, residual pain and activity levels, and radiographic measurements were highly satisfactory even at the early time points. At two months post-op, active wrist motions were: Flexion 38°, extension 53°, radial deviation 16°, ulnar deviation 24°, supination 73°, and pronation 79°. Grip strength was 46% of the uninjured side. At the six-month follow-up, the motion continued to improve and the average grip strength increased to 80% of the opposite side. Radiographic assessment showed an average volar tilt of 5°, radial inclination of 21°, ulnar variance of 0°, and radial height of 12 mm. There was one failure in the group (loss of reduction) but no implant had to be removed for soft-tissue complication.

In unpublished data, one of us (VT) followed 13 patients to the one year mark. The average active ranges of motion for these patients were: wrist flexion 55°, wrist extension 68°, radial deviation 20°, ulnar deviation 33°, pronation 87°, and supination 82°. Final radiographs showed radial inclination of 22°, radial height of 11 mm, ulnar variance of 0 mm, volar tilt of 4°. Grip strength was 86% of the uninjured side and the Disability of the Arm, Shoulder and Hand score was 4 (range 0–16).

SUMMARY

The MICRONAIL is an IM implant that can be inserted by minimally invasive techniques and allow for secure internal fixation of unstable distal radius fractures. A future direction of this technique includes development of complementary adjunct methods for stabilizing AO Type C3 fractures. Indications for the MICRONAIL include:

- Unstable extra-articular fractures (AO Types A2 and A3)
- Displaced intra-articular fractures that can be reduced by closed or percutaneous manipulation (AO Types B2, B3, C1, and C2)
- Fractures that are redisplaced with casting, pinning, or external fixation
- Distal radius malunions (see chap. 24)

The advantages of MICRONAIL fixation compared to open plating of distal radius fractures are:

- Minimal surgical dissection
- No soft-tissue stripping of the fracture fragments
- No prominence of hardware
- Early return of range of motion, grip strength, and function.

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Dorsal Nail Plate Fixation for Distal Radius Fractures

Jorge L. Orbay and Amel Touhami
Miami Hand Center, Miami, Florida, U.S.A.

INTRODUCTION

The treatment of distal radius fractures has evolved as a variety of management techniques have been introduced. These include closed reduction and immobilization with splints or casts (1–3), extrafocal or intrafocal percutaneous pinning (4–8), external fixation (9–14), and different methods of internal fixation (15–19). Nonetheless, fixation failure in osteoporotic bone, poor reduction, and reflex sympathetic dystrophy remain a concern for all techniques (20–24). Open reduction and internal fixation performed by various methods has recently gained acceptance, especially when stable reduction cannot be achieved by manipulative means. Conventional buttress plate fixation, however, has proven inadequate for the majority of dorsal injuries due to poor fixation and frequent soft tissue complications (25–29). For these reasons, fixed-angle internal fixation through a dorsal or volar approach has been advocated. The latter presents the advantage of avoiding extensor tendon dysfunction (30,31). Most importantly, with fixed-angle fixation, early range of motion can be initiated promptly even in patients with poor bone stock (32,33).

Because plate application often requires substantial surgical dissection and many distal radius fractures are easily reduced by closed manipulation; therefore, a method of minimally invasive fixed-angle fixation is desirable. A narrow intrafocal fixed-angle nail–plate, the Dorsal Nail Plate Anatomic (DNP-A™; Hand Innovations DePuy, Miami, Florida, U.S.A.), has been developed for this purpose. It is inserted through a small dorsal incision after closed or open reduction of the fracture is achieved. Trauma to the extensor tendons is minimized by avoiding dissection of all but the third extensor compartment and by transposing the extensor pollicis longus (EPL) tendon into a subcutaneous position and utilizing the floor of its sheath as the site of implant application. This technique has proven in practice to be a simple and effective method of fixation for extra-articular fractures, particularly in patients with significant comorbidities.

INDICATIONS

Specific Diagnoses

The decision to proceed with minimally invasive dorsal nail plating is based upon a combination of factors: patient's age, general medical condition, fracture type, stability, and the functional impact of the injury. We prefer this procedure for patients over 60 years of age, as osteoporosis becomes prevalent and simple pinning is often insufficient fixation. Conversely, these patients commonly present simple fracture patterns (AO types: A2 and A3) that can be easily reduced and fixed without extensive dissection. The direct subchondral support provided by the fixed-angle pegs in the DNP effectively prevents settling or secondary loss of reduction. From a radiological standpoint, fracture instability is defined as loss of initial reduction with radiographic evidence of any of the following: more than 20° of angulation in any plane, displacement greater than two-thirds the width of the shaft, shortening greater than 5 mm, and associated distal ulnar fracture. The latter, if present, further increases instability and can therefore be an indication for a concomitant internal fixation. However, these criteria are not absolute and other clinical factors should be taken into consideration before proceeding with surgery. Extra-articular fractures that have displaced after nonoperative treatment can be salvaged by this method if treated before callus formation becomes excessive. Fractures with nondisplaced articular lines can also be good indications. In general, unstable extra-articular distal radius fractures in active elderly patients are the best indications for this form of treatment.

Contraindications

Contraindications to the procedure include severe articular comminution and displacement, comminution that extends into the diaphyseal portion of the radius and advanced nascent malunions, or inveterate fractures with extensive callus formation. General factors contraindicating surgical repair are active or latent infection, inadequate soft tissue coverage, and an unreliable patient. Low demand patients with severe deformity but stable impacted fracture patterns, which do not present pain or functional loss, usually do not benefit from surgical treatment.

This procedure may be contraindicated in severe medical conditions such as immunosuppression, bleeding disorders, and septicemia. Cardiopulmonary failure can also be a contraindication.

Indications When Compared with Similar Open Techniques

This technique is preferred for extra-articular fractures in the compromised patient because it requires only modest dissection and brief surgical time, particularly when local or regional anesthesia is indicated. It also presents an advantage in the polytraumatized patient where surgical time must be kept at a minimum. Patients with coagulopathy or those on renal dialysis, who are in need of frequent heparinization, also benefit as the small wound volume decreases the chance of hematoma formation. The fixed-angle support provided by this device is not as extensive as that offered by a volar fixed-angle plate; fractures with severe articular fragmentation are better treated with the latter device. Fractures that require significant soft tissue release and those in need of debridement of large volumes of callus should be treated through more extensive volar or dorsal exposures.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Preoperative Physical Examination

A neurovascular assessment should be performed to evaluate perfusion, discount compartment syndrome, and detect concomitant median or ulnar neuropathy. The soft tissue envelope should be assessed, and the presence of an open fracture must be noted. The surgeon must also note excessive pain or loss of finger motion.

Fracture mobility is important for performing minimally invasive fixation. The time elapsed since the injury is a critical factor and must be assessed as the difficulty of reduction escalates between the third and fourth week. Preoperative fluoroscopic evaluation is often very useful to clarify this issue.

Preoperative Imaging

Proper radiological evaluation must be performed in order to understand the fracture pattern, and exclude cases with significant articular comminution. Standard posteroanterior and lateral radiographs must be obtained and oblique views are occasionally useful. Sometimes provisional reduction or traction views should be performed prior to radiographs in order to improve the information yielded. Tomography and computed tomography scanning may occasionally be helpful to assess the degree of articular displacement. Nerve conduction studies are usually not indicated; however, a good neurovascular physical examination is necessary.

SURGICAL TECHNIQUE

Operating Room Setup

This minimally invasive dorsal nail plating surgical procedure is usually performed in the outpatient setting, under local or regional anesthesia. A tourniquet is applied and the patient's arm is prepared, draped, and extended on a standard radiolucent hand table. The image intensifier is draped sterile and introduced into the field as necessary.

Equipment: Implant Description

The technique described here uses a specific implant, the DNP-A. This implant is best described as an intrafocal nail–plate. It is inserted through the fracture site, has a distal fixed-angle plate portion placed on the surface of the distal fragment, and a proximal locked intramedullary nail portion placed inside the proximal fragment (Fig. 1). These two sections are joined by a neck portion across the fracture site. The head section presents a narrow cross-sectional area in order to prevent impingement on the adjoining extensor tendons. This area is placed on the bone surface prepared by mobilization of the EPL tendon and flattening of Lister's tubercle. Proximal surgical dissection is minimized as a result of the intramedullary location of the proximal portion of the implant, which automatically aligns itself with the axis of the radius inside the medullary canal. This feature also places the head of the implant in its correct position in space, therefore facilitating reduction of the distal fragment (indirect reduction). Distal fixation is provided by fixed-angle elements that fan off the head of the implant and underneath the subchondral bone. Proximal fixation is provided by unicortical locking screws that compress the body of the implant against the endosteal surface.

FIGURE 1 The dorsal nail plate (DNP) is an intrafocal nail–plate hybrid. It is inserted through the fracture site, has a distal fixed-angle plate portion, and a proximal locked intramedullary nail portion. The two sections are joined by a neck that traverses the fracture site.

Operative Approach

A straight dorsal 3- to 4-cm longitudinal incision is made over Lister's tubercle (Fig. 2) and the extensor retinaculum is opened over the third extensor compartment. Care must be taken to protect the crossing sensory branches of the radial nerve during the dissection. The EPL tendon sheath is easily identified as it is usually filled with blood distal to Lister's tubercle. This sheath is released several centimeters proximally and distally to the latter structure. The EPL tendon is then retracted toward the radial side (Fig. 3), and Lister's tubercle is exposed subperiosteally. Consideration must be given to release the brachioradialis if reduction is difficult. The fracture is exposed, debrided, and reduced.

Nail Insertion and Fracture Reduction

Lister's tubercle is either flattened by downward digital pressure or removed with a rongeur. This creates a flat surface for proper seating of the head of the implant. The joint line is then located by inserting an 18-gauge needle. The site for insertion of the body of the implant into the medullary canal is estimated, and is usually at or close to the dorsal fracture line. To allow for proper seating of the DNP neck, a small amount of bone may require removal with a rongeur (Fig. 4). The medullary canal is now identified and opened in a proximal direction using a curved bone awl. The DNP alignment jig is assembled onto the implant. The intramedullary end of the DNP is inserted into the proximal fragment of the radius through the fracture site. The nail is advanced until the head of the device seats flush against the bone. The next critical step is to properly reduce and fix the fracture. Provisional fixation is achieved using Kirschner (K)-wires,

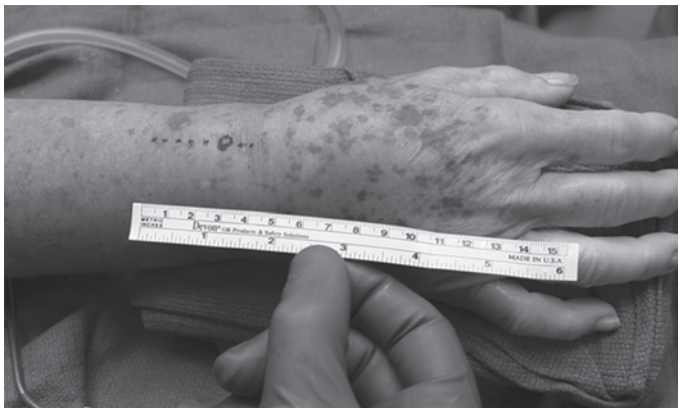
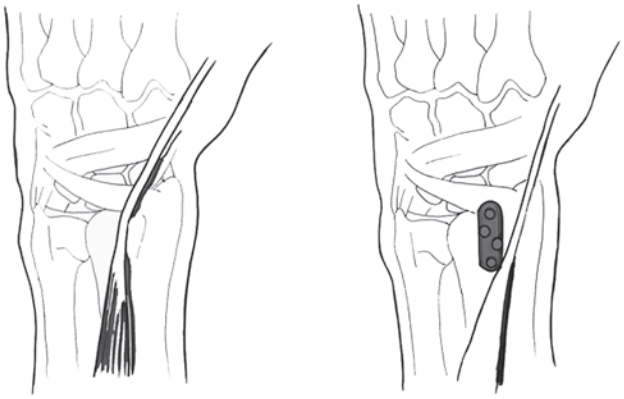


FIGURE 2 A small dorsal incision in line with Lister's tubercle provides the exposure necessary for insertion of this device.



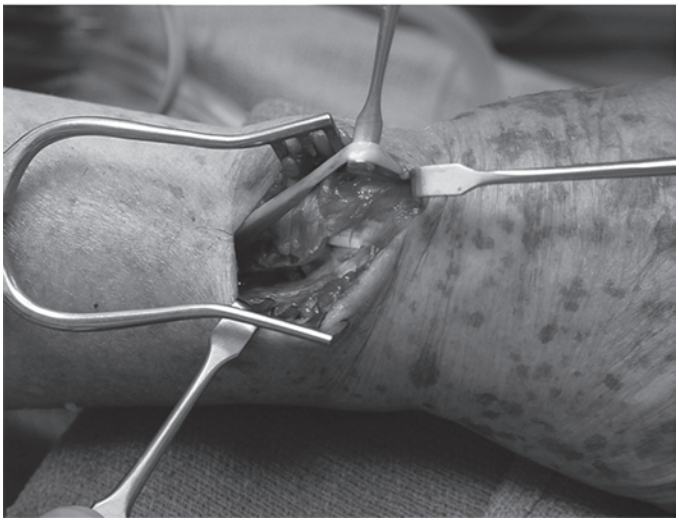


FIGURE 3 The extensor pollicis longus (EPL) tendon sheath is opened and the tendon retracted toward the radial side in order to provide space for the head of the implant. Lister's tubercle is exposed and flattened while the brachioradialis tendon must be released if reduction proves difficult.

FIGURE 4 Some bone may need to be removed from the edges of the fracture line in order for the neck of the implant to seat properly.

inserted through the jig (Fig. 5). The distal wire anticipates the future position of the pegs and must be seen in the 20° elevated fossa-lateral view as placed just a few millimeters below the subchondral bone (Fig. 6) (34).

If the surgeon is satisfied, permanent fixation of the distal fragment is then secured by inserting pegs or locking screws. While drilling for the pegs, the distal fragment must be pushed up against the implant to assure that the head is flush with the bone surface. After drilling, the preassembled drill guides are removed. Pegs must not protrude through the far cortex as this can potentially damage the flexor tendons. After fracture reduction is confirmed, and proper subchondral peg positioning is verified radiographically, the provisional K-wires are removed.

The next step is to secure the plate to the proximal fragment. The soft tissues are retracted to expose the dorsum of the proximal fragment. Using the jig handle as a guide, holes are drilled and the proximal locking screws are inserted (Fig. 7). These are unicortical screws that engage threads on the implant, and will provide compression between the implant and the endosteal surface of the bone. The jig is now detached from the head of the implant and any remaining empty peg holes are filled. After device application, the EPL tendon will course proximal to the head of the implant and along the sides of the wrist and finger extensors, preventing tendon impingement (Fig. 8). Rerouting the EPL creates a minimal functional

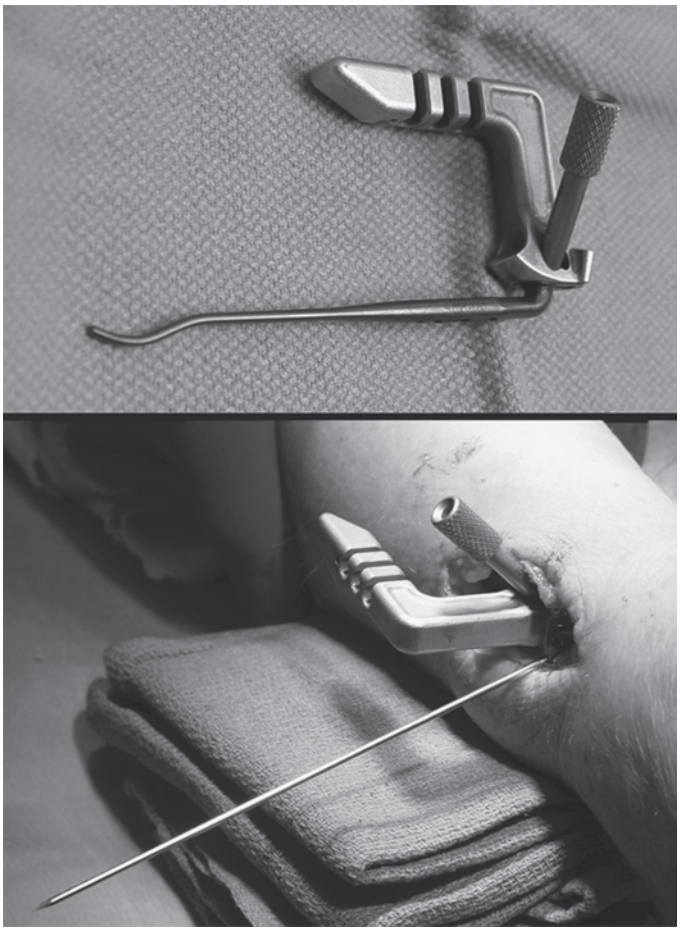


FIGURE 5 The implant is introduced using a jig that serves as a drill guide and allows the use of fixed-angle Kirschner wires (K-wires) for temporary fracture stabilization.

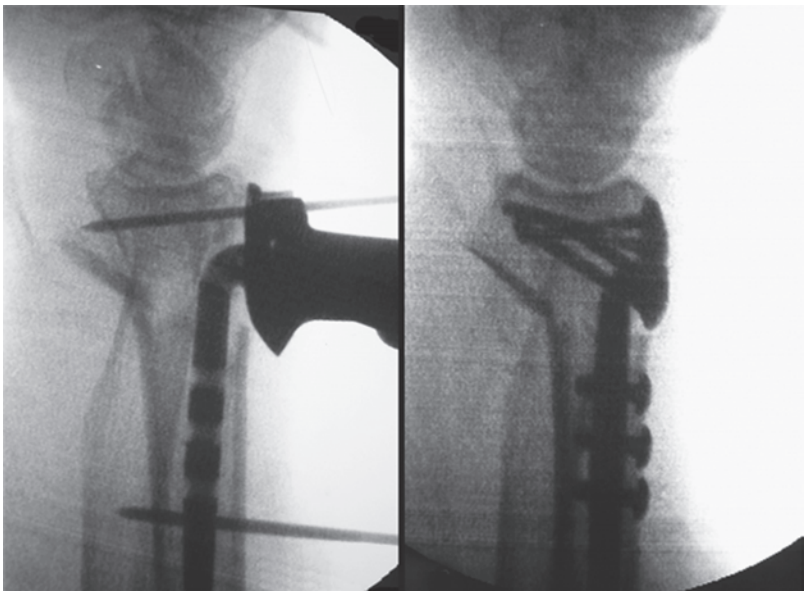


FIGURE 6 Fixed-angle Kirschner wires (K-wires) not only provide provisional fixation but also anticipate future peg position and therefore facilitate proper implant placement.

FIGURE 7 Proximal fixation is provided by unicortical locking screws that engage the implant and compress it to the endosteal surface. The jig guides their application.

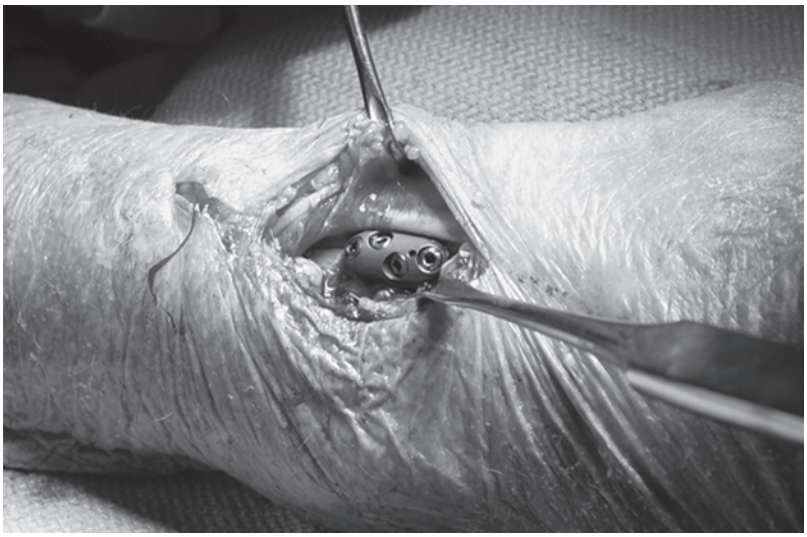


FIGURE 8 Tendon irritation is avoided because the extensor pollicis longus (EPL) tendon courses proximal to the head of the implant and the wrist and finger extensors along its sides.

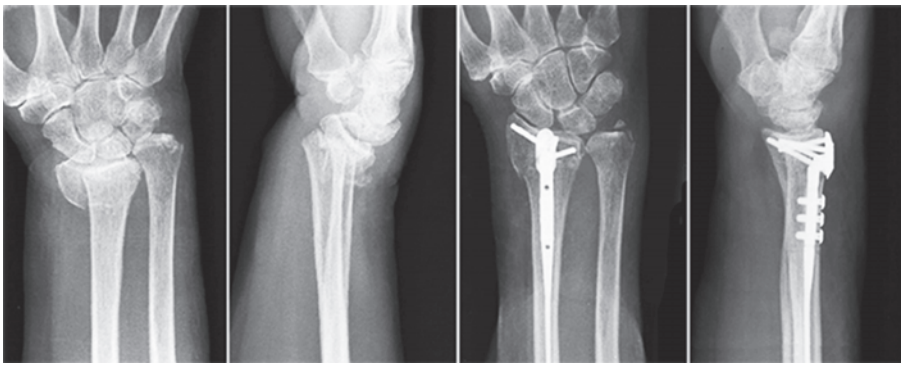


FIGURE 9 Preoperative and postoperative radiographs of an unstable extra-articular distal radius fracture in an 82-year-old patient with osteoporosis.

disturbance. Final radiographic views are obtained before closing the wound.

CLOSURE AND POSTOPERATIVE MANAGEMENT

Postoperative rehabilitation is critical to a quality long-term outcome. After simple skin closure, a postoperative dressing that allows finger motion is applied. A standardized program of rehabilitation is used to maximize functional recovery. The patient is instructed on elevation and on finger active range of motion exercises immediately after surgery. At one-week follow-up, the operative dressing is removed, the patient is referred to therapy, and a custom-formed plastic short-arm splint is provided. Functional use of the hand is encouraged and the patient is given a 5-pound weight lifting limit on the affected extremity. Full finger flexion (fingertips to distal palmar crease) is expected at this time and forearm rotation is now commenced.

At four-week follow-up evaluation, the splint is discarded. We expect the patient to have recovered significant forearm rotation by this time, and attention is now placed on wrist flexion–extension and strengthening. After radiographic union, most patients will spontaneously use their hands to perform activities of daily living after the first or second postoperative week. At two months, most patients do not require further therapy. At four months, wrist extension and forearm rotation are usually at pre-injury levels. Wrist flexion takes somewhat longer to return, presumably because of the dorsal location of the incision. The anatomical and functional results provided by this technique are very satisfying (Figs. 9 and 10).

COMPLICATIONS AND THEIR MANAGEMENT

Our experience has shown that complications are relatively infrequent and can be successfully treated.

Pitfalls

- Poor indications, excessive articular comminution
- Inadequate exposure
- Inadequate or loss of reduction; however, minor imperfections in reduction such as the absence of volar tilt and slight (1 mm) loss of radial length do not usually result in appreciable functional deficits
- Improper implant application with pegs too proximal to provide subchondral support
- Hypertrophic scar formation limiting wrist flexion
- A radial nerve injury at the time of exposure
- An unrecognized median neuropathy
- Inadequate creation of the notch for introduction of the neck of the implant

FIGURE 10 Functional results 10 weeks after surgery.

Bailouts

- In the presence of excessive callus formation preventing reduction, the incision must be extended, the fracture callus debrided, and the soft tissues, including the brachioradialis, must be released
- In case of unforeseen comminution, adjuvant fixation with small plates or K-wires must be used
- In case of a large metaphyseal defect, a bone graft may be required

OUTCOMES

Only one reference is available for the analyses of the outcomes of this technique when using the DNP (35). In a retrospective series, 46 unilateral unstable extra-articular distal radius fractures fixed with the DNP were compared to 24 extra-articular fractures fixed with volar fixed-angle fixation. Two-thirds of these fractures resulted from a low-impact trauma; 37 occurred in females and 9 in males. The average age was 70±6.5 years, and the mean follow-up was 18 months. The data revealed a brief surgical time with an average tourniquet time of 22±4 minutes. The functional results were such that wrist extension and forearm rotation were close to pre-fracture levels at an average follow-up of six weeks. However, the recovery of wrist flexion was delayed in the early postoperative phase (12±4 weeks) when compared with the volar fixed-angle fixation series. This parameter fully recovered at final follow-up (12±6 months). Grip strength averaged 82% of the contralateral side at final follow-up. Patient satisfaction was high, demonstrated by an average Disability of Arm Shoulder and Hand score of 17±3. Most importantly, complications were fewer for the DNP than for the volar plates in this study.

SUMMARY

General Conclusions

Dorsal nail minimally invasive fixation is an acceptable treatment option for extra-articular distal radius fractures. The technique is simple and fast, and the functional recovery is usually satisfactory. This technique is particularly indicated for the elderly and compromised patients.

Future Direction of the Technique

This technique should gain popularity among orthopedic surgeons as its benefits clearly outweigh its drawbacks. The learning curve is short and the results are reproducible.

SUMMATION POINTS

Indications

- Unstable extra-articular distal radius fractures
- Active, elderly, medically compromised, osteoporotic patients

Outcomes

- Fast recovery of function with slight delay in wrist flexion

Complications

- Loss of reduction following poor indication or poor implant application
- Hypertrophic scar limiting wrist motion, particularly in flexion

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Balloon Reduction and Grafting of Distal Radius Fractures

José M. Nolla
Department of Hand and Upper Extremity Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, U.S.A.

Jesse B. Jupiter
Orthopedic Hand Service, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, U.S.A.

INTRODUCTION

The concept of "cementing" fractures became a reality with the development of polymethylmethacrylate bone cement in the 1960s (1). Schmalholz in 1988 described the use of polymethylmethacrylate in the management of distal radius fractures (2). This approach has been further supported by several other investigators (3–5). By the same token, problems with polymethylmethacrylate have limited its application. These difficulties include its curing with an exothermic reaction, its inability to be incorporated with the host bone, and its requirement for wide exposure of the fracture site.

The advent of injectable cements like Norian SRS (Synthes Corp., West Chester, Pennsylvania, U.S.A.) has brought again to the forefront the potential for cementing fractures through a minimally invasive approach. Norian SRS and other new biologic cements are biocompatible and have a higher compressive strength than cancellous bone (6). Norian SRS cures at a physiologic pH and temperature to form an osteoconductive carbonated apatite with properties very similar to the mineral phase of bone (3,6). Several prospective studies have demonstrated the efficacy of Norian SRS over conventional treatments such as cast, pins, and/or external fixation (3,5). One difficulty that was recognized in attempting to apply the Norian SRS percutaneously was the observation that the viscous cement did not always fill the metaphyseal defect following manipulative reduction. This proved to be the result of cancellous bony spicules blocking the flow of the Norian cement. As a result, it became evident that it was necessary to compact the metaphyseal bone to accommodate the cement. This task can be accomplished through an open approach where tamps and elevators would be used to create a metaphyseal void.

Recently, inflatable balloons for "vertebroplasty" have been developed for spine surgery. This technique has also been evaluated in the management of fractures involving metaphyseal bone such as fractures of the calcaneus, tibial plateau, femoral condyles, and distal radius (4). Such a balloon combines the potential of creating a metaphyseal void with its ability to assist with fracture reduction.

INDICATIONS

Balloon reduction and minimally invasive bone grafting techniques are appropriate for active osteoporotic patients with reducible unstable and/or displaced distal radius fractures resulting from low-energy impact. These should be extra-articular (AO type A2 or A3) or simple articular fractures (AO type C1 or C2) without extension into the diaphysis (Fig. 1). The technique is not applicable to shearing fractures (Barton's), volar displacement fractures (Smith's), highly comminuted fractures, high-energy injuries, or nascent malunions, which are more amenable to open techniques. Active infection, severe medical illness, and patient unreliability also are contraindications.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Careful evaluation of the patient as a whole is important prior to embarking on surgery. It is important to note their activity level, functional independence, reliability, and comorbid medical conditions. Prior to any intervention, it is essential to perform a detailed exam of the involved extremity. A careful examination of the skin and neurovascular status may drastically change the timing of intervention. In the presence of median nerve symptoms, which persist following provisional fracture reduction, a carpal tunnel release should be considered simultaneously with fracture fixation. When the hand and wrist are very swollen, it is beneficial to elevate the limb a few days to allow the soft tissues to heal from the initial injury.

Standard posteroanterior, lateral, and oblique radiographs are often sufficient to delineate the fracture pattern. X rays obtained after longitudinal traction is applied will add further clarity to the fracture definition. Computed tomography may be needed when determining if an articular component is sufficiently displaced to negate balloon-assisted treatment. While examining radiographic studies, it is also important to note the carpal alignment and any distal radioulnar joint involvement.

It is our perception that balloon-assisted reduction and void creation are optimally combined with percutaneous cement infusion as opposed to the use of other bone substitutes, such as allograft or autogenous graft, which must be applied through more extensile exposures.

SURGICAL TECHNIQUE

Regional block anesthesia is preferred unless medical conditions preclude this approach. Preoperative antibiotics are given for prophylaxis. The patient is placed in supine position with the extremity placed on a radiolucent hand table with a pneumatic tourniquet applied. Fluoroscopy is required. Supplemental fixation in the form of Kirschner (K) wires or an external fixator should also be available. Traction fingertraps can help when extra assistance is not available.

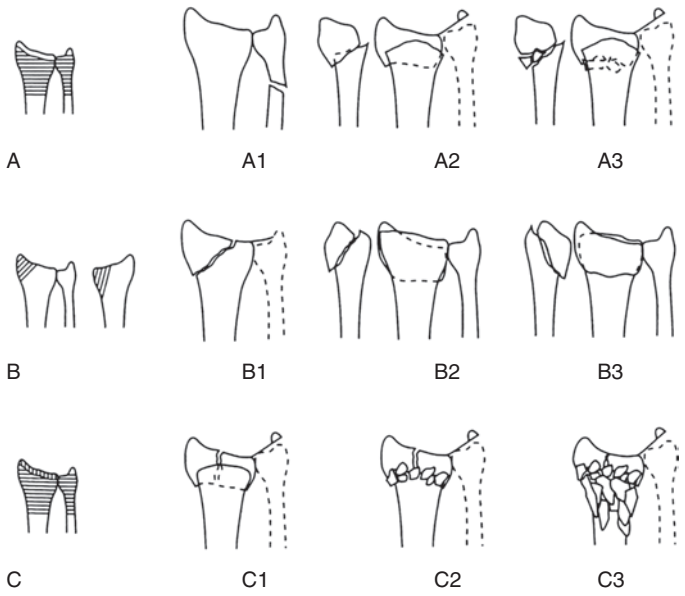

FIGURE 1 AO/ASIF classification of distal radius fractures. *Source*: From Ref. 7.

The procedure begins with a manipulative reduction of the fracture (Fig. 2) (8). To insert the balloon cannula, a 1.5–2 cm incision is made between the first and second extensor compartments with caution to avoid injury to the overlying radial sensory nerves. The incision should also be placed over the metaphyseal fracture zone. Using a 3.5 mm drill bit with a protective drill sleeve, an opening is created for insertion of the balloon cannula. Using fluoroscopic guidance, the vertebroplasty cannula is centered in the metaphyseal defect with the opening directed distally (Fig. 3). Progressive inflation of the balloon with saline will accomplish two things: (*i*) creation of a metaphyseal void and (*ii*) fracture reduction. To maintain the reduction following balloon deflation, a temporary transfixing K-wire is placed between the distal ulna and the radius distal to the metaphyseal defect. Alternatively, an oblique K-wire can be passed across the fracture site through the radial styloid (Figs. 4 and 5).

The Norian SRS is mixed by hand and injected through a separate cannula directly into the defect under fluoroscopic guidance until complete fill of the defect is observed (Figs. 6 and 7). Whenever possible, cement extravasations are to be avoided. The fracture is not to be manipulated for a minimum of 10 minutes to permit the Norian SRS to set properly.

Postoperative Management

Postoperatively, the patient should be placed in a well-molded splint for two weeks. The patient is then placed in a removable splint for four weeks while motion is initiated. If an external fixator was utilized to supplement the phosphate cement, it can

FIGURE 2 Fluoroscopy-assisted closed reduction. *Source*: Courtesy of Dr Mark Cohen.

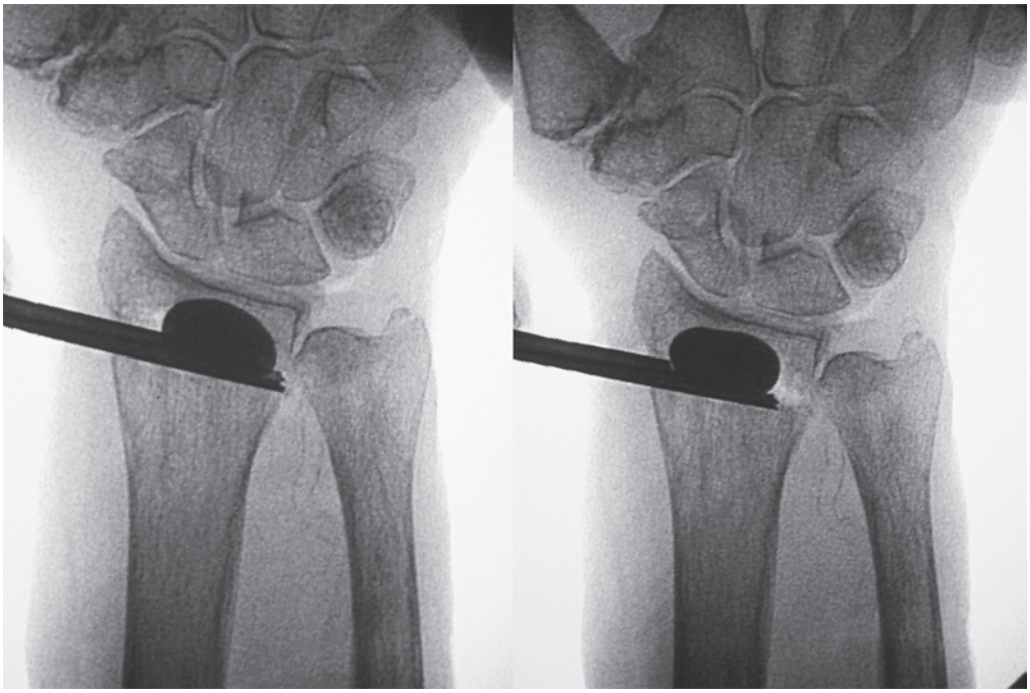

FIGURE 3 The fracture is reduced and the metaphyseal defect is prepared by compacting the cancellous bone with an inflatable balloon. The opening in the cannula should open distally to assist in fracture reduction.

be discontinued at two weeks, followed by a removable splint for four weeks. From the first postoperative day, all patients should work on digital range of motion and elevation to minimize edema. Occupational therapy should be started two weeks after surgery stressing wrist and forearm range of motion.

COMPLICATIONS AND THEIR MANAGEMENT

The most common complication of using Norian SRS is the loss of fracture reduction. In a prospective study by Cassidy and colleagues, this was observed in 46 out of 161 (29%) patients of which 9 patients required secondary treatment (3). In the series by Sanchez-Sotelo and colleagues, this was observed in 10 out of 55 patients treated with Norian SRS (5). In a series of 12 patients treated by Reiley with balloon reduction and cementation, 4 patients showed mild subsidence (4). Another potential complication is pin site infections. These are often seen with K-wires and external fixators. They can often be treated with local wound care and oral antibiotics. More severe cases may require pin removal and operative debridement.

The superficial radial sensory nerve and its branches are at risk during this approach. These are best avoided by the use of protective drill sleeves and avoiding multiple penetrations of the skin in the same area with the K-wires.

Extraosseous cement can be seen in as many as 70% of patients (3). It is best avoided by meticulous application of the Norian SRS. While it dissolves in most with time, it can be associated with other complications including fracture settling,

FIGURE 4 Supplemental fixation. K-wires are used to supplement stability in unstable fractures. *Source*: Courtesy of Dr Mark Cohen.

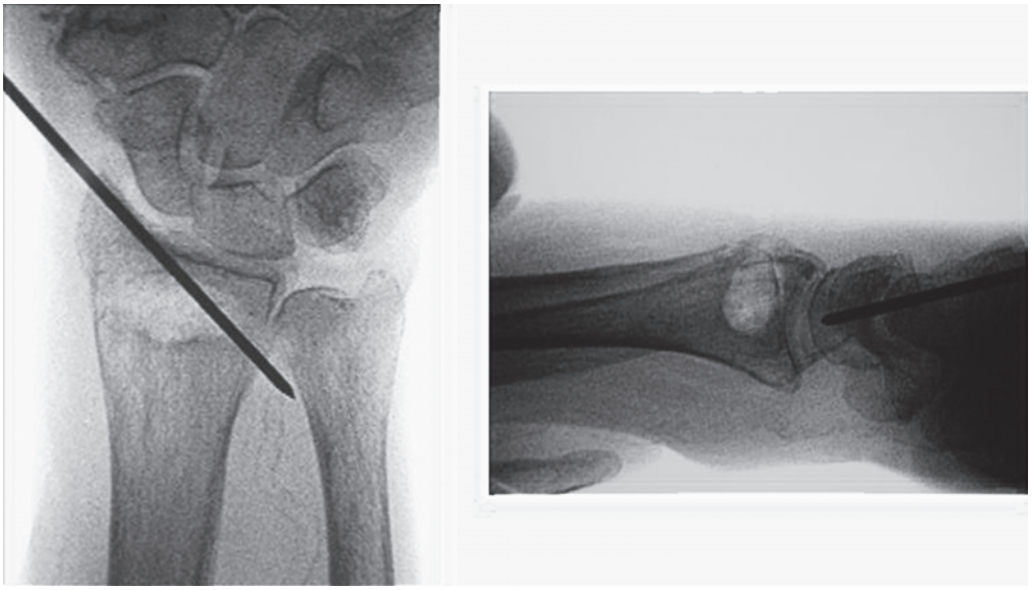

FIGURE 5 A temporary transfixing Kirschner wire is used to maintain the reduction after the balloon is deflated.

carpal tunnel syndrome, and tendon attrition. Intra-articular cement is usually not substantial enough to cause any symptoms, but there is one reported case of symptomatic intra-articular cement requiring surgical excision (5).

OUTCOMES

While little has been published combining balloon-assisted reduction with Norian SRS, other reports utilizing with Norian SRS offer favorable results. In a prospective study of 323 patients treated with closed reduction and Norian SRS cement compared to those treated with external fixation and/or percutaneous pinning, those treated with Norian showed an earlier return of function. However, the difference disappeared at 12 months (3). Similarly, in a prospective study of 110 patients randomized to treatment with closed reduction and Norian SRS cement versus closed reduction alone also showed an earlier return of function in those treated with cement. The difference normalized over 12 months. In this series, the incidence of fracture settling was significantly less in those treated with closed reduction and Norian cement compared to those treated with closed reduction alone (5).

SUMMARY

Recent improvements in bone graft substitutes are making it possible to treat distal radius fractures with less invasive and more reliable techniques. Through percutaneous methods using a balloon it is now possible to reduce the fracture and create a well-demarcated metaphyseal void. This void can then

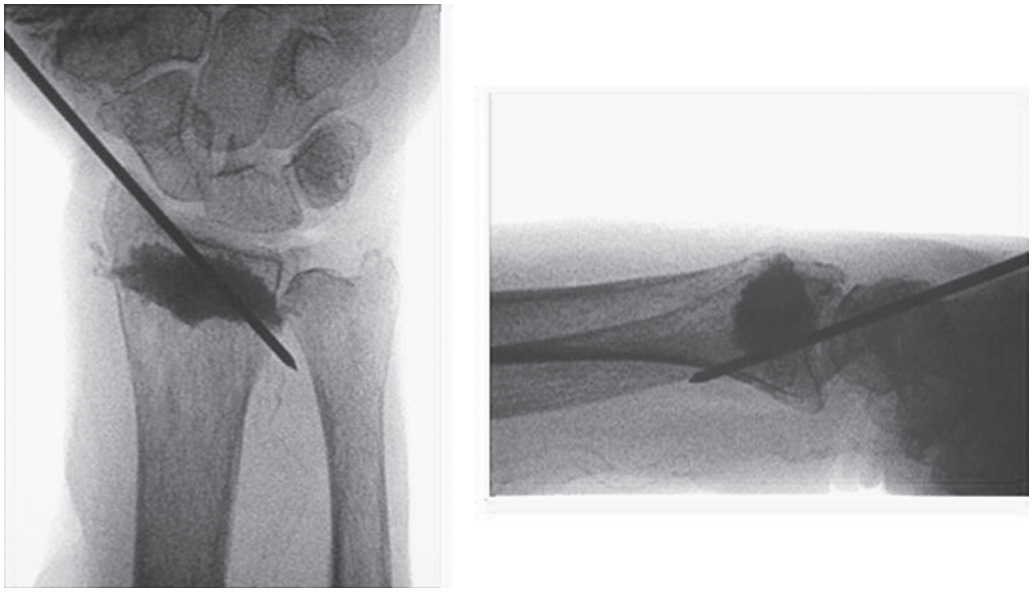

FIGURE 6 The phosphate cement is injected while the temporary Kirschner wire holds the reduction.

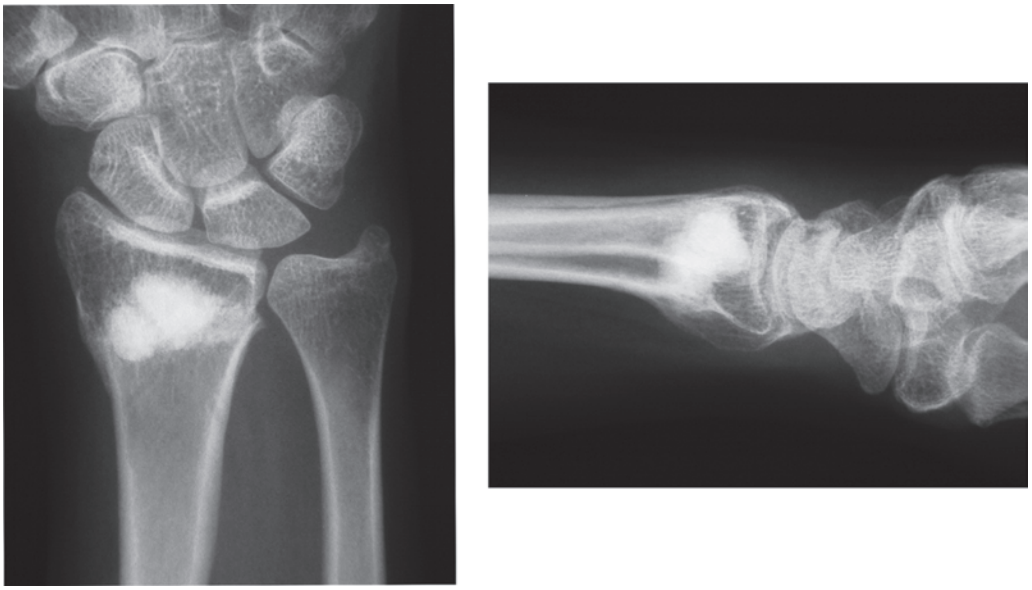

FIGURE 7 Radiographic appearance one year after surgery. *Source*: Courtesy of Dr Mark Cohen.

be filled with biologic cements in order to attain stable fracture fixation.

SUMMATION POINTS

Indications

- Osteoporotic patient with extra-articular or simple intra-articular low-energy fracture.

Outcomes

- Patients treated with calcium phosphate cement can be expected to have a quicker functional recovery.
- Based on available data, fractures supplemented with calcium phosphate cement seem to be less likely to develop settling and/or are less likely to require surgical intervention.

Complications

- Observe for significant settling, since malunions can become symptomatic.
- Extraosseous cement is avoided by meticulous technique. This significantly reduces the incidence and extent. Still, a small amount is commonly observed. This dissolves with time and is rarely symptomatic.
- Supplemental fixation techniques like external fixators and K-wires have inherent risks like neurovascular injury upon application and late pin site infections. These are best avoided by careful technique.
- Digital motion loss due to adhesions should be avoided by careful wire placement and an early range of motion program.

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Limited Approach Open Reduction and Internal Fixation of Distal Radius Fractures

José M. Nolla
Department of Hand and Upper Extremity Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, U.S.A.

Jesse B. Jupiter
Orthopedic Hand Service, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, U.S.A.

INTRODUCTION

The treatment of distal radius fractures has undergone a number of changes in recent years. These have been the result of better understanding of fracture patterns, design of implants, and developments in implant technology. The comprehensive AO classification, as well as work by Fernandez, and the column theory advocated by Rikli and Regazzoni and Medoff have brought light to key components in distal radius fractures (1,2).

Understanding of the key components in the structural support of the distal radius articular surface has allowed the development of implants that provide the needed support in cases of compromised stability. The key components as described by Rikli and Regazzoni include a medial (ulnar) column, which consists of the distal ulna, triangular fibrocartilage complex (TFCC), and distal radioulnar joint (DRUJ) (Fig. 1) (2). The intermediate column consists of the medial aspect of the radius including the lunate fossa and sigmoid notch. The lateral (radial) column consists of the scaphoid fossa and radial styloid.

Studies of force transmission across the wrist have demonstrated more forces transmitted through the intermediate column than previously thought. When looking at the lunate facet of the distal radius, the axial forces vary between 29% and 44% of the total axial force (Rikli DA, personal communication). One can therefore view the role of the radial column as a stability column, providing a bony buttress for the carpus and the origin for the stabilizing capsular ligaments. In contrast, the intermediate column functions in load transmission and serves as the "keystone" to the radiocarpal joint. The ulnar column serves both for load transmission and stability acting as a "pivot point" for wrist mobility.

With a clearer understanding of the structural anatomy and biomechanics of the distal radius, radiocarpal, and distal radioulnar joints, fragment-specific fracture treatment with limited surgical approaches is applicable for a variety of fracture patterns.

INDICATIONS FOR LIMITED APPROACH OPEN REDUCTION AND INTERNAL FIXATION

A number of specific fracture patterns are amenable to limited exposures for internal fixation. These include fractures of the radial column involving the radial styloid, intermediate column including the volar and/or dorsal lunate facets, and the ulnar column, specifically, the ulnar styloid fracture.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

A distal radius fracture can affect anyone and therefore it is essential to have a clear understanding of the patient's activity level, co-morbid medical conditions, independence level, and reliability. During the physical examination it is important to note the neurovascular status of the hand as well as the status of the skin. Excessive skin swelling without median nerve symptoms benefits from a period of elevation to facilitate soft-tissue management.

Radiographic examination should include standard anteroposterior, lateral, and oblique views. In cases of extensive collapse, longitudinal traction films under hematoma block anesthesia are extremely helpful. Computed tomography, with reconstructions in the coronal and sagittal planes as well as three-dimensional reconstructions, is helpful to elucidate specific fragments (Fig. 2). During examination of the radiographs it is important to note any evidence of carpal malalignment or derangement.

Other pieces of information to obtain from the radiographs are fracture fragment recognition and fracture classification. It is essential to recognize radial styloid fragments, lip fragments, volar- and dorsal-ulnar fragments, and ulnar styloid fragments. This knowledge will guide the therapeutic approach. The last piece of information to get from the radiographs is classification as this assists with communication, treatment decisions, and prognosis. The most thorough classification system is the AO/ASIF system. It takes into consideration the severity of the skeletal and articular injury. In this system the fractures are divided into extra-articular (type A), partial articular (type B), and complete articular (type C). Each is then subdivided in increasing order of severity (Fig. 3).

SURGICAL TECHNIQUE

Regional block anesthesia is preferred. Preoperative antibiotics are given for prophylaxis. The patient is placed in the supine position with the extremity on a radiolucent hand table. A pneumatic tourniquet is applied. Fluoroscopy will be required. One should have available a variety of fixation options including stainless steel wire, Kirschner wires,

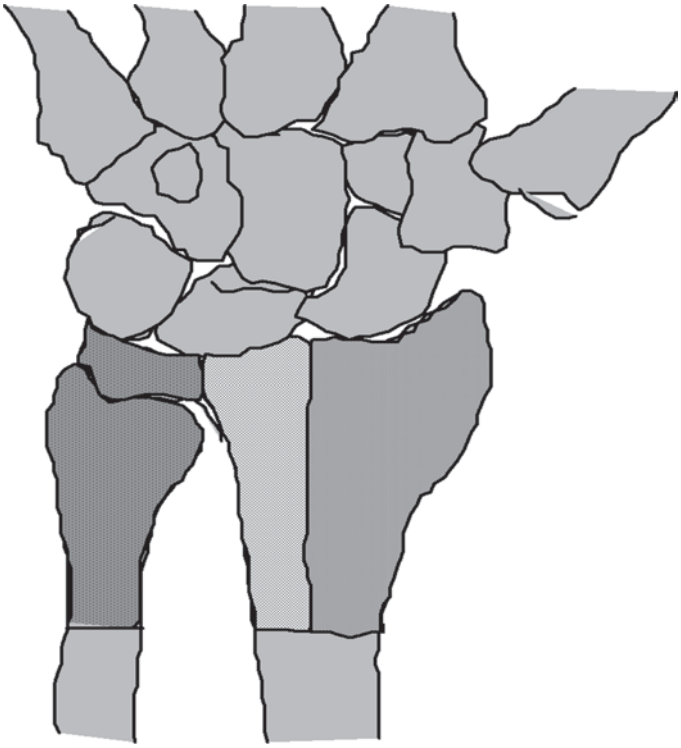

FIGURE 1 Rikli and Regazzoni's division of the distal radius into three columns (medial, intermediate, and lateral).

external fixation, and anatomically shaped plates or wire forms. A number of limited extensile exposures are available to approach either dorsal or volar fracture components (Fig. 4).

Radial Column Fractures

Shearing fractures of the radial column are classified within the AO/ASIF Group as B1 fractures. The subgroup B1.1 is a vertical shearing-type fracture, while B1.2 represents a multi-fragmented radial styloid fracture. These fractures may be isolated injuries as a result of a fall on the outstretched hand with the wrist forced into extension and radial deviation. The scaphoid directly transmits the force of impact onto the radial styloid. Styloid fractures can also be seen in association with perilunate dislocations of the carpus. Smaller avulsion fractures will have the radial capsule attached while larger ones will additionally have the origin of the radioscaphocapitate ligaments. Anatomic reduction and stable internal fixation of these fractures will restore both alignment of the radial column's buttress as well as the integrity of the supporting ligaments of the wrist.

An attempt should be made to achieve a closed manipulative reduction and percutaneous Kirschner wire or screw fixation. When a closed reduction is not successful, open reduction is recommended. A small dorsoradial incision will provide excellent exposure of the fracture and if necessary, the radiocarpal joint (Fig. 4). Stable fixation most often will require one or two screws, but in some instances, a small radial column plate will help buttress a large vertically sheared styloid fracture (Figs. 5 and 6).

Intermediate Column Fractures

While the vast majority of these fractures are due to axial compression of the lunate against the lunate facet, there is a unique fracture pattern involving the dorsal lunate facet characterized by a vertical shear pattern classified as subgroup B1.3. Dorsal lunate facet compression fractures are most often a component of a three-part articular injury or a four-part pattern characterized by a split of the lunate facet with both dorsal and volar components (Fig. 7). In some instances, the dorsal lunate facet fracture can be reduced through a small incision and manipulated into place with an elevator, tamp, or pointed awl. Stability is achieved with either strategically placed Kirschner wires or a small plate or wire-form (Figs. 7 and 8).

Volar lunate facet displacement is less amenable to percutaneous manipulation and Kirschner wire fixation. A limited volar incision is made creating an interval between the ulnar artery and nerve, and the flexor tendons (Fig. 9). By elevating

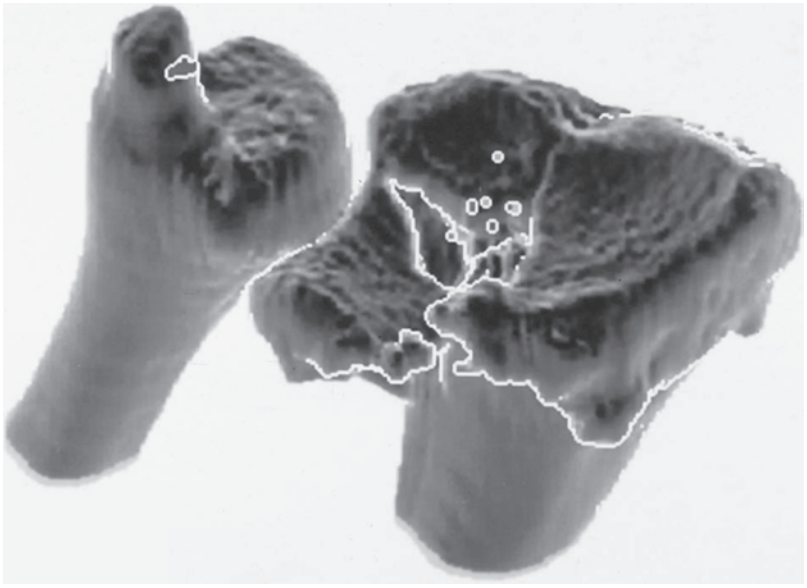

FIGURE 2 Computed tomography scan can assist in elucidating the involved columns in complex fractures.

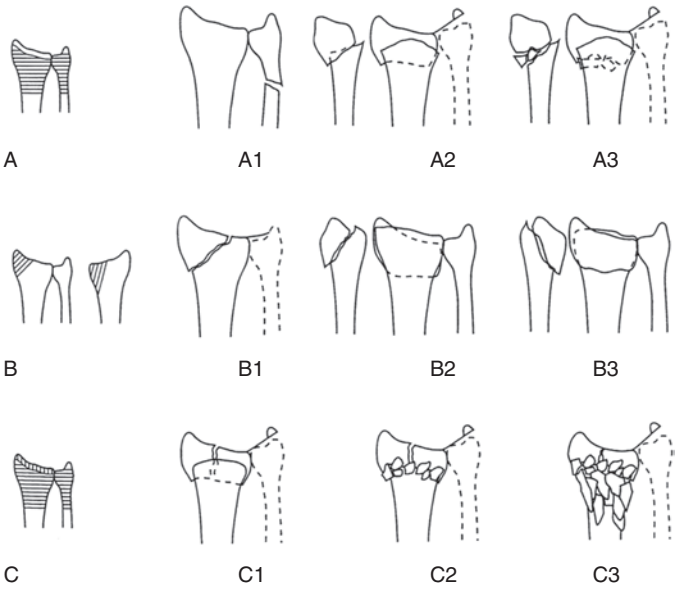

FIGURE 3 AO/ASIF classification of distal radius fractures. *Source*: From Ref. 3.

the distal ulnar corner of the pronator quadratus, the volar lunate facet is readily exposed. Internal fixation can be accomplished either with a tension wire technique or a small plate or wire-form (Figs. 7, 9–12).

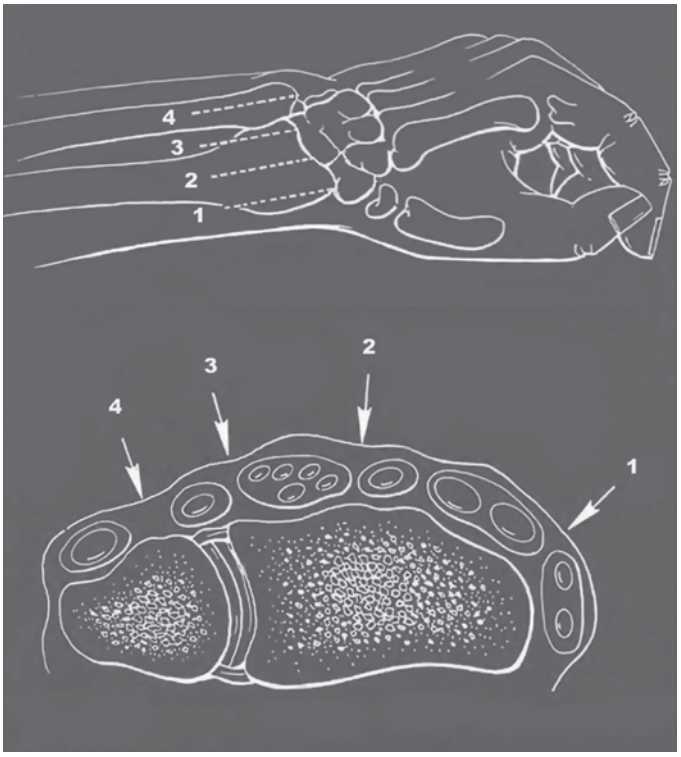

FIGURE 4 Dorsal approaches to the wrist. 1, between the first and second extensor compartments; 2, through the third compartment; 3, between the fourth and fifth compartments; 4, between the fifth and sixth compartments. *Source*: Adapted from Ref. 4.

Ulnar Column

There are instances in which the stability of the distal radioulnar joint will require stable fixation of the ulnar styloid. Following stable fixation of the distal radius fractures, passive forearm rotation will define the presence of distal radioulnar joint instability. In these instances, especially when there is a large ulnar styloid fracture, fixation of the ulnar styloid is recommended.

The ulnar styloid lies relatively anterior to the longitudinal axis of the ulna, thus the surgical approach should be through a small incision over the styloid itself. If done with the forearm supinated, the styloid will rest in a more dorsal position, facilitating exposure and internal fixation. The fixation of the ulnar styloid will depend in part upon its size. Small screws, headless screws, or tension band wire or wire-forms are all applicable (Figs. 14 and 15).

COMPLICATIONS AND THEIR MANAGEMENT

Open approaches are at risk of wound healing problems, the most severe being wound necrosis. Prevention is best treatment in these situations. The surgeon should be cautious and not proceed with the surgery until the soft tissues have recovered from the initial soft-tissue trauma.

Complex fractures at times cannot be securely fixed with internal hardware only. In these cases, it is useful to have an external fixator available. The fixator can help not only with the fracture reduction, but also with maintenance of the reduction. In this situation, the fixator is kept in place for at least three weeks. Bone graft can also be used to supplement fixation, particularly for support of articular fragments. Bone graft will also assist in fracture healing.

The median nerve and the sensory branches of the radial nerve are at risk during some approaches to the wrist. Excessive retraction of the median nerve can lead to significant motor and sensory disturbances. Minimizing the use of self-retaining retractors and frequent changing of their positions during volar approaches minimizes the incidence of neuropathies. Careful dorsal dissection minimizes damage to the superficial sensory branches of the radial nerve.

Peritendinous adhesions can severely limit digital motion. This complication is best avoided by covering dorsal and volar hardware with periosteum and/or muscle and by promptly starting a digital and wrist motion protocol soon after surgery. Severe cases that have failed to improve with range of motion exercises and splinting may require operative tenolysis and capsulotomies.

Dorsal instrumentation places the extensor tendons at risk for complications, namely, tenosynovitis and tendon rupture. Whereas this risk was significant with prior implants, newer implants have been designed with the goal of minimizing tendon irritation. If tenosynovitis is still encountered, it is best addressed by plate removal. Tendon rupture is best addressed with plate removal and an appropriate tendon transfer.

OUTCOMES

The important aspect in obtaining a good result in these fractures is attaining and maintaining an adequate articular alignment (9,10). Work by Jakob and colleagues using the same principles outlined above revealed greater than 95%

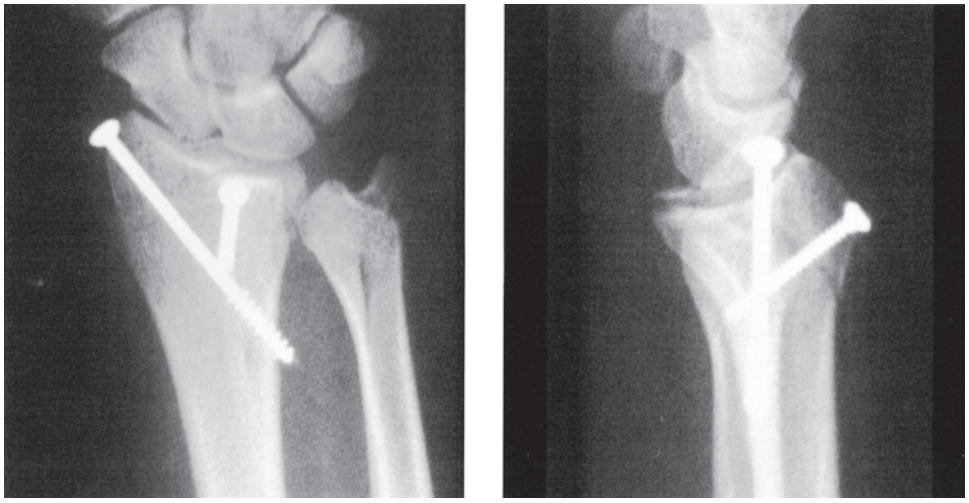

FIGURE 5 Fixation of radial and dorsal intermediate columns with 3.5 and 4.0 mm screws accomplished through minimal incisions. *Source*: Courtesy of Dr Diego L. Fernandez; From Ref. 5.

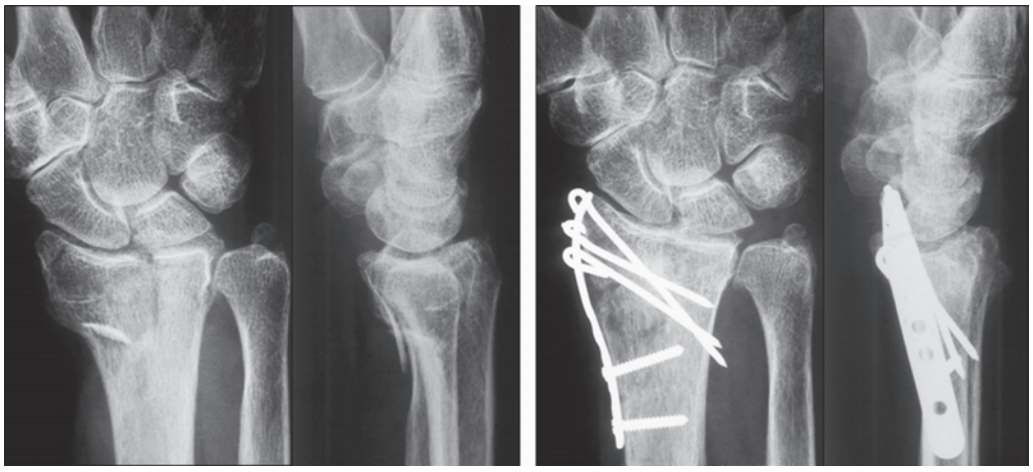

FIGURE 6 Radial column buttressed with a radial plate. *Source*: Courtesy of Dr Robert J. Medoff.

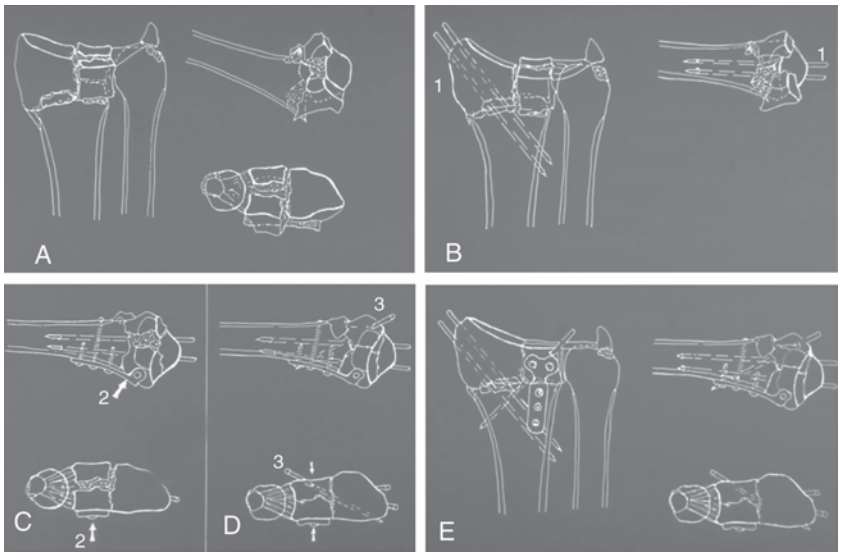

FIGURE 7 (**A**) Axial loads transmitted can result in a four-part fracture with the lunate fossa split into a volar and a dorsal piece. (**B**) In this model, the radial styloid fragment has been stabilized with Kirschner wires. (**C**) The volar lunate facet is stabilized with a plate. (**D**) The dorsal lunate fragment is stabilized with a Kirschner wire. (**E**) The distal radioulnar joint should then be evaluated for instability, especially when the ulnar styloid has been fractured through its base. *Source*: Adapted from Ref. 6.

FIGURE 8 Radial styloid and dorsal ulnar fragments stabilized with columnar pin plates. *Source*: Courtesy of Dr Robert J. Medoff.

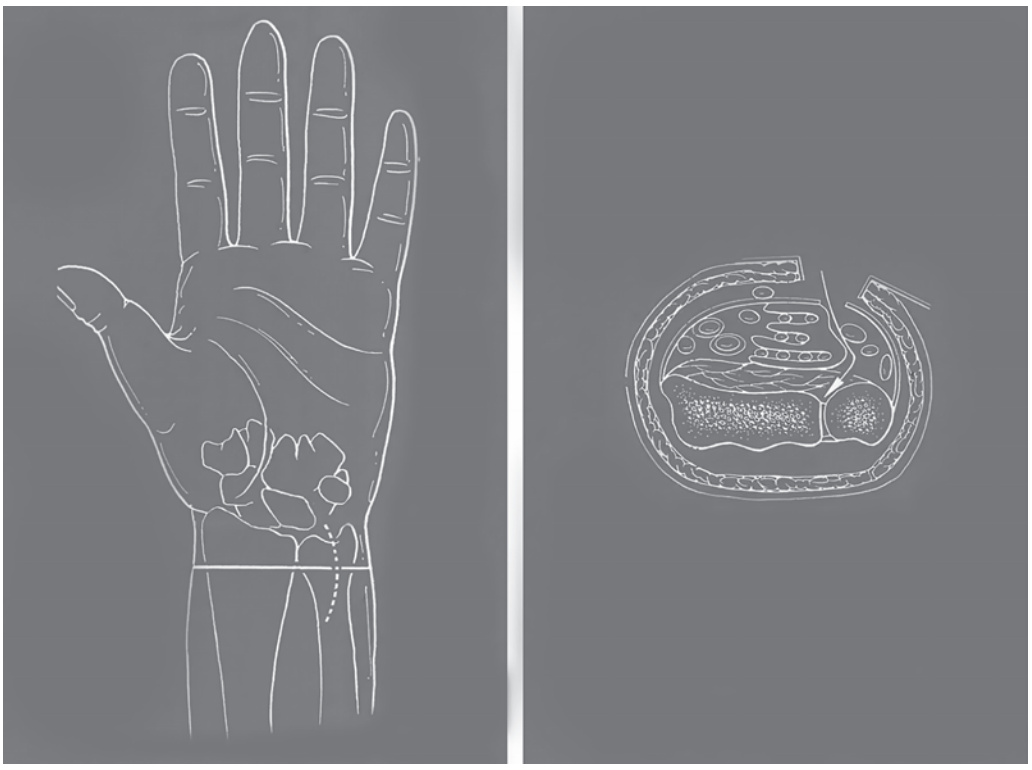

FIGURE 9 Volar ulnar approach between the ulnar artery/nerve and flexor tendons. *Source*: Adapted from Ref. 7.

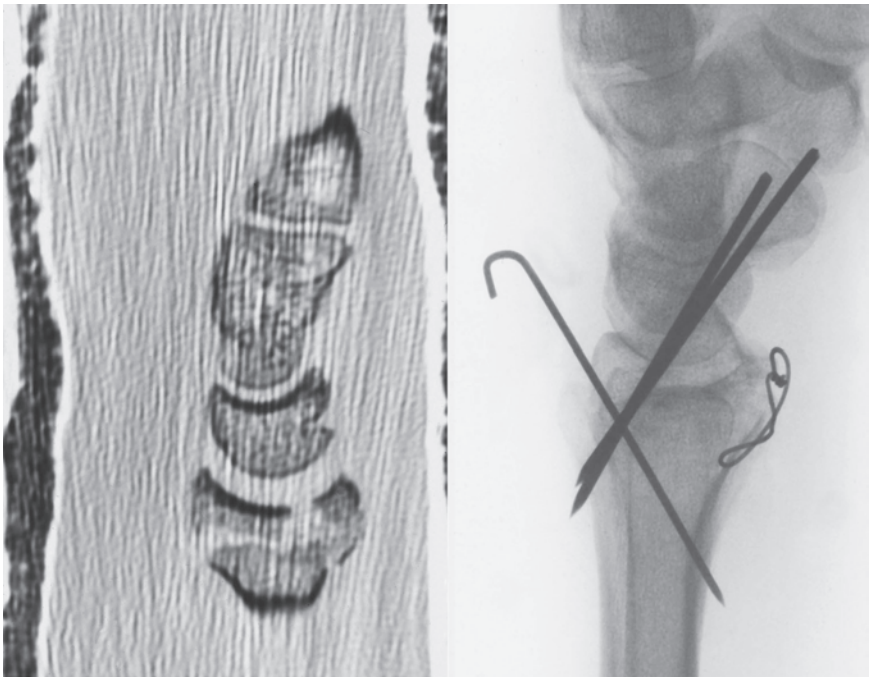

FIGURE 10 Small volar ulnar fragment fixed with 24-gauge wire. *Source*: From Ref. 8.

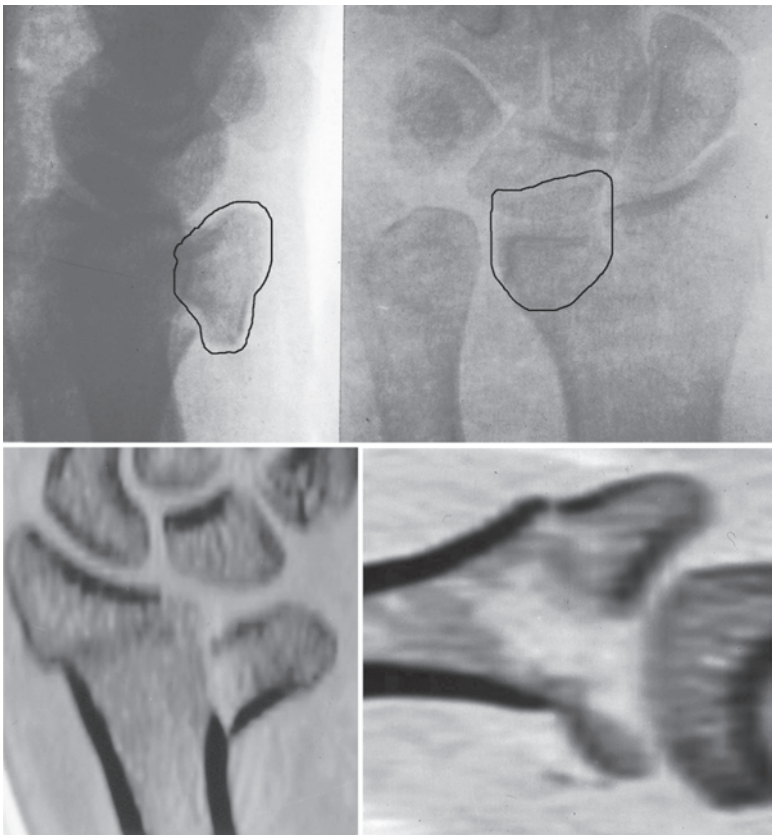

FIGURE 11 Split lunate facet with large volar fragment.

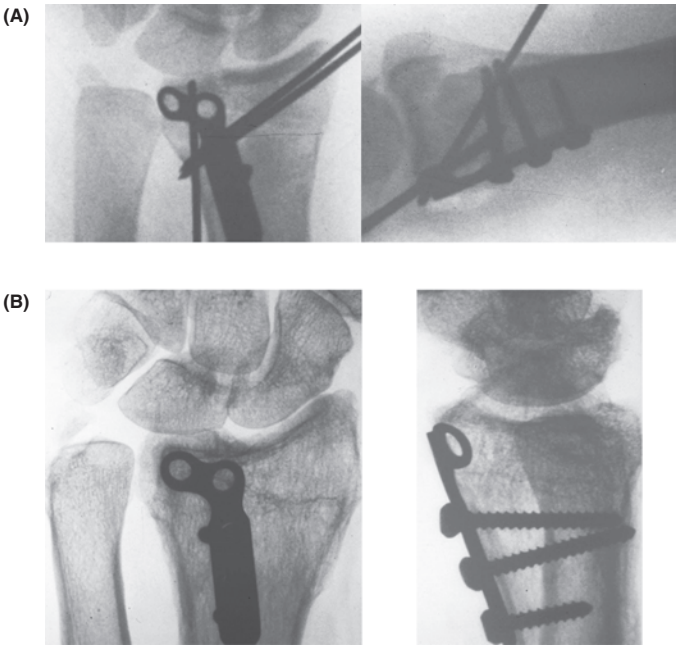

FIGURE 12 Fracture from Figure 11. (**A**) The volar fragment has been buttressed with a plate and the radial styloid has been stabilized with Kirschner wires. (**B**) X-rays 1 year after surgery.

good and excellent results (11). In their treatment of 74 fractures, of which 58 were severely comminuted, they were able to effectively treat them using dual dorsal titanium plates. In their early experience they had five cases of tendon rupture, which did not occur again once they stopped cutting the distal extent of their plates. Similarly, in their treatment of 12 patients with mini-fragment titanium plates, Martinez and colleagues obtained 11 excellent results and one good result according to the Gartland and Werley Scale (12). They had no cases of tendon irritation at an average follow-up of 18 months.

■ SUMMARY

Recent improvements in the understanding of distal radius fracture patterns, design of fragment-specific implants, and developments in implant technology have revolutionized the care of this injury. It is now possible to specifically tailor incisions to fit specific fracture patterns with small implants that minimize soft-tissue irritation. These implants provide strong fixation, which can withstand early motion. As a result, excellent outcomes can be attained with minimal complications.

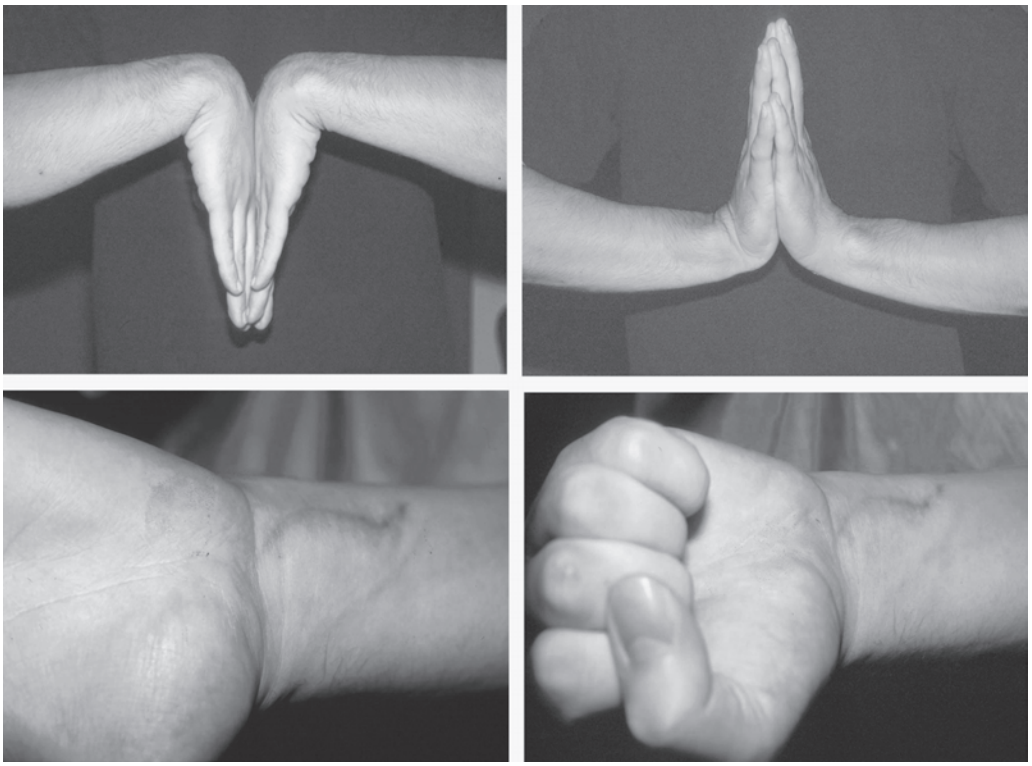

FIGURE 13 Clinical result for fracture in Figure 11 six months after surgery.

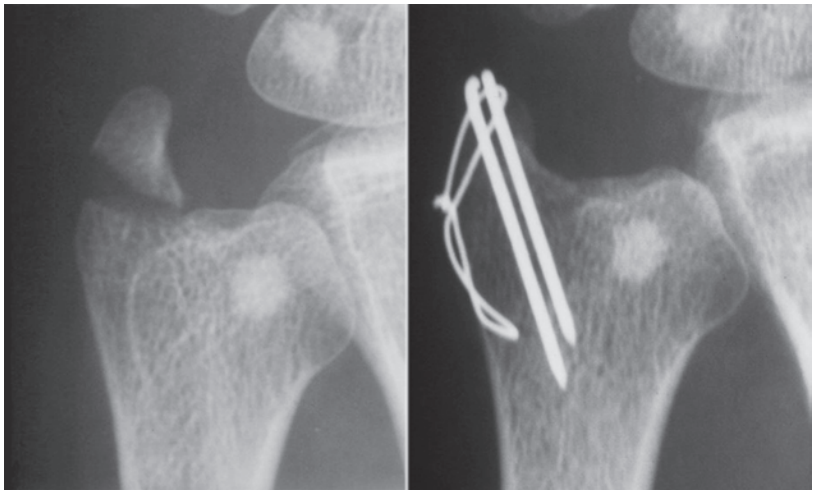

FIGURE 14 Ulnar styloid stabilized with tension-band construct.

SUMMATION POINTS

Indications

- Intra-articular AO type B fractures including fractures of the radial column involving the radial styloid, intermediate column including the volar and/or dorsal lunate facets, and the ulnar column, specifically, the ulnar styloid fracture.
- More extensile approaches are needed for those with severe shortening and those with extensive intra-articular involvement (AO group C), especially if they extend into the diaphysis.

Outcomes

- Excellent to good results can be expected as long as articular alignment is obtained and maintained.
- Use of newer, low profile dorsal implants and avoidance of plate cutting, minimizes the incidence of tendon irritation and/or rupture

Complications

- Wound necrosis is best avoided by allowing the soft tissues to stabilize from the initial trauma prior to embarking on surgical treatment.
- An early motion protocol can minimize the incidence of peritendinous adhesions.
- Dorsal instrumentation should not be cut and should be covered with periosteum to minimize extensor tendon irritation.

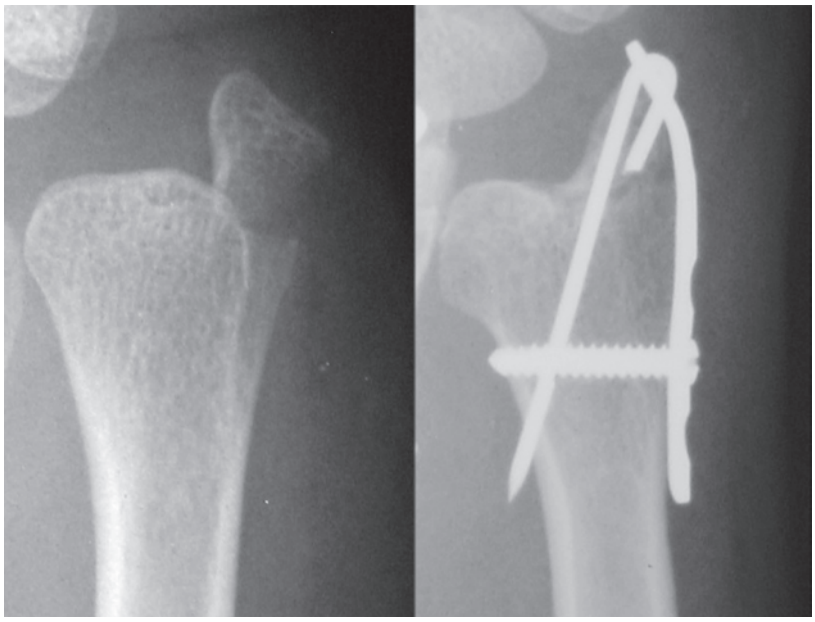

FIGURE 15 Ulnar styloid fracture stabilized with pin plate. *Source*: Courtesy of Dr Robert J. Medoff.

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Repair of Distal Radial Malunions with an Intramedullary Nail

John T. Capo, Damon Ng, and Virak Tan

Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Fractures of the distal radius are one of the most common fractures that are treated by orthopedic surgeons. They account for up to 20% of all fractures seen in the emergency department (1,2). There is a bimodal age distribution, occurring most commonly between the ages of 5 to 14 and 60 and 69 years. Within the second age group, there is a predominance of female patients with a ratio of approximately 4:1. Also within this age group, the fracture is usually the result of a low energy injury; typically the patient presents after a fall on an outstretched hand. The accelerating body weight produces a bending moment on the distal forearm, and the distal radius fails through the softer metaphyseal bone. The result usually is a displaced, extraarticular metaphyseal fracture of the distal radius. Extraarticular distal radius fractures without significant comminution typically prove to be stable after closed reduction and are usually amenable to cast immobilization.

This was historically thought to be so often the case, that in 1814 Abraham Colles suggested, "the limb will at some remote period enjoy perfect freedom in all of its motions and be completely exempt from pain" (3). However, with further understanding of the anatomy surrounding the distal radius and the increased physical demands of patients, the effect of distal radial malunions have received increased attention in the past several decades. Malunion is actually the most common complication following a distal radius fracture (4). Distal radial malunions can result from inappropriate initial treatment or failure of appropriate treatment due to osteopenia or fracture comminution. The clinical result from a malunion is variable as X-ray findings do not always correlate with patient symptoms and function (5). Often patients with malunions can be plagued by pain, limited range of motion (ROM), decreased grip strength, and poor cosmesis.

Corrective osteotomy for distal radial malunions has been described as early as the 1930s by Ghormley and Mroz (6). As osteosynthesis techniques evolved, so did the treatment for distal radial malunions. Currently, the "gold-standard" of surgical intervention for malunions is osteotomy followed by internal fixation as described by Diego Fernandez (5). The osteotomy is carefully planned to correct the deformity, the resulting defect is replaced with bone graft, and the final position is stabilized rigidly with plates and screws. Traditionally for dorsally displaced malunions, a direct approach with dorsal plating has provided excellent results (7). With the advent of locked plates, a volar approach has also been utilized (8–10). These locked plates placed on the volar surface have a theoretical advantage of less tendon irritation. However, direct visualization of the correction cannot be achieved and an external plate still needs to be applied. Elevation and stripping of the pronator quadratus is required and there is a potential for decreasing vascularity to the region.

Intramedullary (IM) nail fixation for distal radius fractures has recently been described with promising results (11,12). The IM nail is inserted through the radial styloid, spans the length of the fracture, and is fixed proximally and distally. As with all locked IM implants, it acts as a load sharing device rather than load bearing. Fixed angle interlocking screws stabilize the distal fragment while locking bolts proximally provide length stability. Also, like other IM devices, a limited approach is used to deploy the device with very little soft tissue being disrupted. By definition an IM device rests within the confines of the bone. Therefore, there is no external hardware to cause tendon irritation and attrition. In the case of distal radial malunions, the correction is directly visualized dorsally and the nail is deployed into the bone through a limited approach at the radial styloid.

INDICATIONS

Classic radiographic anatomic criteria for acceptable healing in the distal radius is: radial shortening of <3 to 5 mm, radial inclination $>15°$, sagittal tilt on the lateral projection between 10° dorsal tilt and 20° volar tilt, and incongruity of intra-articular fractures <1 to 2 mm at the radiocarpal joint (13). Distal radial fractures that heal outside of these parameters and that present with clinical deformities are candidates for osteotomy, bone grafting and fixation with an IM nail.

From the perspective of functional limitation, a distal radial malunion disrupts the normal mechanics of the wrist including ROM, load distribution, and force coupling between the forearm, wrist, and hand (14–16). In the case of a dorsal malunion, as the distal radial articular surface is directed dorsally, the amount of wrist flexion decreases and extension motion increases. This altered anatomy disrupts the pull of the wrist flexors and extensors. As the deformity worsens, compensatory midcarpal instability ensues. The midcarpal joint creates a dorsal intercalated segmental instability pattern to compensate for the extended position of the distal radius and proximal carpal row.

In addition, load profile between the carpus and the distal radius is altered. The load is shifted dorsally with the distal radius being point loaded. With distal radial deformity, the distal radial–ulnar joint (DRUJ) can become subluxated and is subjected to altered load forces. In his study, Palmer demonstrated that the load transmitted through the distal ulna increased from 21% to 67% as the volar angulation of the distal radius increased from palmar tilt of 10° to a dorsal tilt of 45° (17,18). As the distal radius is shortened, it brings with it the triangular fibrocartilage complex (TFCC); this abnormal

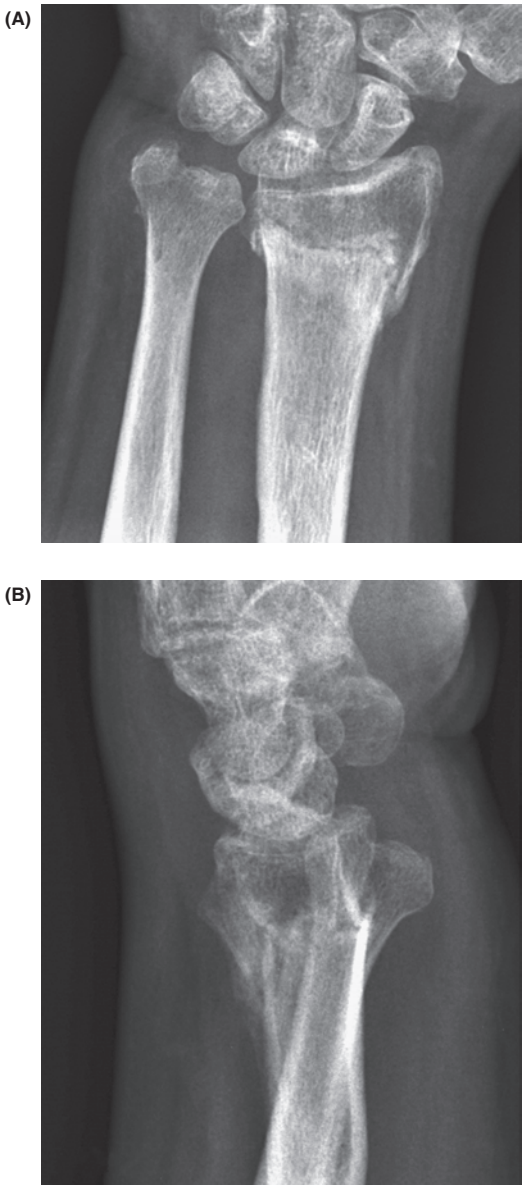


FIGURE 1 (**A**) Anteroposterior and (**B**) lateral views of an established distal radial malunion. The alignment shows that the radius is short, dorsally angulated and that the inclination is decreased. *Source*: Courtesy of John T. Capo, MD.

tensioning of the TFCC blocks normal sweep of the TFCC over the head of the ulna which in turn can limit normal motion of the DRUJ (1,5). Clinically, these altered load profiles, instability and sites of possible arthrosis can be manifested as pain and functional limitations.

Osteotomy and fixation with an IM device is ideally suited for malunited extraarticular distal radius fractures which are either dorsally or volarly angulated. The patient typically has pain in the dorsal or ulnar wrist and is unhappy with the cosmesis of the extremity. Issues of bony defects do not represent significant problems as bone graft or bone substitute can be placed at the site of the osteotomy. In cases of distal radius fractures with limited extension into the articular surface, osteotomy and fixation with an IM device can be utilized if the articular surface can be stabilized first.

In the case where there is significant arthrosis and deformity as a result of a long standing established malunion,

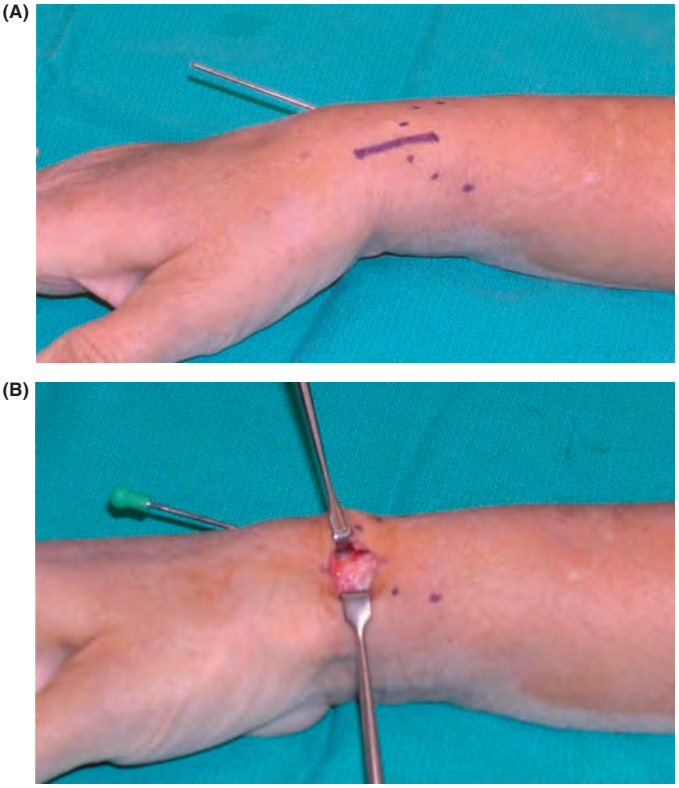


FIGURE 2 (**A**) Two centimeter radial sided incision centered over radial styloid and (**B**) the interval between the first and second dorsal compartments has been used. The tendons and superficial radial nerve are retracted to expose the radial styloid. *Source*: Courtesy of John T. Capo, MD.

corrective osteotomy and fixation with an IM nail is not indicated. In these late stage situations, the extraarticular alignment is no longer the main issue. Salvage procedures such as arthrodesis and arthroplasty should be considered.

CONSIDERATION FOR PREOPERATIVE PLANNING

Preoperative Evaluation

The first step in evaluating a patient with a distal radial malunion is a complete history and physical exam. One must elucidate the details surrounding the injury including mechanism of injury and importantly the time since index injury in order to determine the chronicity of the malunion (19). Patient related factors such as general health, associated medical problems, hand dominance, occupation and level of activity must be evaluated. Assessment of the post injury wrist must include degree of functional limitation in daily and vocational activities, and the frequency, duration and quality of pain in the wrist (including narcotic and analgesic requirement).

Careful exam of both the affected and the unaffected extremity is imperative. The location of the pain must be clearly identified. Examination must include palpation directly at the fracture site, in the DRUJ, the radial-carpal joint and the ulnar-carpal joint. The following provocative maneuvers should be performed: axially loading on the ulnarly deviated wrist, palpation of the scapholunate interval and evaluation of stability of the carpus and DRUJ. The ROM in flexion, extension, pronation, supination, radial, and ulnar deviation should be recorded.

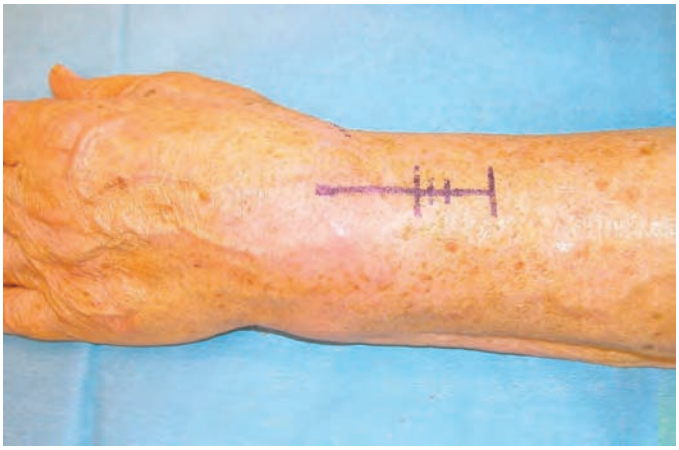


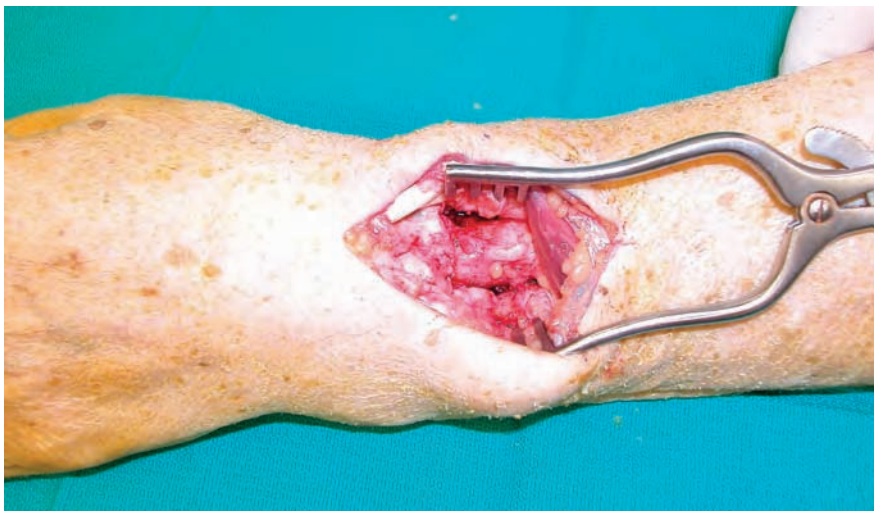
FIGURE 3 Dorsal incision for exposure of the malunion and placement of the proximal locking bolts. The proximal hash marks represent the limits of the incision for screw insertion only, as in an acute fracture. *Source*: Courtesy of John T. Capo, MD.

Grip strength measurements must be made. Motor and sensory exam of the wrist and hand is critical, as median nerve compression from a severely dorsally angulated malunion can occur.

Preoperative Imaging

Straight anterior–posterior, oblique and true lateral views of the affected wrist need to be obtained. A similar series of the contralateral wrist helps with planning the degree of correction. The radiocarpal and midcarpal joints should be examined for arthrosis. Shortening of the distal radius produces abnormal loading of the carpus on the distal ulna, so careful attention must be made toward the ulnacarpal articulation. There may be cysts in the distal ulna or proximal lunate with ulnarcarpal impaction. A computed tomography scan is an adjunct that can be employed but is not always necessary. Situations in which it can be best utilized include evaluation of DRUJ for arthrosis and congruence, and three dimensional visualization of the distal radial deformity.

(A)



(B)

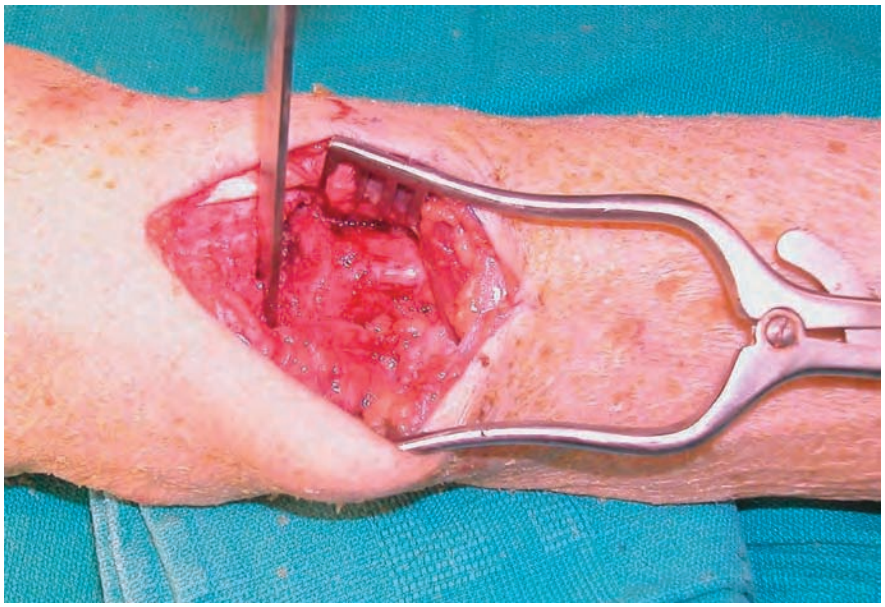


FIGURE 4 (**A**) The second and fourth dorsal compartments are elevated in a subperiosteal manner and the malunion is exposed. The extensor pollicis longus muscle belly can be seen proximally and (**B**) the malunion is found and then opened with an osteotome. *Source*: Courtesy of John T. Capo, MD.

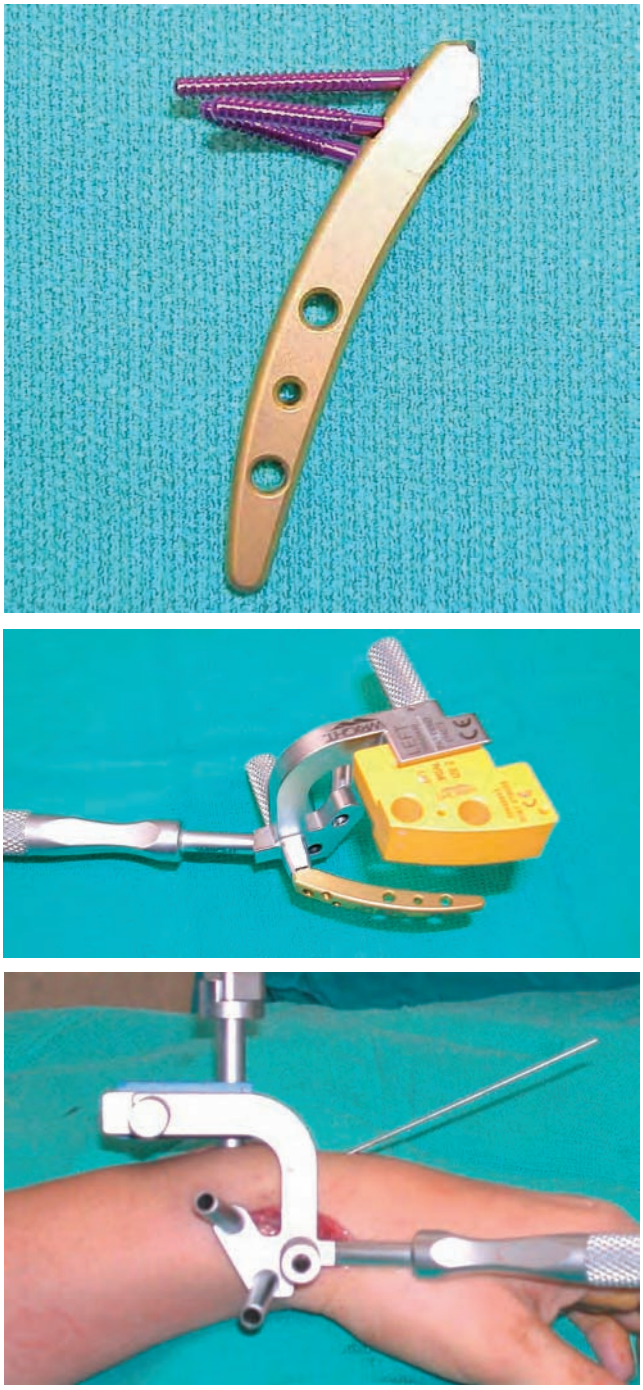


FIGURE 5 (**A**) The Micronail™ has three divergent distal screws that lock into the nail, (**B**) the outrigger jig is assembled with the appropriate nail and proximal locking guide attached, and (**C**) the nail is inserted into the channel made in the radial styloid. The drill sleeve is inserted in the dorsal locking guide for drilling of the proximal locks. *Source*: Courtesy of John T. Capo, MD.

Preoperative planning of the osteotomy is templated off the normal wrist (5). On the anteroposterior, zero rotation radiograph, shortening is measured between the distal surface of the ulna and the lunate facet of the distal radius. The degree of radial inclination is also measured on the anteroposterior radiograph. If the inclination is decreased, the osteotomy will be opened more on the radial side and a trapezoidal shaped bone graft will be needed. The degree of dorsal or volar tilt is measured on the lateral radiograph of the wrist. Accurate lateral radiographs must be obtained for the affected and normal wrists. In a true lateral view of the wrist, the pisiform lies between the scaphoid tubercle and the volar cortex of the capitate.

In planning for the distal radial osteotomy, the size of the defect needs to be estimated to determine the dimensions and type of bone graft necessary. Nascent malunions often have a significant amount of hypetrophic callus which can be used as local cancellous graft. In the case of an established malunion where correction of the shortening and angulation will produce a gap which requires a significant amount of bone graft, one must plan to either harvest iliac crest autograft or have allograft or synthetic bone graft available (Fig. 1). When harvesting iliac crest, it is not absolutely necessary to harvest structural graft; recent literature has demonstrated similar rates of union and maintenance of correction when either structural or cancellous iliac autograft were used (20).

SURGICAL TECHNIQUE

Operating Room Setup and Equipment

A radiolucent hand table or radiolucent arm-board long enough to adequately support the wrist are necessary. An image intensifier, either a mini fluoroscopy unit or a standard C-arm is required. Instrumentation which should be available is a basic fracture reduction set including bone holding and reduction clamps, periosteal elevators, a sharp dental pic, osteotomes, mallets, and ronguers. A power saw such as a microsagittal saw should also be available. General anesthesia is preferred due to the possible requirement of performing an iliac crest bone graft.

OPERATIVE TECHNIQUE

Dorsal Malunion

The patient is positioned supine with the arm abducted 90° and placed on a radiolucent hand table. A nonsterile tourniquet is used on the upper arm, and the arm is prepped and draped in a standard fashion. Using the image intensifier the location of the malunion and the site of the proposed osteotomy are marked out. Once the anatomy and the site of the osteotomy are defined, the extremity is exsanguinated with an Esmarc bandage and the tourniquet is inflated. A direct radial incision is made between the first and second dorsal compartments at the level of the radial styloid (Fig. 2A). Care is taken to identify and protect branches of the radial sensory nerve. These nerves are usually within the dorsal or volar soft-tissue flaps. Dissection is then carried down to the level of the radial styloid (Fig. 2B). This will mark the point of insertion of the IM nail.

Once the approach for the nail is completed, attention is directed at the malunion. A second dorsal longitudinal incision is made directly over the level of the malunion (Fig. 3). This second incision is the working portal through which the nonunion will be taken down, and also where the proximal locks will be placed. The skin incision is carried deep through the subcutaneous tissue and the extensor retinaculum is identified. The extensor pollicis longus (EPL) tendon is found distally and the third dorsal compartment is released from distal to proximal. The second and fourth compartments are then elevated in a subperiosteal manner and the nonunion is exposed (Fig. 4A).

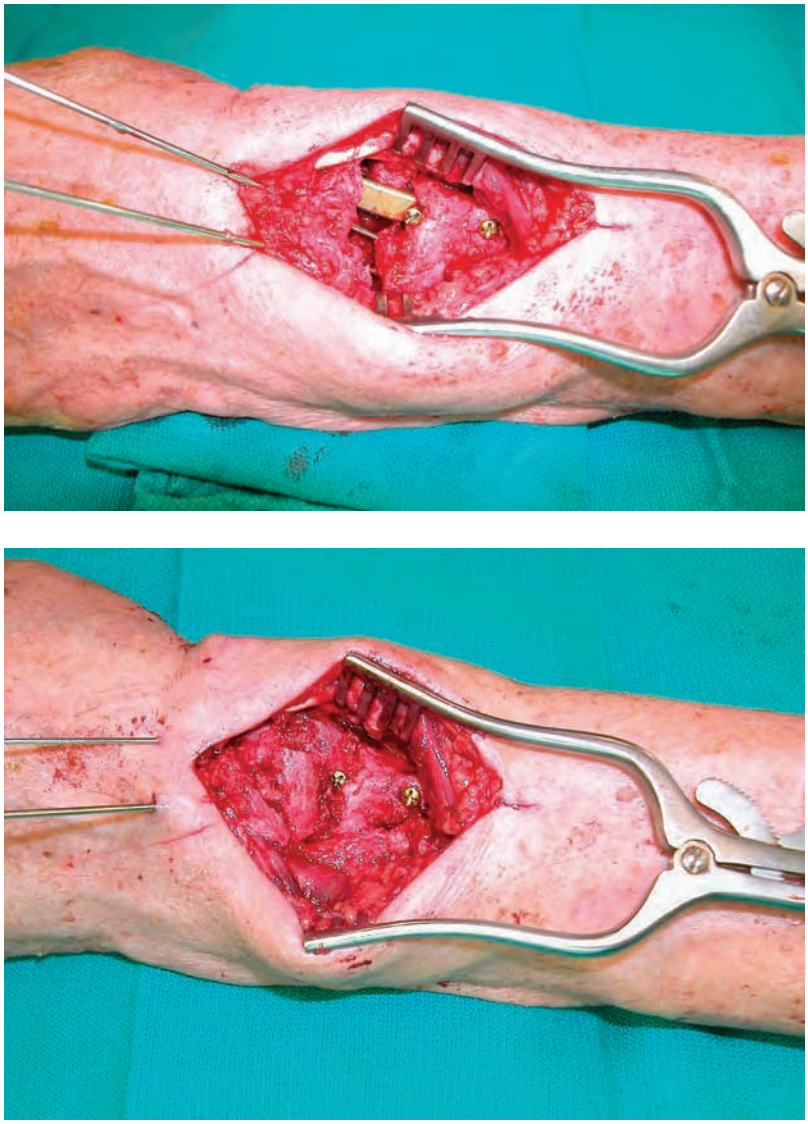


FIGURE 6 (**A**) After the malunion has been corrected and held with Kirschner (K) wires the nail is inserted and locked proximally and distally and (**B**) the osteotomy defect has been filled with iliac crest graft placed around the nail with the cortical portion placed dorsally. *Source*: Courtesy of John T. Capo, MD.

If it is a nascent malunion, often the fracture line can be found using either an osteotome or an elevator. If the fracture is more completely healed then a power saw or an osteotome is used to cut the radius at the apex of the deformity (Fig. 4B). The osteotomy should be perpendicular to the longitudinal axis of the radius in the coronal and sagittal planes. The volar periosteum can be left intact to facilitate hinging open the osteotomy, while laminar spreaders can be used to open the defect dorsally. Often the brachioradialis as well as the periosteum must be completely released. The osteotomy should be opened until the proper volar tilt and inclination is restored. If inclination needs to be increased, the radial side of the osteotomy site will require more distraction. When the distal fragment alignment approximates the contralateral wrist, the fragment is stabilized with Kirschner (K) wires. The first wire is placed retrograde along the ulnar border of the radius and the second is placed from the radial styloid, but in a dorsal position to avoid the path of the nail.

Once the deformity is provisionally stabilized attention is turned back to the IM nail insertion. The nail guide wire is placed at the styloid roughly 5 to 6 mm proximal to the articular surface. The cannulated reamer is next used to enter the radius, and sequentially larger broaches are used to open the canal. The appropriate IM nail is assembled to the jig with the corresponding proximal locking guide. The nails and proximal locking guides are color matched to avoid confusion. The nail is then inserted through the styloid incision and is placed below the K-wires to the appropriate level (Fig. 5). The three distal screws are placed and locked to the nail. At this point, the distal fragment, attached through the nail and jig, can be distracted or angulated to make fine adjustments in the position of the corrective osteotomy. The nail is then locked proximally in an open fashion through the proximal aspect of the dorsal incision.

Next the appropriate bone graft is placed around the nail. If it is a nascent malunion, often the local callous can be morselized, combined with demineralized bone graft and inserted in the defect. If a very small defect results, a synthetic calcium sulfate or phosphate replacement can be used. For large structural defects, we prefer cortico-cancellous bone graft taken from the anterior iliac crest (Fig. 6). The graft can be split into two fragments and inserted alongside the nail, or a single piece can be inserted first and the nail placed through the graft. After the nail and graft are inserted the K-wires can usually be removed (Fig. 7).

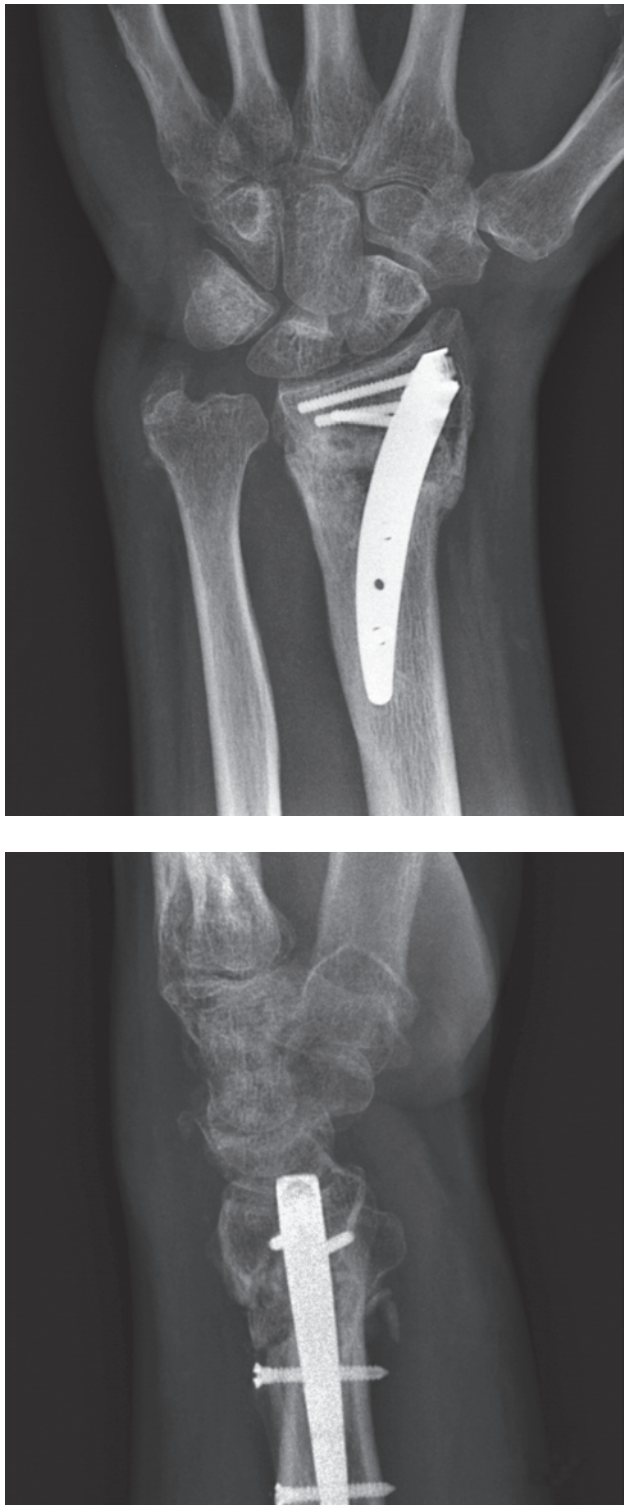


FIGURE 7 Follow-up radiographs showing: (**A**) anteroposterior and **(B)** lateral views of correction of the dorsal malunion. The Micronail™ is placed in the center of the intramedullary canal and the most distal screw is ideally placed subchondral to the articular surface. Early graft consolidation can be seen. *Source*: Courtesy of John T. Capo, MD.

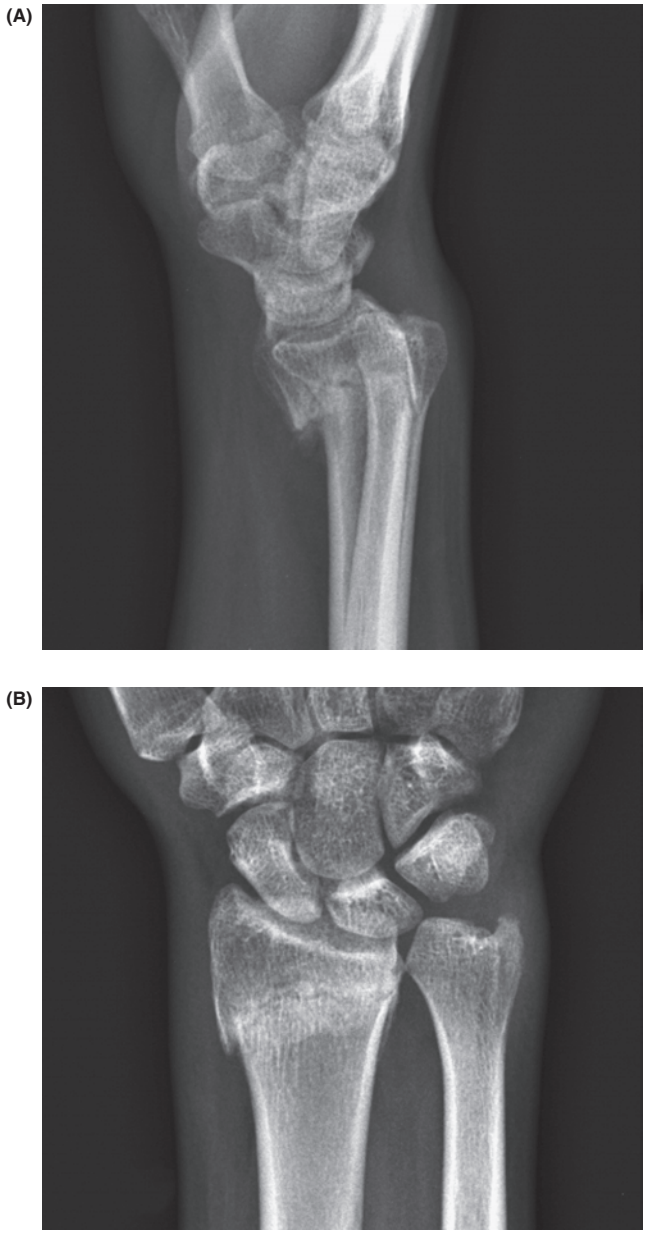


FIGURE 8 (**A**) Anteroposterior and (**B**) lateral views of a distal radial malunion with excessive volar angulation. *Source*: Courtesy of John T. Capo, MD.

Volarly Angulated Malunion

In the case of volarly displaced malunions, the procedure is technically the same with the exception of the approach to the malunion (Fig. 8). The Henry approach to the volar radius is utilized for exposing and directly correcting the malunion, while the nail is still inserted through the standard radial styloid approach (Fig. 9). Alternatively, once incision alone can be used. The styloid, nail insertion site, can be approached through an extension of the volar Henry approach in a distal and radial oblique fashion. The location of the apex of the malunion and subsequent osteotomy is identified and the malunion is divided with either an osteotome or a sagittal saw. The distal fragment is then aligned and stabilized with K-wires. The IM nail is placed through the radial styloid but the nail is locked volarly through the Henry approach. This requires mounting the nail on the insertion jig in a reversed fashion. The nail is locked distally and proximally and the graft is inserted volarly (Figs. 10 and 11). The provisional K-wires are removed and the wrist is checked for ROM and

FIGURE 9 Clinical photograph demonstrating a volar Henry approach for visualization and correction of the malunion and a radial incision for insertion of the nail. The dorsal Kirschner (K) wires are holding the corrected malunion in place. *Source*: Courtesy of John T. Capo, MD.

stability. If the DRUJ is unstable it should be addressed at this time (Fig. 12).

Closure and Postoperative Management

Through the dorsal wound the retinaculum is closed using a 2-0 nonabsorbable sutures and the EPL tendon is left transposed. The subcutaneous tissue is closed using 2-0 absorbable suture and the skin of both incisions is closed with nylon sutures. A short arm splint is placed in the operating room and the patient is discharged that day or the next morning. Finger ROM is encouraged immediately and the patient is seen in the office in 10 to 14 days. Sutures are removed, gentle wrist ROM is started, with an orthoplast splint worn between exercises. Healing typically occurs in 8 to 10 weeks.

Illustrative Case Example: Nascent Malunion

The patient is a 23-year-old right hand dominant male laborer who sustained an extraarticular distal radius fracture. He was initially managed with cast immobilization and eventually presented to our clinic approximately three months post injury. Preoperative X-rays revealed a healing fracture with 27° of dorsal angulation and significant shortening (Fig. 13). Because of the patient's high-functional demands and the associated increased risk of late degenerative arthritis, operative correction of the malunion was indicated. He underwent open correction of his malunion through a dorsal approach and stabilization with a Micronail™ (Wright Medical Technology Inc., Arlington, Tennessec, U.S.A.) with local cancellous grafting from his malunion site.

Five months postoperatively the patient is doing very well. He is pain free. Grip strength is 90% of the contralateral side, extension is 40°, flexion 70°, supination 85°, pronation 90°. Recent X-rays reveal restoration of distal radial volar tilt, inclination and height (Fig. 14).

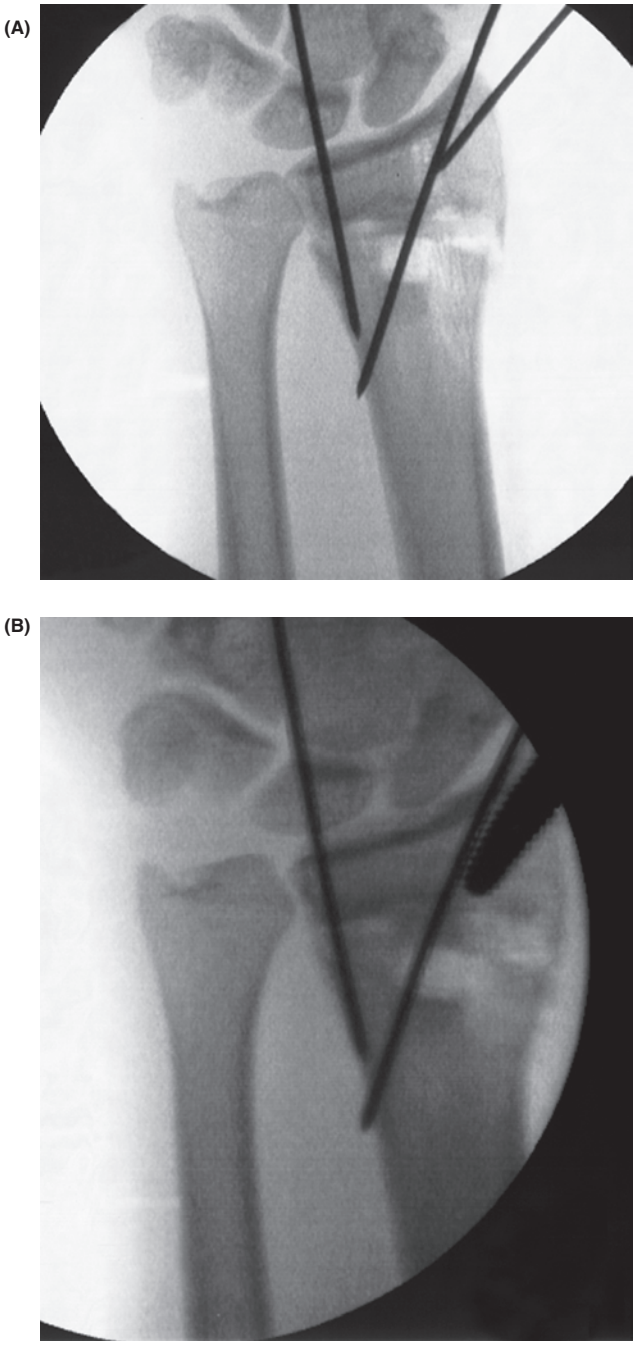


FIGURE 10 (**A**) Fluoroscopic image showing the osteotomy gap opened and stabilized with two dorsal Kirschner (K) wires. The third, most radial wire in the styloid is the guide wire for reaming and nail insertion and (**B**) the guide wire is removed and the broach is used to create a path for the nail. *Source*: Courtesy of John T. Capo, MD.

COMPLICATIONS

Complications are inherent to any surgical procedure. Use of this implant for distal radial malunions is relatively new. To date, there have been few reported complications. The radial sensory nerve is at risk during the approach to the radial styloid. In the authors reported series of acute fractures, two patients had a temporary minor radial sensory nerve disturbance (11,12). Symptoms resolved in all of these patients within two months. Other theoretical risks specific to this procedure are risk of graft dislodgement because there is no plate to incarcerate the graft.

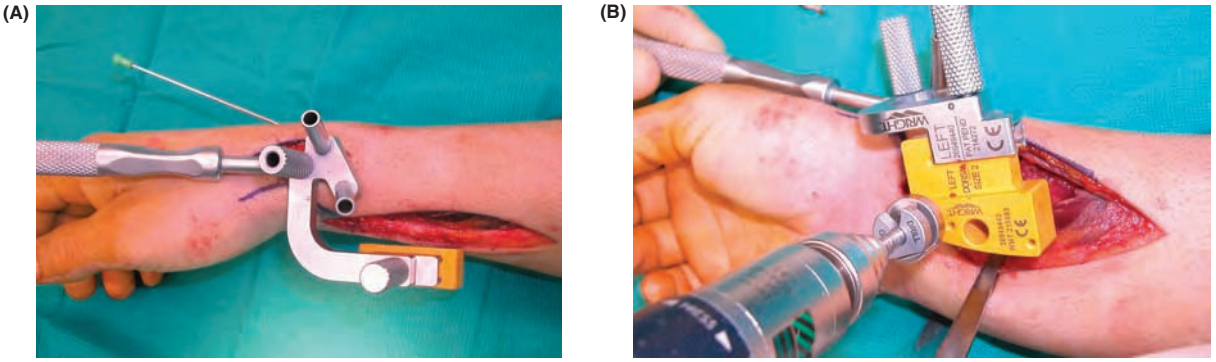


FIGURE 11 (**A**) The nail is mounted on the jig with the proximal locking guides on the volar surface of the wrist and (**B**) this allows the proximally screws to be place through the open volar approach using the appropriate guide. *Source*: Courtesy of John T. Capo, MD.

Firm impaction of the graft ensures stability, and an additional K-wire may be left in place for three weeks if desired. We have not seen this complication occur in our experience.

The risk of nonunion of the osteotomy appears to be similar to conventional plating. If non or delayed union occurs, the strength of the nail would minimize hardware failure and make repeat grafting easier. The risk of tendon irritation and rupture is lower than dorsal plate application, since the implant is buried entirely within the distal radius.

OUTCOMES

Many different authors have demonstrated excellent outcomes for corrective osteotomies for displaced distal radial malunions. Diego Fernandez has had several series which reported his results for both dorsally and volarly displaced distal radius fractures (5,21–24). In a series published in 1982 (24), he performed an opening wedge osteotomy on either the dorsal or volar surface depending on the initial direction of displacement. The osteotomies were stabilized with a buttress plate based on the side of the osteotomy. Rigid fixation allowed for early postoperative ROM. Patients went on to maintain the correction radiographically and improve functionally. With this approach, he found good to excellent results in 75% of the patients. The patients that had the best outcome had greater preoperative ROM and no existing degenerative changes in the radiocarpal joint. However, approximately 40% of the patients underwent subsequent operation to remove the hardware.

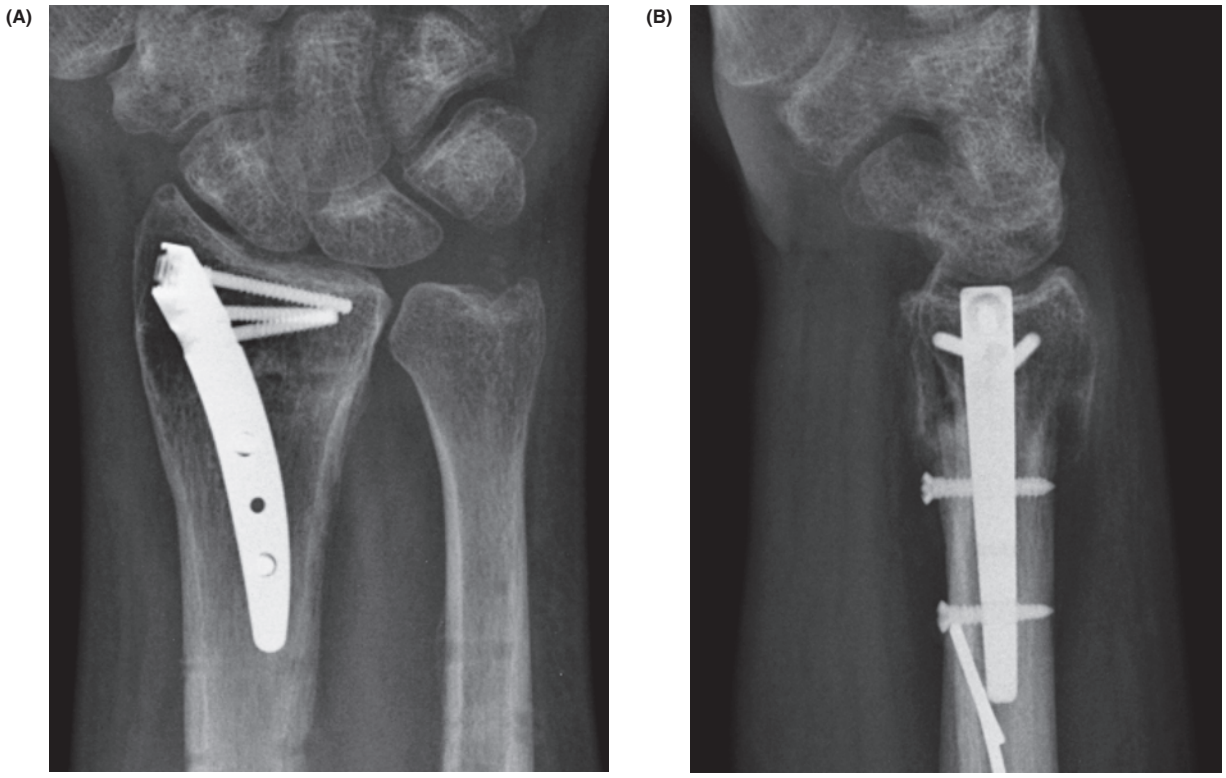


FIGURE 12 (**A**) Anteroposterior and (**B**) lateral follow-up x-rays demonstrating restored near anatomic alignment of the distal radius. After fixation with the intramedullary nail the distal radial–ulnar joint was found to still be unstable. This was reduced closed and stabilized with Kirschner (K) wires proximal to the nail. These wires can be seen on the lateral view. *Source*: Courtesy of John T. Capo, MD.

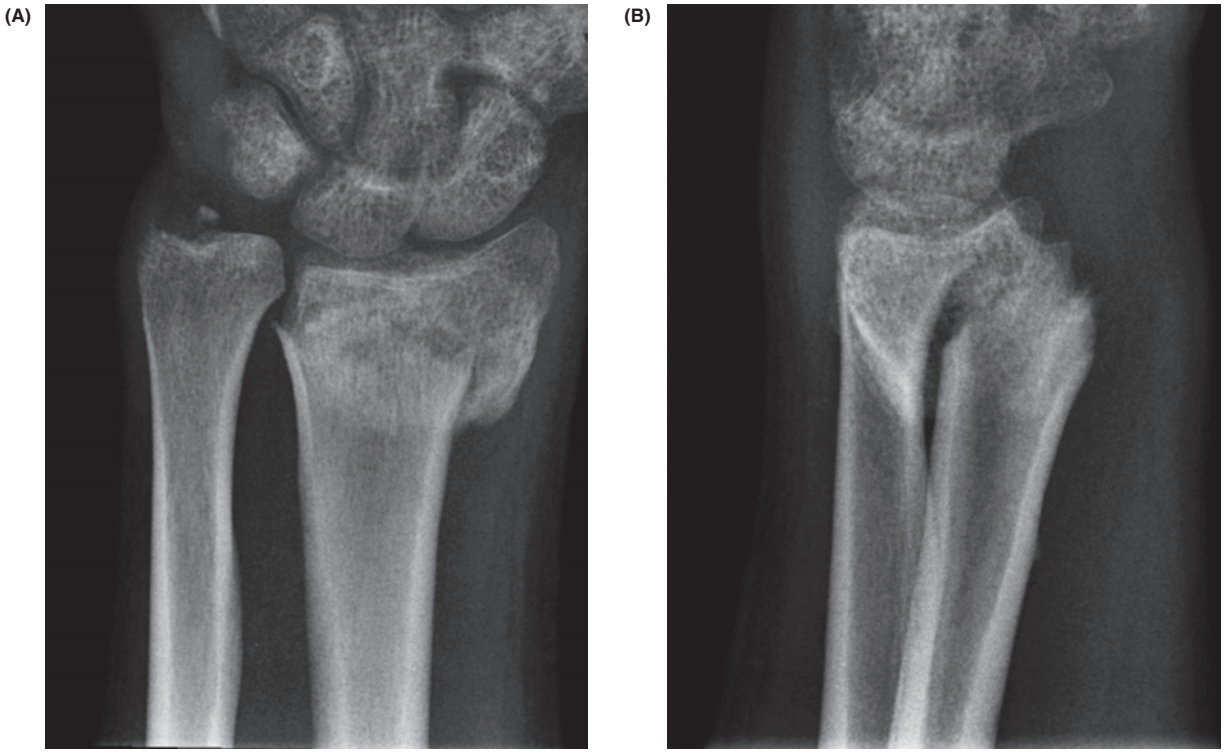


FIGURE 13 (**A**) Anteroposterior and (**B**) lateral views of a nascent malunion demonstrating severe shortening and dorsal angulation of the distal radius. *Source*: Courtesy of John T. Capo, MD.

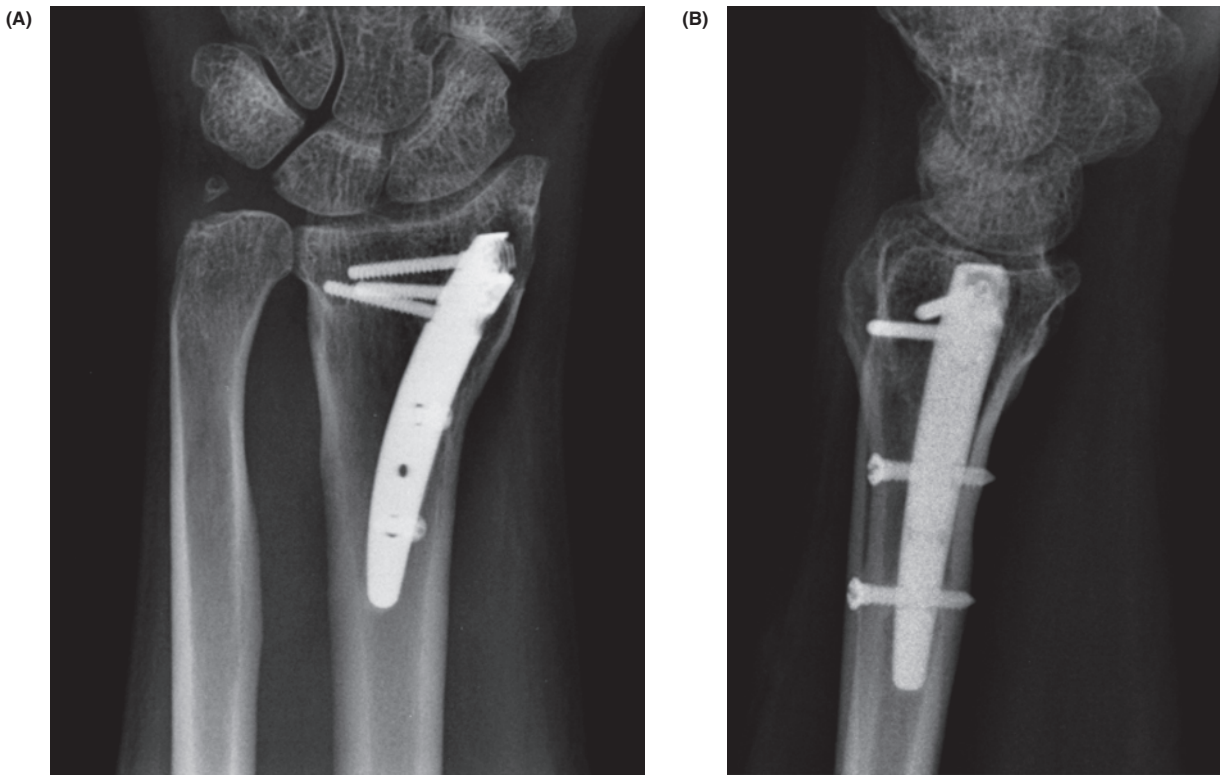


FIGURE 14 (**A**) Anteroposterior and (**B**) lateral radiographs showing restoration of normal articular anatomy. Local cancellous graft was used from the nonunion site and placed in the defect. *Source*: Courtesy of John T. Capo, MD.

There were also two cases of tendonitis of the EPL but no cases of tendon rupture.

With the advent and evolution of fixed angled locking plates, their use has spread to distal radial osteotomies. In a series by Malone et al. in 2006 (10), volarly based locking plates were employed to stabilize dorsally displaced distal radial malunions augmented with cancellous bone graft. Results demonstrated maintenance of correction on follow-up radiographs, improved disabilities of the arm, shoulder, and hand (DASH) scores, and grip strength and ROM that approached that of the uninjured side. The authors reported one complication; a fracture seven months after the time of the injury at a site proximal to the plate after a fall. At the time of the repeat surgery, there was evidence of union at the site of the osteotomy. There were no reports of tendon irritation, decreased finger or hand ROM, hardware problems or nonunion.

Preliminary results from our experience have been positive. We have performed distal radial osteotomies and IM nail fixation for distal radial malunion in 16 patients and have adequate follow-up data on 11. These 11 patients were operated on at an average of 7.6 months after the time of the original fracture. Bone graft was taken from the iliac crest in six patients, locally from the distal radius callous in four patients, and was an injectable calcium-sulfate paste in one. There were 10 dorsal malunions and one volar malunion. The volar tilt for the dorsal malunions averaged 13.1° (apex volar), while the volar malunion measured +28° (apex dorsal). All 11 of the patients healed their osteotomies at an average time period of 7.8 weeks following surgery. Physical exam, at an average follow-up of 6.1 months, showed wrist flexion of 46°, extension of 59°, forearm supination of 75°, and pronation of 80°. Radiographs postprocedure showed a correction of alignment to the following average values: volar tilt of 2.2°, radial inclination of 22.6°, and a radial length of 0.4 mm ulnar positive. There were no cases of nerve injury or tendon irritation, and grip strength averaged 67% of the contralateral side.

SUMMARY

General Conclusions

Extraarticular distal radial malunions can be addressed safely and adequately through minimally invasive procedures. A new technique of locked IM nail fixation of distal radius malunions has been shown to be effective and to have an acceptable complication rate. With careful preoperative planning, the site of the malunion can be approached through a limited incision, adequately corrected, and stably fixed through a second limited approach with an IM nail.

Future Direction of the Technique

As the technique of IM nail fixation of acute distal radius fractures becomes more mature and widely accepted, the use and indications in fixation for malunions will expand. Improvement in injectable bone substitutes will allow the procedure to become even less invasive. Indications for intra-articular malunions may expand as IM nail fixation devices are improved and are coupled with other methods of fixation.

SUMMATION POINTS

Indications

- Patients with a functional deficit secondary to malunited distal radius fractures: dorsal or volar malunion.
- Extraarticular malunions.
- Limited articular extension.
- Nascent or established malunions.

Outcomes

- High union rate.
- Little to no tendon irritation.
- Minimal hardware prominence.
- Early return to functional ROM.

Complications

- Temporary radial sensory nerve irritation.
- Nonunion rate similar to conventional techniques.

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Repair of Distal Radial Malunion with Volar Plating

David A. Fuller
Cooper University Hospital, University of Medicine and Dentistry of New Jersey, Camden, New Jersey, U.S.A.

INTRODUCTION

Osteotomy of a malunited distal radius fracture is indicated for a healed fracture, which has already produced an unfavorable outcome, or one that is likely lead to a poor clinical or radiographic result. Historically, osteotomies of the distal radius have been performed for extra-articular fracture malunions using a dorsal buttress plate and iliac crest bone grafting (1). Dorsal plating has been associated with tendon adhesions (2) and iliac crest bone grafting has donor site morbidity (3). A less invasive osteotomy technique is now possible that offers improvements over the established technique. Advances with the new osteotomy technique are attributable to improved implants, new surgical techniques, and the recent availability of synthetic bone graft substitutes. This chapter will focus on use of a volar surgical approach and volar plate fixation when performing osteotomy for malunion of the distal radius. Both extra- and intra-articular malunion will be considered in this chapter.

Newly designed implants now make it possible to treat acute, dorsally displaced distal radius fractures from a volar surgical approach (4). The implants are plates designed with locking screws that prevent settling of the construct. By placing the plate fixation on the volar aspect of the bone, extensor tendon problems can be avoided. These new implants can now be used for extra-articular osteotomies of the distal radius. For intra-articular malunions, fracture fragment-specific implants are also now available. These focal implants combined with higher resolution and reformatted, three-dimensional computed tomography (CT) scans have recently expanded possibilities for intra-articular osteotomies (5,6).

The need for iliac crest bone grafting in many clinical situations, including treatment of distal radius fracture has become unnecessary with the recent rise of bone graft substitutes (7,8). Bone morphogenic proteins and synthetic bone graft substitutes can provide both the osteoinductive and the osteoconductive environment needed to heal challenging bone defects such as osteotomies. While these products do not provide the mechanical support of an iliac crest bone graft, the improved strength of the new, fixed angle implants appears to have obviated the need for a structural graft in osteotomy of the distal radius. Utilizing these various techniques allows for a less invasive treatment of distal radius fracture malunions.

INDICATIONS

The same radiographic parameters established for treatment of acute distal radius fractures must be considered as indications for osteotomy in the symptomatic patient. These recommendations include: radial shortening of greater than 2 mm, dorsal tilt of greater than 10°, radial inclination of less than 15°, intra-articular step-off of greater than 1 to 2 mm, an incongruent sigmoid notch, and the presence of carpal malalignment or subluxation (9). These findings are predictors of a symptomatic malunion (9). Using these radiographic guidelines, the potential benefits of surgery must be weighed against the risks for each individual patient. Patient age, medical comorbidities, lifestyle, and occupation must all be considered.

Poor bone quality is a relative contraindication to osteotomy with volar plate fixation. This technique relies on structural support of the volar, fixed angle implant underneath the articular surface while the osteotomy heals. Poor bone quality can lead to settling of the bone around the implant or even cut out of the implant into the articular surface. Using the described technique, there can be difficulty gaining substantial length of the distal radius. If joint leveling for an ulnar positive wrist is necessary, a structural bone graft in the radial osteotomy site or shortening of the ulna may be required.

CONSIDERATION FOR PREOPERATIVE PLANNING

Osteotomy for extra-articular malunion is performed more commonly than osteotomy for intra-articular malunion. For an extra-articular malunion of the distal radius, orthogonal radiographs of the involved wrist are typically the only preoperative diagnostic studies necessary. The sagittal and coronal plane deformities can be determined from the radiographs. The rotational deformity in the axial plane, that is pronation or supination of the articular fragment relative to the shaft, is often best determined intraoperatively. A reformatted three-dimensional CT scan can be helpful preoperatively in evaluation of rotational malalignment. For an intra-articular malunion, a CT scan is necessary preoperatively. Radiographs of the contralateral, uninvolved wrist may provide a better reference than population data (10) and therefore may also be considered as part of the preoperative evaluation prior to osteotomy.

In addition to understanding the bone deformity, the design of the implant must be understood by the surgeon. Many implants are now available which can be used effectively for osteotomy, but the implants can differ in their screw-plate angles and screw-hole positions. The position of the locking screws within the distal, articular fragment will determine the correction achieved with osteotomy. The surgeon, prior to effective implant usage, must know the angular relationship between the locking screws and the plate so that the screws can be inserted in appropriate position into the articular fragment during osteotomy (Fig. 1).

SURGICAL TECHNIQUE

The patient is positioned supine, with a tourniquet around the brachium and fluoroscopy immediately available for

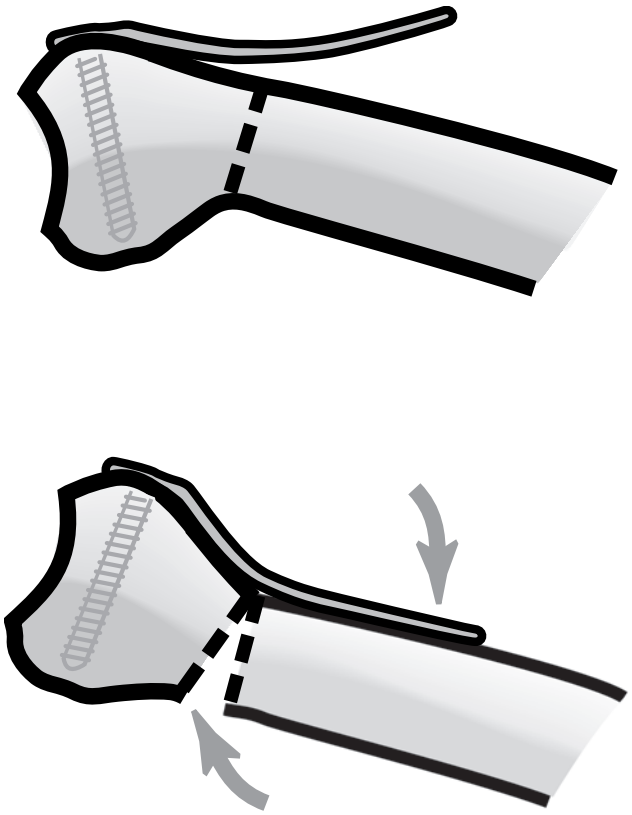

FIGURE 1 Schematic drawing of technique of using fixed angle, volar plate to achieve correction of dorsally angulated malunion when performing distal radius osteotomy. After fixation of the plate into the subchondral bone, the osteotomy is completed underneath the plate. By bringing the proximal end of the plate down to the volar surface of the radial shaft, the dorsal opening wedge defect is created. The volar tilt is restored to the joint surface of the distal radius.

intraoperative assessment. A volar incision centered over the flexor carpi radialis (FCR) tendon is made, beginning at the distal wrist flexion crease, and extending approximately 7 cm proximally. The FCR tendon sheath is incised allowing ulnar retraction of the FCR tendon along with the other volar flexor tendons and the median nerve. The pronator quadratus (PQ) is released with electorcautery from its radial attachment on the distal radius and a periosteal elevator is used to elevate the PQ in an ulnar direction. The brachioradialis (BR) tendon insertion is released by incising sharply from proximal to distal along the radial aspect of the distal radius. Releasing the BR tendon improves the mobilization of the distal radius articular fragment. Good visualization of the volar aspect of the distal radius is now possible. Often it is possible to see exactly where the original fracture occurred.

In some patients, difficulty exists visualizing the ulnar aspect of the volar distal radius with ulnar retraction of the FCR. Slight flexion of the wrist can relax the tendons to allow adequate visualization. If visualization of the ulnar aspect of the volar, distal radius from this approach remains poor, then all of the finger flexor tendons, the median nerve, and the FCR tendon should be retracted radially to expose the ulnar aspect of the distal radius prior to osteotomy. A penrose drain or rubber vessel loop can be looped around the finger flexor tendons, the median nerve, and FCR allowing easy ulnar and radial retraction of these structures as needed for the osteotomy.

Extra-Articular Osteotomy

The most common malunion of the distal radius has excessive dorsal angulation (Fig. 2) and the goal of surgery is to increase the volar tilt. For the osteotomy of the extra-articular malunion, the soft tissues should be mobilized on the dorsal aspect of the distal radius by sweeping a small periosteal elevator around the dorsal aspect of the distal radius from both the ulnar and the radial sides. The tendons of the first dorsal compartment are elevated in a subperiosteal fashion while working around the dorsum from the radial side. On the ulnar side, the capsule of the distal radioulnar joint is typically not opened as the osteotomy is just proximal to this joint. Once the dorsal soft tissues have been mobilized, small reverse retractors can be passed at the approximate level of the osteotomy from both the radial and the ulna aspects of the distal radius to protect the dorsal soft tissues.

Based upon intraoperative inspection and preoperative determinations, the level of the osteotomy can be marked on the volar distal radius with a surgical marking pen. Routinely, the osteotomy is performed directly through the old fracture site which is in the mid-metaphysis. The volar plate is brought into the surgical field now and placed against the volar, distal radius to approximate its position. Adequate bone distal to the osteotomy site should exist to allow for safe insertion of the distal, subchondral screws through the plate, and into the articular fragment. Fluoroscopy should be used at this point to confirm the level of the osteotomy and plate position. The position of the distal, locking screws in the subchondral bone will determine the final alignment of the distal articular fragment.

The plate should now be removed from the surgical field and the osteotomy started along the pen line using fine, sharp osteotomes. Oscillating saws may cause thermal injury and unnecessary loss of bone and are not recommended. The osteotomy should be made incompletely at first. The volar aspect of the distal radius and the thick cortical bone along the radial and especially ulnar aspects should be cut. This should leave the dorsal cortex of the distal radius malunion intact.

With the dorsal cortex intact, the plate should be brought back into the surgical field to begin insertion of the distal, locking screws. The distal, locking screws should be inserted into the subchondral bone distal to the osteotomy site. The proximal end of the plate needs to be held in an elevated position off of the radial shaft while the distal screws are inserted. The number of degrees that the plate is elevated off of the radial shaft equals the amount of sagittal plane correction that will occur at the completion of the surgical case. This amount of correction is determined from the preoperative X-rays and is based on the severity of the malunion.

Another measure to confirm the correct position of the plate is to evaluate the angle subtended by the locking screws and the articular surface of the distal radius intraoperatively on the lateral fluoroscopic view of the joint. For a plate with the screws positioned at 90° relative to the plate, placement of the screws parallel to the joint in the subchondral bone will only bring the joint to neutral (0°) once the plate is affixed to the radial shaft later in the case. Radial inclination is often decreased in distal radius malunions and the osteotomy should attempt to restore radial inclination as well. Rotation of the proximal end of the plate toward the ulna prior to insertion of the subchondral screws will allow increasing radial inclination after osteotomy as the plate is brought down to the radial shaft.

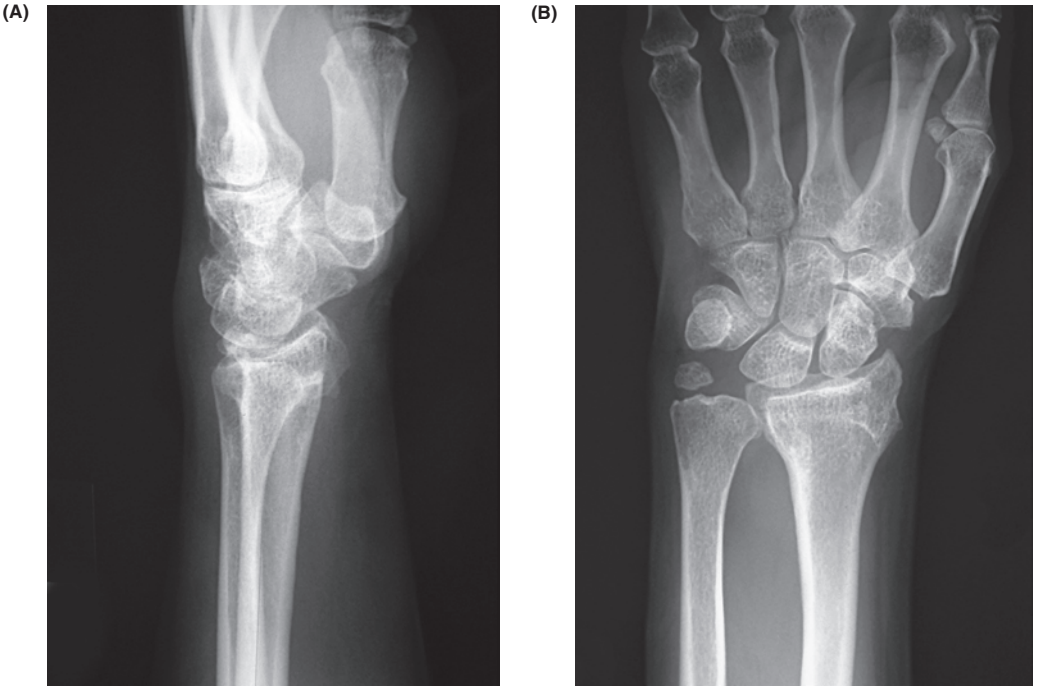

FIGURE 2 (**A**,**B**) Radiographic images of a 35-year-old female with a dorsally angulated malunion of the distal radius. The dorsal tilt measures 28°. The original injury was treated one year previously with dorsal bone grafting and pinning. She was painful and weak at presentation one year after the initial injury.

Once the distal screws are in the subchondral bone and are locked into the plate, the proximal end of the plate should be in a position of elevation from the radial shaft. This applies for the more common malunions that heal with dorsal angulation.

The osteotome is used once again and working underneath the plate, the dorsal cortex of the distal radius is cut (Fig. 3) thus completing the osteotomy. Once this cut is completed, the distal, articular fragment is mobile relative to the shaft.

The correction (Fig. 4) is now achieved by bringing the proximal end of the volar plate down to the volar aspect of the radial shaft. By bringing the plate down, the distal articular piece will flex the predetermined amount. Coronal correction will also be achieved by bringing the plate into alignment with the radial shaft. There is typically some flexibility with coronal correction due to the flat nature of the volar aspect of the radial shaft. Greater correction of radial inclination can be achieved by rotating the proximal end of the plate away from the ulna. As the plate is brought down against the volar shaft, correction of malrotation in the axial plane should occur as well if the distal end of the plate is anatomically contoured to the volar distal radius. The position of the subchondral screws should be observed to make sure that they are not cutting through the bone. The screws should be positioned as distally as possible where the bone is strongest.

Once the plate has been brought down flush with the radial shaft, then several bicortical screws should be inserted into the proximal end of the plate to stabilize the construct. This will leave an opening wedge bone defect underneath the plate at the osteotomy site. Working around the radial aspect of the distal radius, this defect is easily accessed. This gap can be filled with a granular synthetic bone graft substitute such as tricalcium phosphate or hydroxyapatite. Other agents that can stimulate bone healing, such as bone morphogenic proteins, can be considered as well. Once the gap has been filled, the wound can be closed.

Intra-Articular Osteotomy

For the osteotomy of the less common intra-articular malunion, the volar surgical approach is essentially the same and will be directed at the malunited fragment. From the volar approach, this may be a displaced volar, ulnar corner fragment (Fig. 5), or an unacceptable step-off between the scaphoid and lunate facets. Unlike the osteotomy for the extra-articular malunion, the joint capsule must be opened to visualize the joint surface for an intra-articular malunion. The volar capsule can be opened transversely and should be repaired later. Very fine osteotomes should be used to gently mobilize the malunited fragment. Once the osteotomy has been preformed and the joint surface reduced, a small implant is used in a buttress fashion to hold the bone fragment reduced (Fig. 6). Typically bone graft is not necessary, but if desired, a small amount can be harvested as a core punch from the distal radius or alternatively a synthetic bone graft substitute can be used.

The tourniquet should be deflated prior to closure to inspect for any bleeding particularly around the radial artery. During closure, the PQ can sometimes be reapproximated over the plate. Skin is typically closed with a 3-0 absorbable suture in the subcutaneous tissue and a 3-0 nonabsorbable suture in the skin. Patients are admitted to the hospital overnight to help manage pain and swelling. A drain is typically left in the wound, which is removed on the first postoperative day prior to discharge. Active wrist flexion and extension exercises are encouraged beginning on the first postoperative day. The patient is given a removable wrist orthosis to use for the first few weeks after surgery for comfort.

COMPLICATIONS AND THEIR MANAGEMENT

Complications of the described, less invasive, extra-articular osteotomy technique are not fully known yet as this is a new technique with few outcomes reported (11). Because the

FIGURE 3 Intraoperative view of osteotomy. The plate is fixed to the subchondral bone distally. The osteotomy, which was partially completed prior to attachment of the plate distally, is now being completed underneath the plate. The dorsal cortex is being cut with the osteotome which is positioned in the osteotomy site. The volar, radial, and ulnar cortices of the distal radius were cut prior to attachment of the plate.

alignment after osteotomy depends entirely on the plate and screws rather than a strong piece of cortical bone in the osteotomy site, concern exists for settling of the articular fragment and loss of alignment. It is theoretically possible for the screws to cut through the articular surface particularly in osteopenic bone which may be encountered from disuse. The more quickly the osteotomy site can heal, the shorter the dependence on the hardware. For the very small fragments encountered during intra-articular osteotomy, avascular necrosis of the fragment is a risk. Nonunion is also a potential

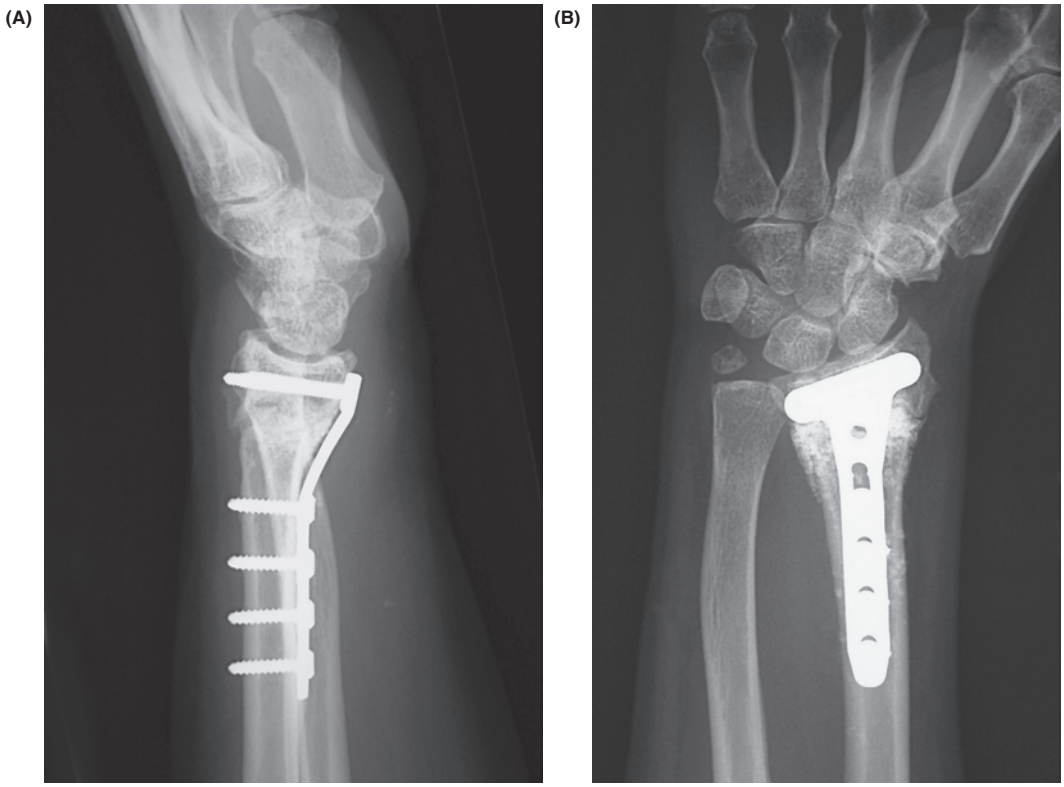

FIGURE 4 (**A** and **B**) Eight month follow-up radiographs of patient. The volar tilt and radial inclination of 11° and 22°, respectively, have been restored. Tricalcium phosphate has been placed into osteotomy site and is incorporating as new bone. No loss of alignment has occurred from immediate postoperative radiographs.

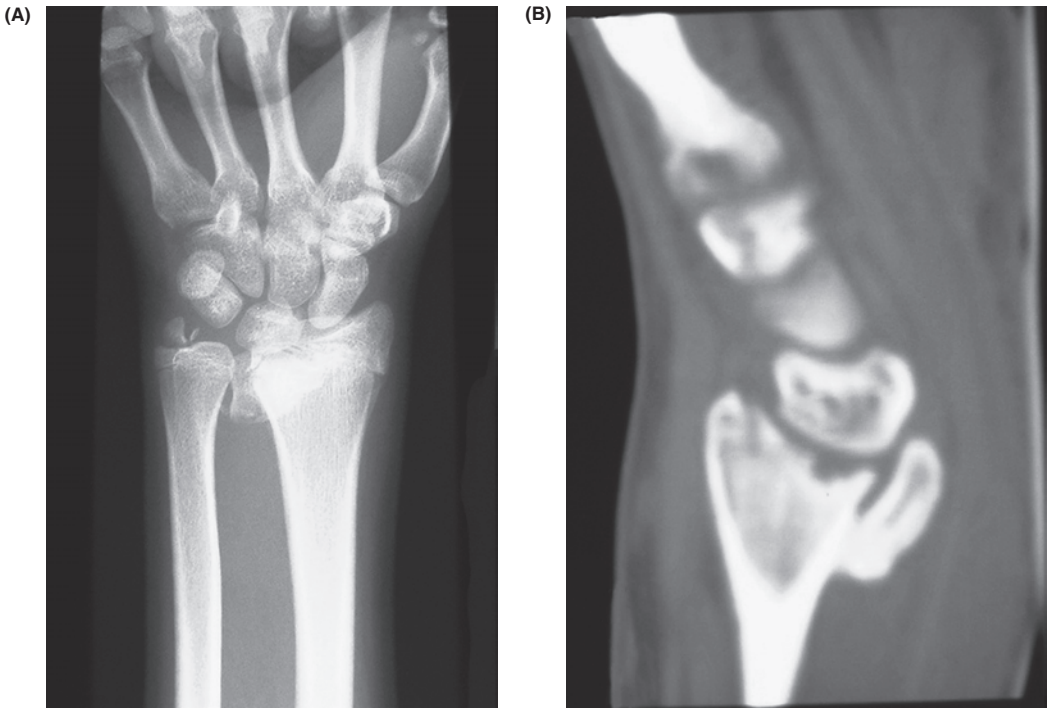

FIGURE 5 (**A**) Radiographic image of 16-year-old female with a 3-month-old, intra-articular malunion of distal radius fracture. There is deformity of the lunate fossa. The initial injury was treated nonsurgically. She was painful, weak, and had very limited motion particularly in pronation and supination. (**B**) Computed tomography scan of malunion. Image shown is a sagittal view through the lunate fossa. The articular fragment is displaced volarly with the articular surface rotated 90° and facing dorsally. The fragment has healed to the volar cortex in this position. There is volar subluxation of the lunate. This is a rotational injury in the axial plane, wherein the entire carpus pronates away from the radial shaft.

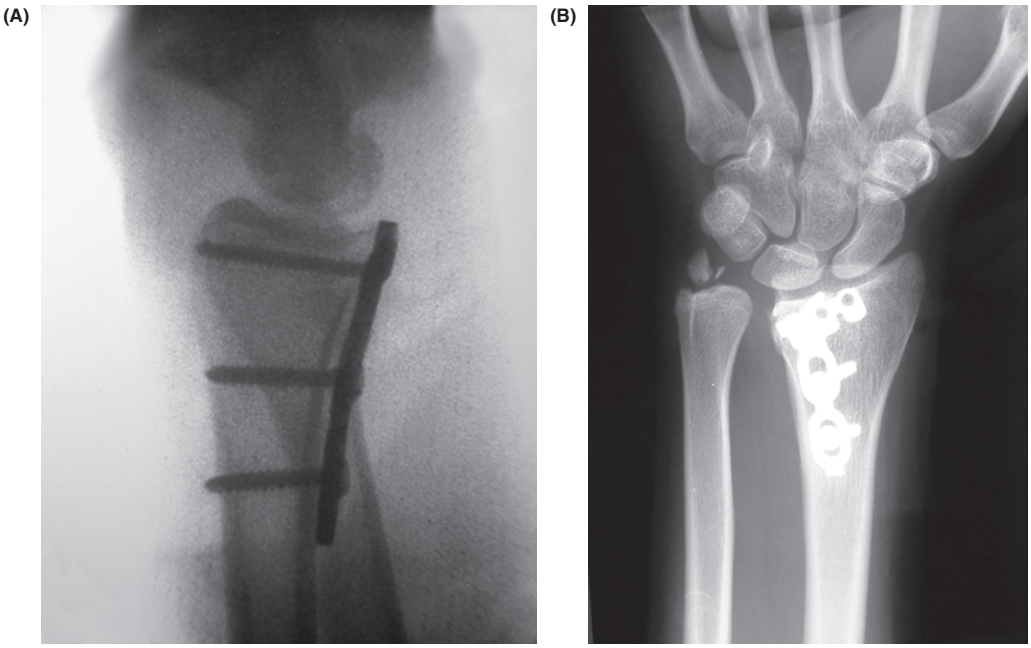

FIGURE 6 (**A**) Intraoperative lateral fluoroscopic view of volar plate buttressing the articular fragment after osteotomy. The articular fragment was approached through a volar incision and mobilized by using osteotomes to cut through the healed section attaching the fragment to the distal radius. Direct visualization of the joint surface is necessary to guide the osteotomy, reduction, and placement of the plate. (**B**) One-year follow-up radiograph. Healing occurred without any signs of avascularity of the fragment. Complete and pain free motion and strength were restored for the patient.

complication of osteotomy. None of these complications have been observed in this author's experience.

If difficulty is encountered intraoperatively with achieving adequate correction, it may be possible to bend the plate in situ to establish more volar tilt to the articular fragment. If the fixation does not appear to be adequate or the bone appears weak, it is possible to reinforce the construct with more support in the bone defect. Bone graft substitutes that will harden in situ do exist that can be inserted and will provide some resistance to compression. Alternatively, a cortical strut of bone can be inserted from this approach, if it is felt that this is necessary. Once the reduction with the plate has been achieved, a wedge-shaped piece of cortical bone can be impacted into the gap underneath the plate from the radial side of the plate.

OUTCOMES

Extra- and intra-articular osteotomy of the distal radius are established techniques, both safe and effective, for treatment of symptomatic malunion of the distal radius (1,5). Only recently has a peer-reviewed series of extra-articular osteotomies done using a technique similar to that described in this chapter been published (11). In this series, outcomes were favorable in the four reported patients. Radiographic parameters and functional scores all improved after osteotomy. One important distinction between this published series and the technique described in this chapter is that the published series included the use of varying types of autologous bone graft. The described technique in this chapter without the use of autologous bone graft has been effective in this author's experience of five patients with short-term follow-up. For these five patients, the osteotomies were clinically healed by three months and all patients were very satisfied. All of these extra-articular osteotomies were performed for dorsally angulated, extra-articular malunions. Volar tilt was restored for all these patients to a range of 0° to 10°. No nonunions or loss of reduction were observed in this series of five patients.

The advantages of a less invasive procedure have been realized at least in early follow-up in a few small series. Long-term follow-up is necessary to ensure that the final functional outcome is at least equivalent to the established technique of dorsal plating with iliac crest bone graft.

SUMMARY

Realignment of the skeletal system after a healed fracture is inherently a major operation that attempts to alter an undesirable outcome. Outcome studies after distal radius fractures guide our understanding of what is acceptable alignment for a healed fracture and therefore when an osteotomy should be considered. Osteotomy has been shown to improve outcome after a malunited fracture. A less invasive technique for osteotomy of the distal radius is now possible and has been described in this chapter. This technique is possible due to new implants and synthetic bone graft substitutes. Long-term follow-up and greater patient numbers are needed to validate this technique.

SUMMATION POINTS

Indications

- Symptomatic malunion.
- Minimal osteoarthrosis.
- Adequate bone quality for fixation.

Outcomes

- Restoration of bone anatomy.
- Good patient satisfaction.
- Safe and effective.
- Functional improvement.

Complications

- Loss of reduction.
- Plate failure.
- Nonunion.

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Surgical Setup and Intra-articular Anatomy

David J. Bozentka
Department of Orthopedic Surgery, University of Pennsylvania Medical Center, Philadelphia, Pennsylvania, U.S.A.

INTRODUCTION

Wrist arthroscopy has become a common diagnostic and therapeutic tool following improvements in instrumentation and description of the various wrist portals in 1985 (1). As the benefits of wrist arthroscopy became evident, the arthroscopic assessment of other small joints such as the metacarpophalangeal (MP) joints and carpometacarpal (CMC) joints developed. Surgical small joint arthroscopy of the upper extremity has continued to evolve.

Due to magnification of the intra-articular structures and the small size of the arthroscopic instruments, arthroscopy improves access to small joints and our visualization as compared to open exposures. Arthroscopy provides an invaluable opportunity to evaluate the extent and significance of joint disorders allowing the surgeon to palpate cartilage surfaces and ligaments. In addition to the diagnostic capabilities, arthroscopy provides multiple therapeutic options. Many open procedures can now be performed more efficiently through smaller incisions with limited surgical dissection, less postoperative pain and earlier return of function.

INDICATIONS

Common arthroscopic procedures for the small joints of the upper extremity involve debridement with loose body removal, synovectomy including lavage for a septic joint, arthroscopic assisted fracture treatment, as well as the assessment and management of chondral lesions. Procedures specific for the wrist include repair or debridement of triangular fibrocartilage complex (TFCC) injuries, wrist ganglion excision. Bone excisions can be performed such as a radial styloidectomy, carpal bone excision including proximal row carpectomy (PRC) or partial distal ulna excision (i.e., wafer procedure). Wrist arthroscopy is helpful in the treatment of interosseous ligament injuries including the use of thermal shrinkage, as well as treatment of scaphoid and distal radius fractures (2). Fracture treatment at the CMC and MP joints are also aided by arthroscopy due to the difficulties related to the shape and limited space of these joints. Repair of ulnar collateral ligament (UCL) injuries of the thumb MP joint can be assisted with arthroscopy as well as, arthroplasty of the thumb CMC joint with or without ligament reconstruction (3–5).

Despite the advantages of upper extremity small joint arthroscopy, there are several situations in which the arthroscopic procedure is contraindicated. Certain disorders are best treated by open techniques. Although TFCC injuries are treated arthroscopically, procedures such as ligament reconstruction for distal radial joint instability are best performed by an open technique. Arthroscopic treatment of scaphoid fractures is considered for the fracture without a collapse deformity. Scaphoid fractures with a humpback deformity should be treated with an open reduction and wedge bone graft to reconstruct the normal scaphoid alignment. Limitations are also related to the timing of the procedure. For example, arthroscopic treatment of distal radius fractures is ideally performed at three to seven days after the injury. There tends to be less intra-operative bleeding, two to three days following the injury. In addition, fracture healing that occurs after this time period makes manipulation of the fragments more difficult (6).

PREOPERATIVE PLANNING

The diagnosis of an upper extremity disorder is usually evident following a thorough preoperative history, physical examination, and appropriate X-rays. Further imaging using high resolution MRI will aid in the diagnosis of avascular necrosis, arthritic changes small non-palpable ganglion cysts and documentation of interosseous ligament and TFCC injuries (7,8). Documentation of the location and severity of symptoms is essential since asymptomatic disorders found during the preoperative work up and at the time of arthroscopy may not require treatment (9).

SURGICAL TECHNIQUE

Operative Setup

Arthroscopy of the wrist and hand is performed under regional block or general anesthesia. The patient is supine on the operating table and the involved upper extremity is placed on an attached hand table (Fig. 1). The video tower is positioned on the opposite side of the operating table. The tower includes the video monitor, light source, shaver, and thermal probe power source as well as a video and image documentation system. A small fluoroscopy unit, if required, is placed at the head of the bed and the scrub nurse is at the end of the hand table for assistance. A non-sterile pneumatic tourniquet is applied to the upper arm padded with webril.

In the past, an overhead traction apparatus with the elbow held at 90° was used for joint distraction. The overhead boom tended to be bulky and limited the options for wrist positioning. Now commercially available self-contained traction towers are most often used. These devices allow variable distraction with the forearm suspended in a vertical position and easy access to the joint, which may be placed in various positions. Alternatively, wrist arthroscopy can be performed with the extremity in a horizontal position and traction applied by a weight attached through a pulley over the end of an adapted

FIGURE 1 Photograph of intraoperative wrist arthroscopy setup.

hand table. During arthroscopic assisted fixation of distal radius fractures, distraction may be applied through a traction tower or an external fixator. An external fixator that allows incremental adjustment of distraction and multi-planar alignment is helpful.

Nylon finger traps are placed on the digits for distraction. Metallic finger traps are not used, particularly in the elderly patient, to prevent skin damage or digital neuropraxia adjacent to bony prominences. Ten to 15 lbs of traction is applied through the joint.

A gravity assisted flow irrigation system is adequate with the height of the bag of fluid correlating to the amount of joint distension. In-flow pressure may also be maintained by an assistant with a syringe or pinch pump on the infusion line. Pressure sensing irrigation systems allow a constant flow of fluid for a consistent pressure for joint distension. Care must be taken with any of these devices to limit fluid extravasation particularly during the treatment of wrist fractures.

The radiocarpal joint (RCJ) is evaluated using a 2 to 3 mm diameter arthroscope angled 25° to 30°. To assess the CMC or MP joints, a 1.5 to 2 mm arthroscope is utilized. These smaller arthroscopes may also be useful for the assessment of the midcarpal and distal radioulnar joints (DRUJ). Additional useful instrumentation includes appropriately sized probe, assorted graspers, suction punch, and shaver with a full radius resector and bur. Small joint electro thermal micro ablation probes are useful in TFCC debridement while thermal probes are also available for chondroplasty and interosseous ligament thermal shrinkage. TFCC repair kit should be available for treatment of peripheral TFCC injuries.

Operative Technique

Wrist Joints

The major neurovascular structures traversing the wrist are located palmarly; Therefore, the majority of portals for arthroscopic assessment and instrumentation are situated on the dorsal aspect of the wrist. A systematic evaluation of the articular surfaces and ligaments is performed initially at the RCJ (Fig. 2). The portals for the RCJ are named according to their location with respect to the extensor compartments (Fig. 3). The 3/4 portal lies between the third and fourth extensor compartments. This is the workhorse portal and is situated just distal to Lister's tubercle. The 4/5 portal, located between the fourth and fifth extensor compartments lies just distal to the DRUJ. The 6R portal is located just radial to the extensor carpi ulnaris tendon. The 6U portal, which lies ulnar to the extensor carpi ulnaris tendon, is used less often due to the higher risk of injury to the adjacent dorsal ulnar sensory nerve branch. Another seldom-used portal is the 1/2 portal, which provides a radial view of the RCJ similar to that of the 3/4 portal. It is located radial to the extensor carpi radialis longus tendon and ulnar to the extensor carpi radialis brevis tendon just distal to the radial styloid. Care must be taken on making this portal due to the proximity of the dorsal radial sensory nerve and deep branch of the radial artery.

The arthroscope is initially placed through the 3/4 portal. The fat pad, which lies in front of the radioscapholunate (RSL) ligament, is visualized. This fat pad is a consistent landmark for the arthroscopist. The articular surface of the radius including the scaphoid and lunate facets is examined for chondral

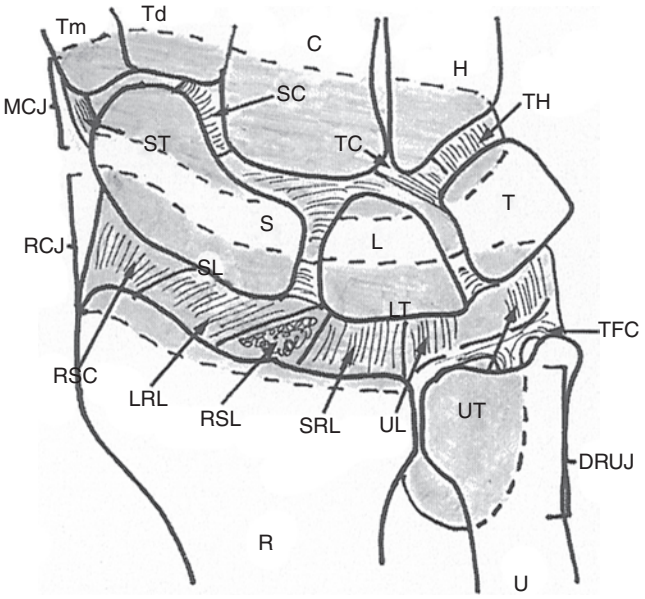

FIGURE 2 Diagram of the wrist from a dorsal perspective demonstrating the regions of the major joints (*shaded regions*) and arthroscopically visible ligaments. *Joint spaces*: DRUJ, distal radioulnar joint; MCJ, mid-carpal joint; RCJ, radiocarpal joint. *Bones*: C, capitate; H, hamate; L, lunate; R, radius; S, scaphoid; T, triquetrum; Td, trapezoid; Tm, trapezium; U, ulna. *Ligaments*: LRL, long radiolunate; RSC, radioscaphocapitate; RSL, radioscapholunate; SC, scaphocapitate; ST, scaphotrapezium; TC, triquetrocapitate; TFC, triangular fibrocartilage; TH, triquetrohamate; UL, lnolunate; UT, ulnotriquetral. *Source*: From Ref. 10.

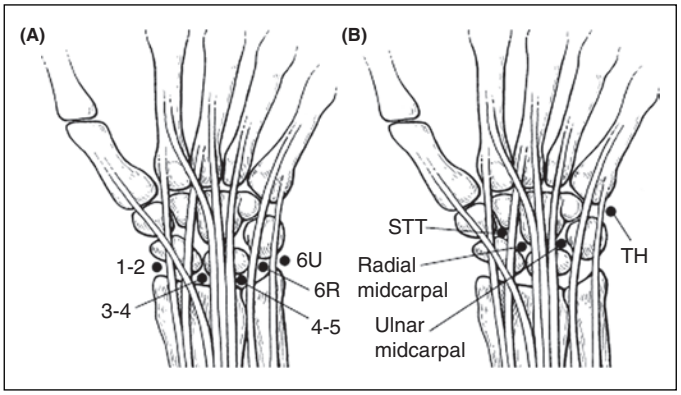

FIGURE 3 (**A**) The standard radiocarpal portals and (**B**) the standard midcarpal portals. *Abbreviations*: STT, scapho-trapezio-trapezoid; TH, triquetrohamate. *Source*: From Ref. 2.

changes. The articular surfaces of the proximal pole of the scaphoid and lunate carpal bones are visualized and the scapholunate ligament is probed through the 4/5 portal. Attention is directed to the radial gutter looking for loose bodies. The extrinsic ligaments, which extend from outside the carpus and attach to the carpal bones, are then evaluated. The radioscaphocapitate (RSC) ligament is the radial most extrinsic ligament of the wrist (Fig. 4). This ligament extends from the distal radius to the capitate coalescing with the ulnocapitate ligament distally to form the arcuate complex. This complex acts as a support for the head of the capitate. The adjacent ligament ulnarly is the long radiolunate ligament. This ligament is very broad measuring two to three times the width of the RSC ligament. Visualization more ulnarly in the region of the fat pad, the RSL ligament is encountered. It was previously termed the ligament of Testut and arises at the ridge between the scaphoid and lunate facets. The RSL ligament once believed to be very important for wrist stability has more recently been found to be of limited mechanical importance carrying neurovascular structures (11). The short radiolunate ligament extends from the lunate facet to the lunate. This ligament is often noted to be intact following a perilunate dislocation holding the lunate to the volar rim of the radius.

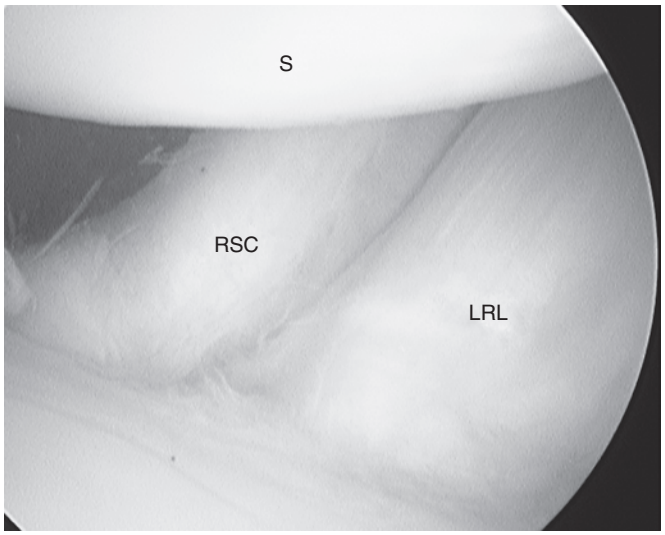

FIGURE 4 Arthroscopic view of the radioscaphocapitate ligament, long radiolunate ligament, and scaphoid from the 3/4 portal. *Abbreviations*: LRL, long radiolunate ligament; RSC, radioscaphocapitate ligament; S, scaphoid.

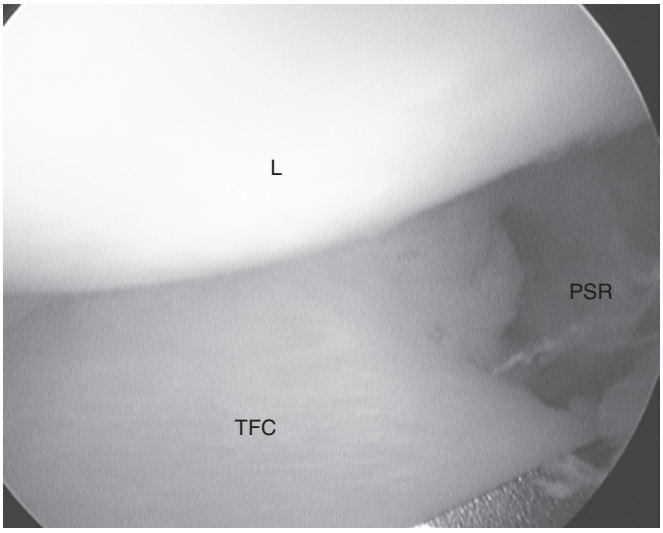

FIGURE 5 Arthroscopic view of the triangular fibrocartilage complex, prestyloid recess, and lunate from the 3/4 portal. *Abbreviations*: L, lunate; PSR, prestyloid recess; TFCC, triangular fibrocartilage complex. *Source*: Courtesy of Mayo.

The ulnar extrinsic ligaments and TFCC lay ulnar to the lunate facet (Fig. 5). The ulnar extrinsic ligaments course from the triangular fibro-complex proximally to the carpus distally. The ulnolunate ligament is the most radial of these ligaments and is contiguous with the short radiolunate ligament. The adjacent ulnotriquetral (UT) ligament forms the ulnar wall of the RCJ. In 70% of normal adults the pisotriquetral joint can be visualized through an opening in the ligament with the scope in the 4/5 or 6R portals. A constant orifice in the UT ligament is the prestyloid recess typically noted to have abundant synovial tissue. The ulnocapitate ligament lies between the ulnolunate and UT ligaments and forms the ulnar aspect of the arcuate complex as it coalesces with the RSC ligament distally (12).

The TFCC is composed of the articular disc, meniscus homologue, volar and dorsal distal radial ulnar ligaments, the ulnar extrinsic ligaments and deep component of the extensor carpi ulnaris tendon sheath. The complex provides support for the ulnar carpus and stabilizes the DRUJ. The integrity of the TFCC is evaluated by performing a trampoline test. A normal TFCC should have adequate tension while balloting the disc with a probe. Laxity on performing the maneuver is consistent with a peripheral tear.

The scapholunate interosseous ligament (SLIL) is found distal to the fat pad at the interfacet ridge of the radius. It is best visualized through the 3/4 portal and palpated with a probe through the 4/5 or 6R portals. The ligament is probed to evaluate the thick volar and dorsal components as well as the thin less clinically significant central or intramembranous component. The dorsal component of the SL ligament is well visualized with the arthroscope through a more ulnar radiocarpal portal while the probe is placed through the 3/4 portal. The volar aspect of the SLIL can be directly assessed through the volar radial portal. To make this portal, an incision is made just proximal to the volar wrist crease to expose the flexor carpi radialis tendon (FCR). The FCR tendon is retracted and the portal position is verified with a 19-gauge needle just radial to the FCR sheath at the RCJ line. The lunotriquetral (LT) interosseous ligament is not well visualized through the 3/4 portal and requires the arthroscope to be placed in the 4/5 or 6R

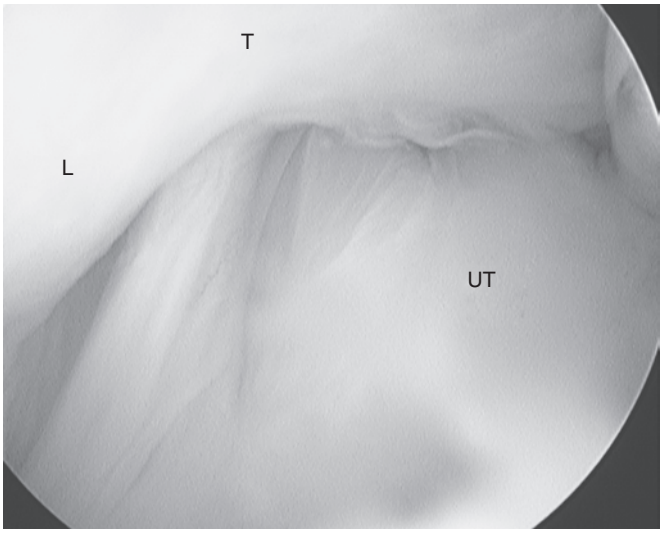

FIGURE 6 Arthroscopic view of the lunotriquetral interval from the 3/4 portal. The lunate, triquetrum, and ulnotriquetral ligament can be visualized. *Abbreviations*: L, lunate; T, triquetrum; UT, ulnotriquetral ligament.

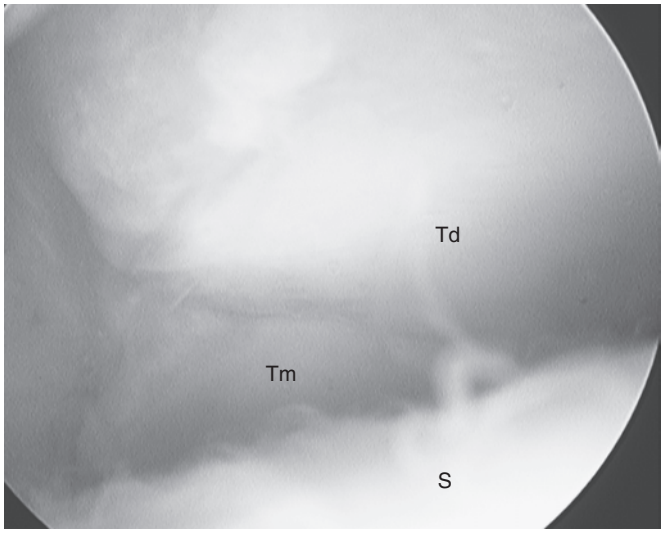

FIGURE 8 Arthroscopic view of the scaphoid, trapezium, and trapezoid at the scaphotrapezialtrapezoidal interval viewing from the radial midcarpal portal. *Abbreviations*: S, scaphoid; Td, trapezoid; Tm, trapezium.

portal. The intact ligament appears as a smooth convex surface between the lunate and triquetrum (Fig. 6).

The midcarpal joint is initially evaluated through the radial midcarpal portal. This portal is made 1 cm distal to the 3/4 portal in line with the third metacarpal. The location for the portal can be palpated as a depression between the scaphoid and capitate. The ulnar midcarpal portal, located 1 cm distal to the 4/5 portal is used initially for outflow. The scapholunate and LT intervals at the midcarpal joints are devoid of ligament. The intervals are evaluated for step-off or widening, which if present is consistent with ligamentous injury (Fig. 7). The scapho-trapezio-trapezoid (STT) interval is visualized by directing the scope distally between the scaphoid and capitate (Fig. 8). The articular surfaces are evaluated and typically an area devoid of articular cartilage is noted on the dorsal aspect of the trapezium. Visualization taken ulnarly in the midcarpal joint allows for an evaluation of the four-corner region.

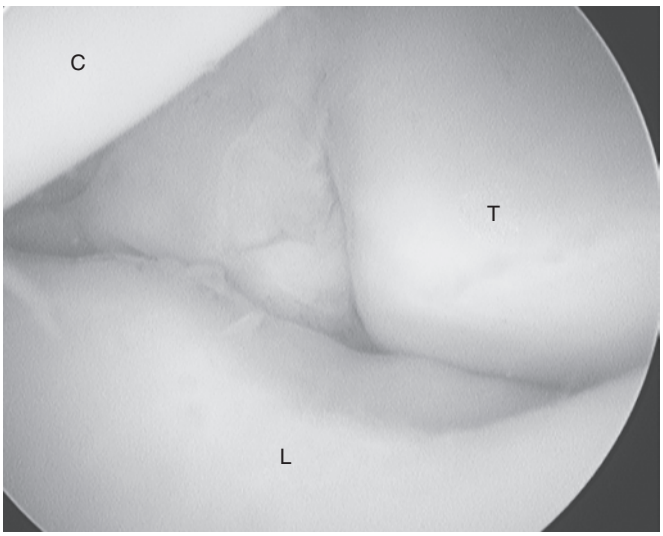

FIGURE 7 Arthroscopic view of the lunotriquetral interval from the radial midcarpal portal. Note the extra facet of the lunate adjacent to the triquetrum. The head of the capitate can be seen distally. *Abbreviations*: C, capitate; L, lunate; T, triquetrum.

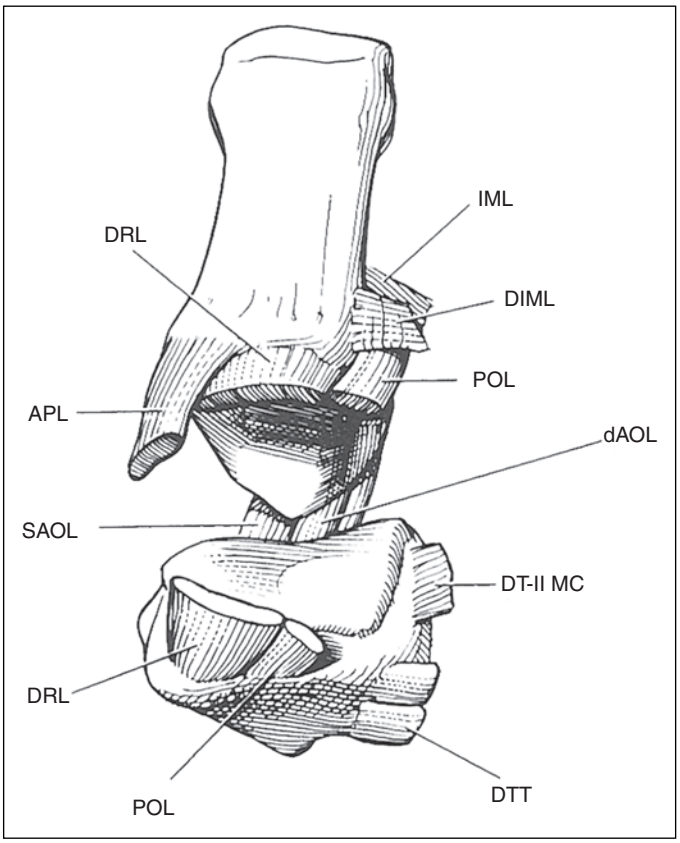

FIGURE 9 Diagram of the trapeziometacarpal joint hinged open from the dorsum to reveal the deep anterior oblique ligament (beak ligament) lying just ulnar to the volar tubercle of the metacarpal. *Abbreviations*: APL, abductor pollicis longus tendon; dAOL, deep anterior oblique ligament; DIML, dorsal intermetacarpal; DRL, dorsoradial; DT-II MC, dorsal trapezio-II metacarpal; DTT, dorsal trapeziotrapezoid; IML, intermetacarpal; POL, posterior oblique; SAOL, superficial anterior oblique. *Source*: From Ref. 14.

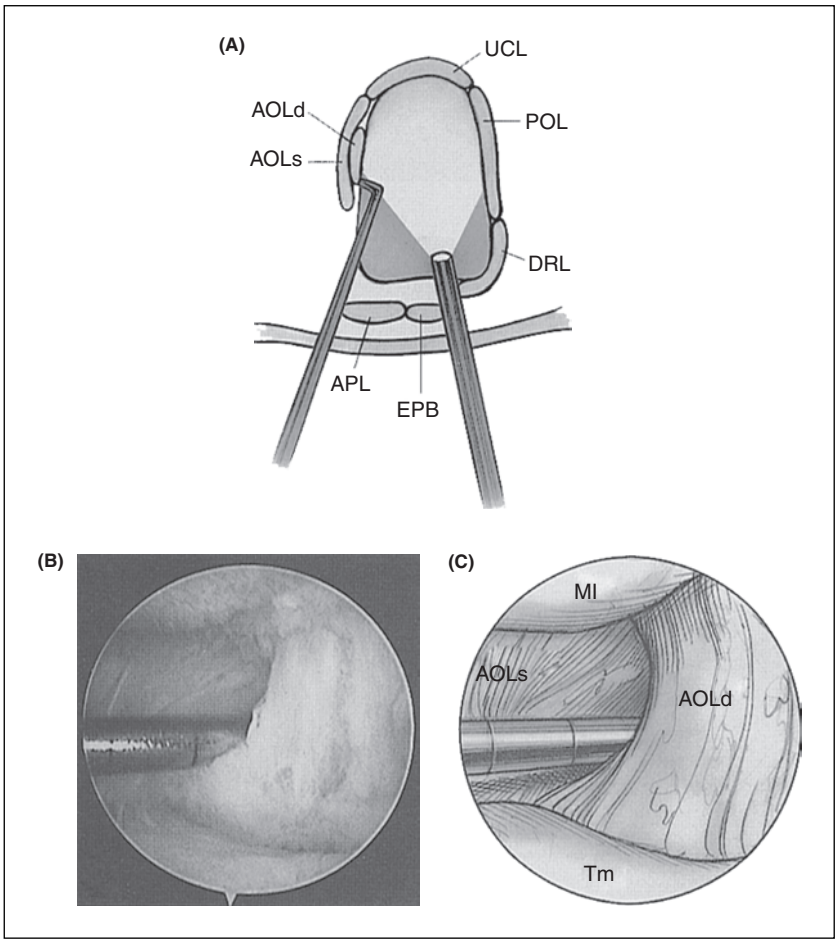

FIGURE 10 Arthroscopic view of the anterior margin of the TM joint. (**A**) The TM joint from a distal perspective showing the arthroscope in the 1U portal and its viewing area (*non-shaded*). Note the position of the probe in the 1R portal. (**B**) View taken through an arthroscope in the 1U portal. The tip of the probe is in the radial recess between the superficial anterior oblique ligament and deep anterior oblique ligament. (**C**) Structures visible in part B. *Abbreviations*: AOLd, deep anterior oblique ligament; AOLs, superficial anterior oblique ligament; APL, abductor pollicis longus tendon; DRL, dorsoradial ligament; EPB, extensor pollicis brevis tendon; MI, first metacarpal; POL, posterior oblique ligament; TM, trapeziometacarpal; Tm, trapezium; UCL, ulnar collateral ligament. *Source*: From Ref. 15.

The proximal pole of the hamate should be evaluated for osteochondral changes as a cause for ulnar sided wrist pain. A volar midcarpal portal can be made for visualization of the proximal pole of the hamate and capitate. The portal is placed 1 cm distal to the volar radiocarpal portal. Two other less commonly used midcarpal portals include the scaphotrapezial and triquetral-hamate portals. The scaphotrapezial portal is used for visualization of the STT joint and the triquetral-hamate portal may be used for outflow (2).

The DRUJ may be visualized through a portal proximal to the head of the ulna and another portal distally. The forearm is placed in a supinated position to relax the joint capsule. The arthroscope is placed in the proximal portal to examine the radioulnar articular surfaces. The distal portal is located just distal to the ulnar head and is used for examination of the undersurface of the TFCC and the distal articular surface of the ulna (13).

Thumb CMC Joint

Sixteen ligaments stabilize the thumb CMC joint, and five can be visualized arthroscopically. The superficial anterior oblique ligament (SAOL) originates from the volar tubercle of the trapezium and insert along the volar ulnar tubercle of the thumb metacarpal (Fig. 9). This ligament lies deep to the thenar musculature and superficial to the deep anterior oblique ligament (dAOL). The SAOL is visualized arthroscopically along the entire anterior aspect of the joint. The dAOL, or beak ligament, inserts on the articular margin of the trapezium and thumb metacarpal deep to the SAOL. It is visualized at the anterior aspect of the joint centrally (Fig. 10). The dorsoradial ligament (DRL) is the widest and thickest ligament of the trapeziometacarpal joint. It arises from the dorsoradial aspect of the trapezium inserting on the dorsal aspect of the thumb metacarpal. This ligament is seen covering a large portion of the posterior margin of the joint merging with the posterior oblique ligament (POL). The POL originates on the dorso-ulnar aspect of the trapezium and inserts on the dorso-ulnar aspect of the thumb metacarpal. On arthroscopic visualization, it is contiguous with the DRL. The UCL originates from the distal margin of the transverse carpal ligament and inserts on the palmar tubercle of the thumb metacarpal. There is often a subtle demarcation between it and the SAOL which lies more ulnarly (15).

Several portals have been described for the evaluation of the CMC joint (Fig. 11). The 1R portal is located radial to the abductor pollicis longus tendon. The 1U portal is located ulnar to the extensor pollicis brevis (EPB) tendon. The 1U portal is used to visualize the anterior oblique ligaments and UCL. The 1R portal is helpful in visualizing the DRL, POL, and UCL (16).

Orellana et al. (17) described a more radial portal made just anterior to the FCR tendon distal to the oblique ridge of the trapezium. The portal lies just radial to the SAOL and allows visualization of the dorsal radial ligament and POL.

This thenar portal, as further described by Walsh et al. (18), is located in the thenar eminence 90° to the 1U portal (Fig. 11). This portal has been found to be located at a greater distance from the dorsal radial sensory nerve branch than the 1R portal and provide greater visualization of the CMC since it is

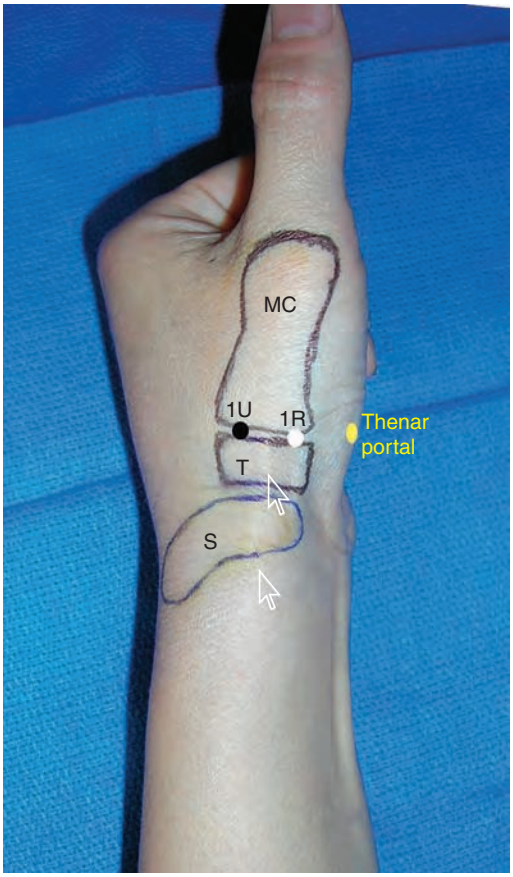

FIGURE 11 Arthroscopic portals for the thumb carpometacarpal joint; Small arrows represents the course of abductor pollicis longus tendon and extensor pollicis brevis tendon. *Abbreviations*: MC, metacarpal; S, scaphoid; T, trapezium. *Source*: Courtesy of Virak Tan, MD.

perpendicular to the 1U portal. The thenar portal is recommended for instrumentation since there is a greater soft-tissue envelope with greater comfort in manipulation of instruments and a larger margin of error.

MP Joints

The MP joints are diarthrodial condylar type joints with an asymmetric metacarpal head. The metacarpal head is wider in the anterior to posterior plane than in the coronal plane providing increased joint stability in flexion than extension. The volar plate limits hyperextension. The membranous portion has some laxity and attaches to the metacarpal neck while the cartilaginous component attaching to the proximal phalanx. The accessory collateral ligaments extend from the volar aspect of the collateral ligaments to the volar plate. The true collateral ligaments lie dorsal to the central axis of the MP joint and become taut with the joint held in flexion due to the cam effect related to the asymmetry of the metacarpal head. The extensor mechanism of the finger MP joint is made up of the central tendon, radial and ulnar saggital bands, medial and lateral slips of the interosseous and insertion of the lumbricle tendon. The MP joint is extended through the saggital bands since there is little connection of the extensor mechanism to the dorsal base of the proximal phalanx. The saggital bands also hold the central extensor tendon reduced over the dorsal aspect of the MP joint.

The thumb MP joint has more limited range of motion and greater stability of the collateral ligaments than the finger MP joints. The extensor mechanism of the thumb MP joint includes the EPB tendon centrally that inserts on the base of the proximal phalanx and the extensor pollicis longus that inserts on the base of the distal phalanx. The adductor aponeurosis makes up the ulnar saggital band component of the thumb extensor mechanism.

The digital neurovascular bundles lie volar to the MP joint adjacent to the flexor tendons and sheath. The dorsal ulnar and radial sensory nerve branches provide sensory innervation to the dorsal aspect of the MP joints and need to be protected during any surgical procedure.

Arthroscopy of the MP joint is performed with a similar setup as wrist arthroscopy. The patient is supine on the operating table with the arm placed in a traction tower for distraction. For arthroscopy of the index, middle, ring or small finger, nylon finger traps are applied to the involved and adjacent digit(s). For thumb MP arthroscopy, a finger trap is placed only on the thumb. The finger traps are applied distally so that they do not interfere with portal placement. Removing any remaining soap scrub from the digits may help the traction of the finger traps. If distraction continues to be limited, a transverse Kirschner (K) wire can be placed in the mid-axial plane in the proximal or middle phalanx (distal to the joint to be evaluated) for traction. Approximately, 8 to 12 lbs of distraction is applied to the digit. The standard portals include the dorsal radial and dorsal ulnar on either side of the extensor communis tendon of the finger and EPL of the thumb. A mini fluoroscopy unit may be required to localize the position of the joint. A 19-gauge needle is placed in one of the portals for insufflation of the joint. The joint is insufflated with saline or lactated Ringer's solution prior to portal placement. Epinephrine is not used in the solution due to the concern for extravasation and the risk of digital ischemia. The MP joint has a volume of approximately 2 mL. An assistant continuously injecting fluid within the joint may help keep the joint distended (19). A 1.9 mm to 2.3 mm arthroscope is placed within one of the portals. The adjacent portal is developed for instrumentation including the shaver. The cartilage surfaces are identified and the shaver is used for synovectomy. The entire metacarpal head and base of proximal phalanx can be visualized. The radial and UCLs are identified. A complete synovectomy can include the volar and dorsal capsular surfaces as well as the radial and ulnar recesses.

■ COMPLICATIONS

Small joint arthroscopy is a safe procedure with a low risk of complication, especially when compared to open procedures. The incidence of complications during wrist arthroscopy has been reported to be 5.2% with the majority of these complications minor (20). There is a relationship of the complication with the complexity of the procedure. The more complex the procedure, the greater the risk of a complication (21). Small joint arthroscopy complications include nerve injury to the dorsal ulnar and radial sensory branches. In addition, injury to the posterior interosseous nerve and reflex sympathetic dystrophy has been reported. Tendon related complications include extensor carpi ulnaris tendonitis, partial injury to extensor digitorum communis of the small finger and a tendon rupture from a K-wire. Complications associated with positioning in the traction tower have included a burn from the base plate and an ulnar nerve injury. Wrist stiffness, inclusion cyst and ganglion cyst development following arthroscopy can occur. Strict adherence to surgical technique, with protection of sensory nerve

branches and tendons at the time of portal placement and instrumentation will limit the occurrence of these complications.

SUMMARY

As arthroscopic equipments and surgical techniques improved, surgeons have applied them to the smaller joints of the upper extremity. The advantages of arthroscopy versus open surgery of the wrist, thumb CMC, and MP joints are similar to those of larger joints. These include: (*i*) less surgical exposure, (*ii*) excellent joint visualization, (*iii*) early postoperative joint mobilization, and (*iv*) shorter rehabilitation period. Small joint arthroscopy is minimally invasive and effective when used for the appropriate indications:

- Joint debridement: Loose body, synovectomy partial or complete, lavage for sepsis
- Carpal instability: Interosseous ligament debridement, thermal shrinkage, SL or LT percutaneous pinning
- Ligament repair: Thumb MP UCL
- Bone excision: Carpal bone excision including proximal pole scaphoid, PRC, lunate for Kienbock's, radial styloidectomy, wafer
- TFCC treatment: Debridement or repair
- Fracture treatment: Distal radius, scaphoid, MP joint—metacarpal head or base proximal phalanx, thumb CMC—metacarpal base or trapezium
- Management arthritis: Debridement chondral lesions, arthroplasty thumb CMC
- Dorsal wrist ganglion excision
- Capsular release wrist

There are relatively few complications from arthroscopy of the wrist and hand and when they do occur, are generally minor. Precise portal placement is important due to the close proximity of the extensor tendons and dorsal sensory nerves.

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Arthroscopic Treatment of Interosseous Ligament Tears, Carpal Instability, and Capsular Electrothermal Shrinkage Techniques

Gregory K. Deirmengian and Pedro K. Beredjiklian
Department of Orthopedic Surgery, Hospital of the University of Pennsylvania, Presbyterian Medical Center, Philadelphia, Pennsylvania, U.S.A.

INTRODUCTION

The development of wrist arthroscopy in the mid 1980s was a major advance in the diagnosis and management of wrist disorders, and its application indications continue to expand with technologic improvements. Prior to the advent of wrist arthroscopy, the diagnosis and treatment of disorders of the wrist was limited to radiographic studies or arthrotomy. Arthroscopy allows for the direct visualization of articular surfaces of the carpal bones as well as the evaluation of their relative positions. The operative modality also allows for the direct inspection of both extrinsic and intrinsic ligaments of the wrist and the triangular fibrocartilage complex (TFCC). This results in the identification of articular pathology that might remain unrecognized with standard imaging studies. Since the use of arthroscopic assessment of the wrist joint has gained a prominent role as a diagnostic tool, it has become clear that magnetic resonance imaging (MRI) and wrist arthrography are less sensitive and specific than arthroscopy in detecting pathologic changes in the radiocarpal and midcarpal joints (1–3). As a result of this increased sensitivity, the procedure allows for the adjudication of diagnoses that had previously been generically classified as "wrist sprain" (4). For example, prior to the advent of wrist arthroscopy, patients with either attenuation or partial tears or attenuation of the scapholunate interosseus ligament (SLIL) or lunotriquetral interosseus ligament (LTIL) not visualized on MRI or arthrography were given the diagnosis of "wrist sprain." Wrist arthroscopy allows for the identification of these pathologic changes and treatment in the form of debridement and/or electrothermal collagen shrinkage (ECS) (5).

In addition to yielding significant improvements as a diagnostic tool, arthroscopy has yielded significant improvements in the treatment of wrist disorders. In the past, operative treatment options by definition involved open, invasive procedures which invariably involved arthrotomy. The introduction of wrist arthroscopy has expanded the standard algorithm for the management of wrist pathology, especially in patients with wrist pain and/or instability. Advantages of the arthroscopic management of ligamentous disorders of the wrist include decreased surgical dissection, less postoperative pain and time to recovery, and earlier return to work (6). Additionally, because in most cases such arthroscopic treatment does not preclude treatment with arthrotomy, more invasive options remain available in cases of failure of attempted arthroscopic treatment.

INDICATIONS

For disorders of the wrist secondary to ligamentous injuries, there are several specific diagnostic and therapeutic indications for arthroscopy, which as mentioned previously continue to expand as the technology evolves. In considering the technique for patients with wrist pain likely due to ligamentous or capsular injuries, two important factors determined on history, physical examination, and imaging studies include: (*i*) timing of the patient's injury; and (*ii*) the presence or absence of clinical carpal instability. Patients who present with mechanical wrist pain in the absence of clinical or radiographic signs of instability should be initially managed with at least a three month course of conservative management, including activity modification, splinting, anti-inflammatory medication, and occupational therapy. Diagnostic wrist arthroscopy is indicated in patients presenting with a history of mechanical pain that have failed conservative measures in which physical examination and radiographic studies have failed to demonstrate a specific pathologic articular process (5).

Arthroscopy as a diagnostic modality is also indicated in patients who have a history and physical examination consistent with carpal instability, but in whom radiographic modalities fail to demonstrate any specific structural disruption. As mentioned previously, wrist arthroscopy is the most sensitive available means of detecting carpal instability (1,2). MRI, while a very useful diagnostic tool in evaluating disorders of the musculoskeletal system, is less than ideal when evaluating disorders of the wrist joint. For example, one study has shown that the sensitivity and specificity of MRI in the detection of central disk TFCC tears is in no better than 73% and 91% respectively. The same study revealed that the sensitivity and specificity of MRI in the detection of complete tears of the scapholunate ligament is no better than 69% and 75% respectively. While it has been suggested that MRI in combination with arthrography may improve the diagnostic accuracy of this modality, there is insufficient data in the literature to justify the routine use of magnetic resonance arthrography for the diagnosis of wrist pathology. For these reasons and as a result of the inadequacies of radiographic imaging, wrist arthroscopy is considered and remains the gold standard in the diagnosis of wrist joint disorders (7).

While the diagnostic superiority of arthroscopy is well established, this modality has led to an improvement in the understanding of wrist joint pathology, particularly as it relates to the SLIL. Traditionally, injury to the SLIL has been considered

as an all-or-none phenomenon, with either an intact structure or complete rupture of the ligament from its bony insertions. Recent experience with arthroscopic assessment of SLIL pathology suggests that injury to the ligament likely occurs in a continuum ranging from an intact ligament, followed by ligament attenuation and partial tears, to complete ligament rupture. Incomplete SLIL injuries can result from trauma generating sufficient tensile forces across the carpal articulation to tear the central membranous portion, but only straining or "stretching" the stouter dorsal portion. It is believed that the instability created by these partial disruptions can lead to persistent symptoms despite conservative care (8,9).

Geissler et al. have introduced an arthroscopic classification of SLIL injuries which is a four grade system based on the appearance of the intercarpal ligament and the level of step-off, incongruence, or instability of the intercarpal space. Type I injuries include those with ligament attenuation without step-off; type II injuries are comprised of those injuries displaying attenuation of the SLIL, as well as a step-off, and/or incongruity of the intercarpal space as seen from the midcarpal joint; type III injuries reveal scapholunate interval step-off seen from the radiocarpal and midcarpal joints; and type IV injuries demonstrate gapping at the scapholunate interval allowing the 2.7 mm arthroscope to be passed between the scaphoid and lunate from the midcarpal to the radiocarpal joint (the so-called "drive-thru" test, which is consistent with complete rupture of the SLIL) (10). The recognition of this spectrum of injuries has lead to new treatment modalities as outlined later in the chapter.

In addition to its preeminent role in the diagnosis of wrist disorders, wrist arthroscopy plays an important role in the treatment of patients with structural disruption of the joint. Arthroscopy as a treatment modality is a less invasive alternative to open repair or reconstruction. Indications for surgical wrist arthroscopy in patients with wrist joint instability include acute, subacute, and chronic intercarpal ligament (SLIL, LTIL) injuries, and those with peripheral tears of the TFCC.

The arthroscopic treatment of intercarpal ligament injuries is guided by the degree of ligamentous injuries. While the following discussion is based primarily on pathology of the SLIL, treatment of LTIL could potentially be addressed with the same algorithmic approach. In patients with partial or incomplete tears of the intercarpal ligaments (Geissler types I–III) debridement of the partial tear using an arthroscopic shaver or a cautery probe has been used with good clinical success (11). More recently, several authors have described their experience with ECS for injuries involving the attenuation of the intercarpal ligaments.

ECS technology involves the application of low temperature radiofrequency energy to soft tissue structures. Application of the probe to soft tissue leads to an increase of the temperature of the tissue to approximately 65°C. This increase in the temperature of the tissues initially leads to the ultrastructural alteration and denaturing of the collagen fibril. This destruction of intermolecular bond within collagen causes a transition from an organized to random state, leading to shortening of the molecules and shrinkage of the attenuated soft tissue at a gross level (12). Attenuation of capsular or ligamentous structures of the wrist can contribute to pain and/or instability and correction of this laxity through thermal shrinkage can resolve the patient's symptoms. Basic science data behind the use of thermal energy to treat capsular, ligamentous, and cartilaginous tissue laxity is extensive (13). The role of thermal stabilization in the treatment of soft tissue laxity in orthopedic surgery continues to be defined. While the clinical use of ECS in the knee and shoulder is well documented in the literature (9), only a handful of clinical studies are available regarding outcomes of the use of ECS in the wrist (Fig. 1) (14).

FIGURE 1 Arthroscopic image of electrothermal probe on an attenuated scapholunate interosseus ligament. The visualization portal is the 3–4 portal, while the probe is inserted in the 4–5 portal. *Source*: Courtesy P.K. Beredjiklian.

Other indications for surgical arthroscopy of the wrist include injuries in patients who present with complete, acute ligamentous injuries. Some authors have advocated arthroscopic treatment of SLIL injuries via arthroscopic reduction of the scapholunate interval followed by percutaneous pinning of the scapholunate joint with Kirschner (K) wires (15). The resulting formation of stabilizing fibrotic tissue between the fixed carpal bones during the period of immobilization leads to stabilization. Most surgeons, however, will perform an open repair of the SLIL via arthrotomy using suture anchors following the arthroscopic assessment of the joint.

For patients presenting with chronic dynamic or static carpal instability, wrist arthroscopy is reserved as an alternative to more extensive open procedures, such as capsulodeses or arthrodeses. Patients who present in this manner can be offered an arthroscopic debridement, synovectomy, and/or radial styloidectomy (depending on the clinical findings) in an attempt to relieve pain and avoid or delay a more definitive open salvage procedure (16).

CONSIDERATIONS FOR PREOPERATIVE PLANNING

The key element of preoperative planning for the use of arthroscopy in the diagnosis and management of ligamentous disorders of the wrist is thorough clinical workup. On history, it is important to determine patient's handedness and occupation, obtain details of any traumatic injury, and to elicit a detailed characterization of the location, quality, and timing of the pain as well as associated mechanical and neurological symptoms. History of bony injuries, and prior injury and surgery to the affected upper extremity are also important.

On physical examination, it is critical to localize the patient's pain and to determine the contribution of instability to the patient's symptoms. On inspection, areas of deformity and swelling should be noted. Active and passive range of motion should be recorded and compared with the opposite wrist. The patient's wrist should be systematically palpated in order to localize areas of tenderness. This should include palpation of the scapholunate interval, just distal to Lister's tubercle, as well as the lunotriquetral interval.

Provocative maneuvers to elicit carpal instability are helpful in determining the presence of structural disruption of the stabilizing ligaments of the carpus. The scaphoid shift test as described by Watson is used to assess for the presence of scapholunate instability due to SLIL disruption. The test is performed by placing the examiner's thumb on the distal pole of the scaphoid on the volar aspect of the palm with the wrist ulnarly deviated. Pressure is placed on the distal pole as the patient's wrist is radially deviated. In cases of SLIL disruption or instability, the scaphoid subluxates dorsally out of the scaphoid fossa of the distal radius. When pressure is released from the scaphoid, a clunk can be felt and heard as the scaphoid returns to the fossa (16). Provocative maneuvers for LTIL instability include the lunotriquetral ballottment test, the shuck test, and the shear test. The lunotriquetral ballottment test is performed by stabilizing the lunate with the thumb and index fingers of one hand, while the other hand attempts to displace the pisotriquetral unit volarly. In the shuck test, the lunate is stabilized with the same technique used in the ballottement test. The wrist is then taken through both active and passive radial and ulnar deviation. The provocative maneuver is positive if it generates pain or clicking at the lunotriquetral joint. The shear test is used to detect the presence of lunotriquetral strain, and is performed by applying a shear force at this joint while stabilizing lunate dorsally and pisotriquetral plane volarly, generating pain in the lunotriquetral interval. To test for midcarpal instability, the forearm is stabilized in a pronated position. With the wrist in ulnar deviation, the examiner's thumb exerts volar pressure at the level of the distal capitate. The wrist is then simultaneously axially loaded at the metacarpals and radially deviated. The result is positive if a painful clunk occurs that reproduces the patient's symptoms (16).

All patients presenting with wrist pain and/or instability should be evaluated with plain films of the wrist. This should include static posteroanterior (PA), lateral, oblique and scaphoid views of the wrist, as well as a dynamic clenched fist supinated PA view. Static views are useful in detecting fractures and dislocations. In addition, degenerative changes arising from chronic instability can be readily assessed radiographically. Static radiographic signs of SLIL disruption include of the scapholunate interval greater than 4 mm (scapholunate diastasis, Terry Thomas sign), foreshortened scaphoid, and the signet ring sign reflecting the distal pole of the scaphoid as it falls into flexion (Fig. 2). Dynamic instability can often be revealed by the clenched fist view with widening of the scapholunate distance. Most acute LTIL injuries will be negative on the PA view. On the lateral view, ligamentous insufficiency can be detected by measuring the scapholunate angle, which in normals should measure between 30° and 70°. In patients with SLIL injuries, flexion of the scaphoid and extension of the lunate and triquetrum leads to an increase in the scapholunate angle (more than 70°), finding which is termed dorsal intercalated segment instability (Fig. 3). In patients with LTIL injuries, flexion of the scaphoid and lunate and extension of the triquetrum leads to a decrease in the scapholunate angle (less than 30°), finding which is termed volar intercalated segment instability deformities. In addition, degenerative changes arising from chronic instability can be readily assessed radiographically. It should be noted that in many cases of acute carpal instability, initial plain X-rays may be negative, as some of the radiographic signs may take several days or weeks to be present. In addition, comparison views of an unaffected contralateral wrist may be helpful in identifying patients with normally increased scapholunate distances.

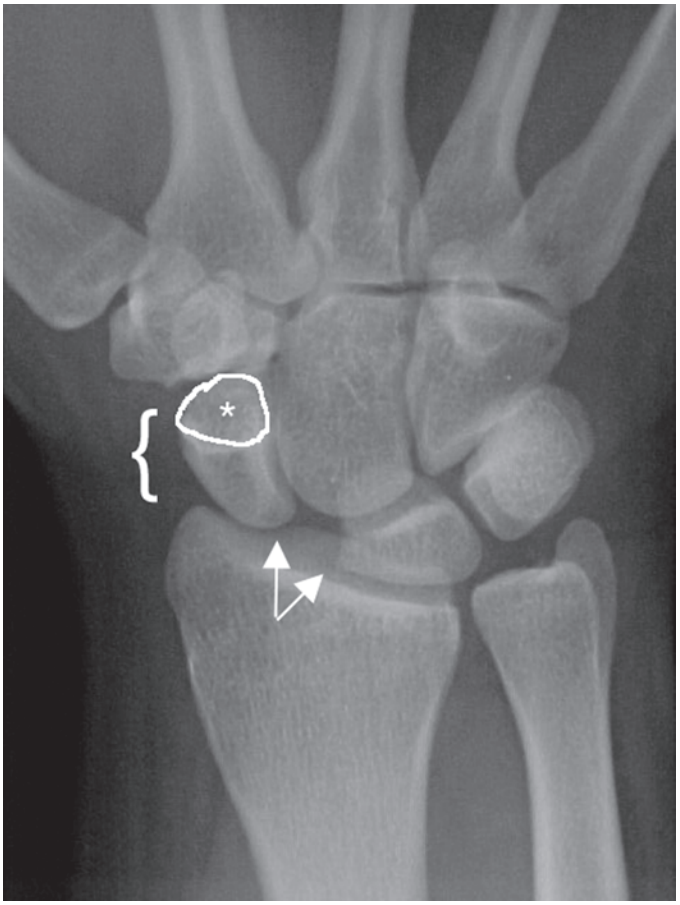

FIGURE 2 Posteroanterior X-ray of a wrist with static instability due to scapholunate interosseus ligament disruption. The arrows point to the scapholunate diastasis, the asterisk within the ring reflects the signet ring sign, and the bracket shows the shortening of the scaphoid length. *Source*: Courtesy P.K. Beredjiklian.

When clinically warranted and in equivocal cases, MRI with or without arthrography can be used diagnostically in patients with potential ligamentous injuries and negative plain radiographs. Arthrography of the wrist alone can show discontinuity of intrinsic ligaments, but does not quantify the degree of disruption and does not evaluate the status of the extrinsic ligaments. Furthermore, arthrography is significantly less sensitive than arthroscopy in the diagnosis of ligamentous injuries of the wrist (2). MRI can show ligamentous tears as well as signal changes or abnormal fluid communication representative of partial tears (Fig. 4). MRI has replaced arthrography as the advanced imaging study of choice, but an adequate study requires resources such as a strong magnet with specific extremity coils and a dedicated musculoskeletal radiologist. While MRI is a useful diagnostic studies in many clinical situations, they should be interpreted with caution and do not substitute for arthroscopy as the diagnostic modality of choice.

FIGURE 3 Lateral X-ray of a wrist with static instability due to scapholunate interosseus ligament disruption. The lines outline the scapholunate angle, which in this case it is increased to about 80°, displaying a dorsal intercalated segmental instability pattern. *Source*: Courtesy P.K. Beredjiklian.

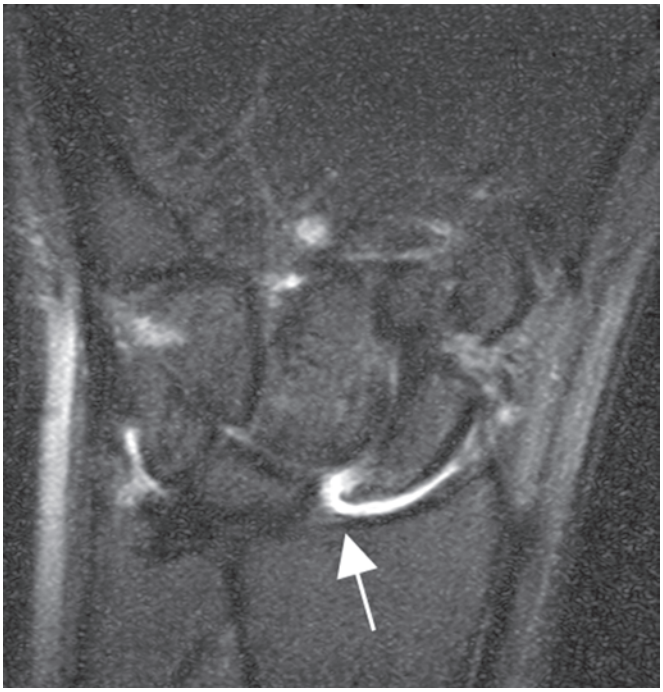

FIGURE 4 Magnetic resonance image of a patient with an acute scapholunate interosseus ligament disruption. The arrow points to the site of injury, which reveals signal changes, edema of the proximal end of the scaphoid, and the ruptured ligament. *Source*: Courtesy P.K. Beredjiklian.

SURGICAL TECHNIQUE

A detailed description of the principles of arthroscopy equipment, surgical setup, portal placement, and relevant intra-articular anatomy can be found in chapter 28. As with the use of arthroscopy in other joints, both diagnostic and therapeutic wrist arthroscopy starts with a systematic evaluation of all visible structures as well as the static and dynamic interactions of intra-articular bony and soft tissue structures. Following the identification and grading of the relevant pathology, a treatment plan is determined and executed.

After prepping and draping the patient in the usual manner and setting up the wrist traction tower to improve visualization, the wrist joint is insufflated with 10 mL of normal saline (Fig. 5). The 3–4 radiocarpal portal is established as the visualization portal and the 4–5 radiocarpal portals is established as the working portal. The 6U portal is commonly used for outflow and the 6R portal is often used as an accessory portal for visualization, instrumentation, or outflow. The midcarpal portal is established for further access, and is especially valuable in assessing intracarpal step-off or incongruity in patients with suspected intercarpal ligament tears.

After establishment of portals, the intra-articular soft tissue and bony anatomy is systematically evaluated with the patient's clinical presentation in mind. This includes evaluation

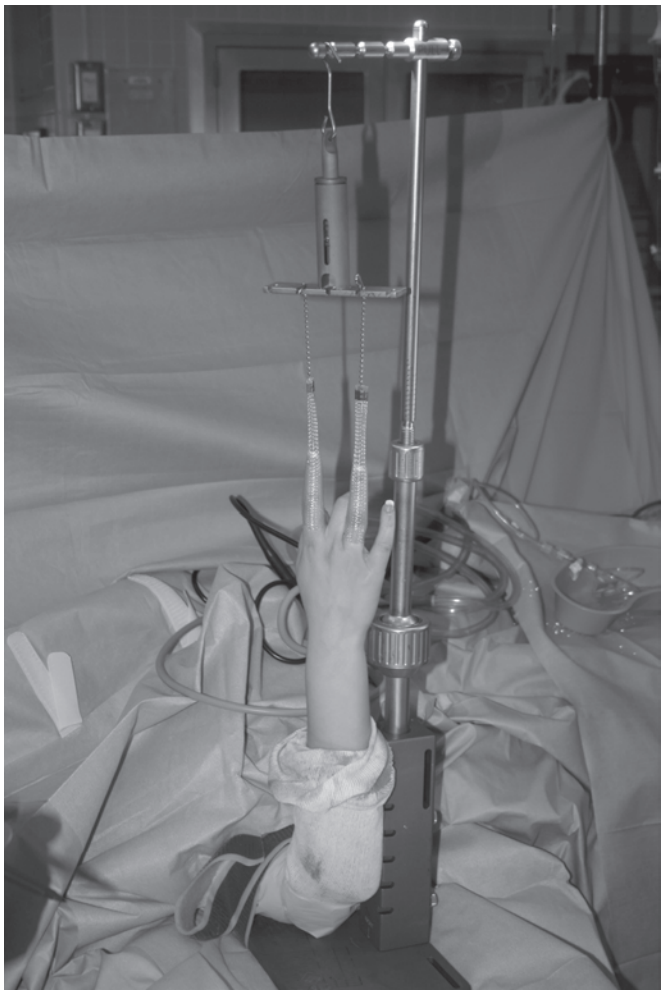

FIGURE 5 Intraoperative photograph of a standard arthroscopic set up. The wrist is distracted with a commercially available distraction tower. *Source*: Courtesy P.K. Beredjiklian.

of the TFCC, wrist capsule, synovium, intrinsic and extrinsic ligaments, articular surfaces, and dynamic interactions of the carpal bones. Following visualization and stress testing of intrinsic ligaments of concern with a probe and determining whether the probe can be passed through intercarpal intervals, the degrees of ligamentous attenuation or disruption are noted, as well as associated articular step-off or incongruities. Ligamentous injuries can then be graded by the method of Giessler to aid in therapeutic decision-making as described previously. Associated pathology that may be contributing to the patient's symptoms, including TFCC tears and synovitis, can be addressed arthroscopically at the same time of surgery through debridement and/or repair.

Therapeutic modalities are used in order to treat the structural pathology in an attempt to alleviate the patient's mechanical symptoms. In general, partial ligamentous tears are debrided with arthroscopic cautery, shavers, and biters down to bleeding bone. It is important to debride the tissue to a stable rim while avoiding areas of healthy ligament. Once each tear is adequately debrided, the stability of the tissue and its surrounding structures is evaluated with a probe. Postoperatively, patients treated only with ligamentous debridement are placed in a splint followed by a cast for four to six weeks after suture removal and physical therapy is then initiated.

Injuries amenable to ECS include attenuated or redundant intrinsic and extrinsic ligaments (Geissler types I–III). A monopolar thermal probe is inserted into the 4–5 portal (with the arthroscope in the 3–4 portal) and thermal stabilization of the scapholunate interosseous ligament is carried out until the redundant ligamentous tissue is made taut. The probe is applied to the all arthroscopically accessible portions of the SLIL, beginning in the most volar aspect of the ligament, moving proximally to the intermembranous portion, and extending to the entire dorsal section of the ligament. The entire procedure is performed under continuous irrigation with a high temperature limit of the probe set at 75°C to prevent heat injury to the tissues about the joint. Once midcarpal visualization confirmed congruency of the scapholunate interval without gapping, thermal stabilization is discontinued. Arthroscopic assessment of scapholunate instability is repeated after thermal treatment from the midcarpal and radiocarpal portals. Patients are immobilized postoperatively for four to six weeks in a thumb spica splint. After discontinuing immobilization, a standard hand therapy protocol was initiated, beginning with range of motion exercises and advancing to strengthening at 8 to 10 weeks postoperatively.

Complete disruption of both the intrinsic ligament as well as the dorsal capsular attachment leads to dynamic carpal instability. The arthroscopic treatment option in this situation is debridement and intracarpal pinning, and serves as an alternative to more invasive open procedures. The arthroscope is placed in the midcarpal portal to best visualize the reduction. Dorsally directed pressure is placed on the scaphoid tubercle and the reduction of the scapholunate joint is directly visualized. A probe can be used for fine tuning of the reduction. Two 0.045-in. K-wires are percutaneously placed across the scapholunate joint and a third wire can be placed across the scaphocapitate joint to improve stability. The reduction and position of the hardware is verified with direct visualization and with fluoroscopy. As stated previously, most surgeons will perform an open repair of complete SLIL disruption using suture anchors to reattach the torn ligament from its bony insertion or origin following the arthroscopic assessment of the joint.

For chronic or static instability, arthroscopy can help to better define the injuries for appropriate planning of the definitive open treatment. Therapeutically, the technique is reserved as a less invasive alternative to open procedures through arthroscopic debridement, synovectomy, and radial styloidectomy in an attempt to achieve temporary relief of symptoms. The 4–5 portal is used for the synovectomy with a shaver. In chronic wrist injuries, the radial styloid often reactively becomes elongated. Impingement associated with this abnormality can contribute to patient's symptoms. A burr is placed in the 1–2 portal and the radial styloid is removed up to the origin of the radioscaphocapitate ligament.

COMPLICATIONS

Complications associated with the arthroscopic treatment of ligamentous disorders of the wrist are estimated as 2% to 5%, with an incidence of major complications occurring in less than 1% of cases (17). In general, arthroscopic procedures of the wrist have a much lower rate of morbidity than alternative open procedures (17). The complications associated with wrist arthroscopy include transient or permanent stiffness, infection, neuropraxia, complex regional pain syndrome, ganglion cyst occurrence and the portal site, tendon irritation, tendon rupture over a K-wire, and injury to the posterior interosseus nerve (5).

There is minimal data regarding complications specific to thermal capsular shrinkage. As with all new technologies, there are concerns associated with use of electothermal probes during arthroscopy. Potential complications including soft tissue heat injuries, damage to periarticular neurovascular structures, and the effects on patients with pacemakers or any other implantable electrical devices should be carefully considered and possibly avoided. In order to minimize thermal damage, the probes are designed to keep a controlled temperature under the range that causes ablation. Clinical data are required to better define the risks and potential complications associated with thermal capsular ablation.

Treatment of complications associated with arthroscopy is generally successful, as most resolve with conservative management. Transient stiffness can be managed with therapy, most neuropraxias resolve with time, and superficial infections resolve with oral antibiotics (17). Awareness of the potential complications associated with wrist arthroscopy allows for their prevention.

OUTCOMES

Since the development of wrist arthroscopy is relatively recent, reports on outcomes of diagnosis and treatment with this technique are scant. Several authors have reported successful outcomes with arthroscopic debridement of ligamentous tears of the wrist. Ruch et al. evaluated two year minimum outcomes for arthroscopic debridement and early motion in 14 patients with partial scapholunate and lunotriqeutral ligament tears. They found all but one of the patients were highly satisfied with the results of the procedure, 11 of the patients had complete resolution of symptoms, and 11 of the patients returned to work within seven weeks of surgery (11).

Weiss et al. similarly evaluated the outcomes of arthroscopic debridement of intercarpal ligament tears (18). Forty-three clinically stable wrists with either partial or complete SLIL or LTIL tears were treated with arthroscopic debridement. Results, with an average follow-up of 27 months, showed that 11 out of 13 (85%) patients with partial SLIL tears and six out of six (100%) patients with partial LTIL tears had their symptoms improved or resolved and did not require subsequential procedures. Additionally, 10 out of 15 (67%) patients with complete SLIL tears and seven out of nine (78%) patients with complete LTIL tears had their symptoms improved or resolved and did not require subsequential procedures (18).

Westkaemper et al. also reported the results of the arthroscopic debridement of 23 patients with SLIL tears and five patients with LTIL tears by an average 15 month follow-up (19). They found good to excellent results in 20 of 23 patients with SLIL tears, but found that four of the five patients with LTIL tears showed poor results, based on the Mayo Modified Wrist Score. They compared their results of debriding LTIL tears to those of Osterman et al. who showed an 80% success rate in 20 patients with stable SLIL tears treated with arthroscopic reduction and percutaneous pinning (20). Westkaemper et al. concluded that debridement alone is insufficient for the arthroscopic treatment of LTIL tears (19).

The results of the treatment of partial tears or attenuation of wrist ligaments with arthroscopic ECS alone or in combination with debridement are few, but promising. In a report of 10 patients with Geissler type 2 SLIL injuries treated with electrothermal shrinkage, Hirsh et al. showed that at an average of 28 months follow-up, nine of the patients were asymptomatic and had returned to their baseline functional level (14). Similarly, Darlis et al. reported 14 of 16 patients with partial SLIL tears treated with arthroscopic debridement and thermal shrinkage had good to excellent results (Mayo Modified Wrist Score) at an average of 19 months follow-up (21). While early case series show excellent potential for the use of ECS for disorders of the wrist, clearly more data is needed before drawing conclusions on its clinical uses.

Few studies have reported outcomes of a series of patients with carpal instability treated with arthroscopic reduction and percutaneous pinning. Whipple et al. reported results of this technique in 40 patients with acute scapholunate instability (22). They found that 33 of the 40 patients (83%) had symptomatic relief after treatment. Success of the treatment of scapholunate instability in this manner depends on using the technique on only patients with acute injuries with a scapholunate gap of less than 3 mm.

SUMMARY

Wrist arthroscopy is a valuable diagnostic and therapeutic tool in managing patients with wrist pain and instability caused by ligamentous injuries. The technology allows for the minimally invasive direct inspection of all intra-articular structures and therapeutic intervention through the use of small shavers and electrothermal probes. Wrist arthroscopy remains the gold standard in the assessment of articular wrist pathology. Although there is only limited available data regarding patient outcomes resulting from these techniques, the literature that is available show promising results. Further study is needed to explore the efficacy of the techniques and to compare these results with those of more invasive means of treating wrist pain caused by ligamentous injuries.

SUMMATION POINTS

Indications

- Mechanical wrist pain that has failed conservative measures
- History and physical examination consistent with carpal instability
- Acute SLIL or LTIL injuries

Outcomes

- 85% to 100% symptom improvement for partial SLIL and LTIL injuries
- 67% to 78% symptom improvement for complete SLIL and LTIL tears
- Scant outcome data on arthroscopic ECS

Complications

- Estimated at 2 to 5%, with major complications less than 1%
- Transient or permanent stiffness
- Infection
- Neuropraxia
- Complex regional pain syndrome
- Tendon irritation
- Posterior interosseus nerve injury

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Percutaneous and Arthroscopic-Assisted Reduction of Intraarticular Distal Radius Fractures

William B. Geissler
Department of Orthopedic Surgery and Rehabilitation, University of Mississippi Medical Center, Jackson, Mississipi, U.S.A.

INTRODUCTION

Displaced intra-articular fractures of the distal radius are a unique subset of radius fractures. These fractures are usually the result of high-energy injury and are associated with intra-articular soft tissue injuries. These fractures are traditionally unstable and are less amenable to casting and closed manipulation.

The prognosis for intra-articular fractures of the distal radius has been shown to depend on numerous factors. These factors include the amount of radial shortening, residual extra-articular angulation, articular congruency of both the radiocarpal and distal radioulnar joints (DRUJ), and associated intra-articular soft tissue injuries (1,2). The use of wrist arthroscopy is a valuable adjunct in the management of displaced intra-articular distal radius fractures. Wrist arthroscopy allows viewing of the articular reduction under bright light and magnified conditions with minimal surgical morbidity. Fracture hematoma and debris may be arthroscopically lavaged which potentially can improve the patient's final range of motion. In addition, associated intra-articular soft tissue injuries may be detected and managed in an acute setting. Pathology not readily identifiable on plain radiographs may be discovered during arthroscopic-assisted reduction and internal fixation of distal radius fractures. In these incidences, it is much easier to manage an acute soft tissue injury that occurs with a distal radius fracture than chronic pathology.

The purpose of this chapter is to review the rationale and technique in the application of wrist arthroscopy in the management of displaced intra-articular fractures of the distal radius. The prognosis for intra-articular fractures of the distal radius has been shown to depend on articular congruity of the joint surface. Two millimeters of articular displacement has become a well-established critical threshold for articular incongruity of the distal radius over the past several years (3,4). Knirk and Jupiter, in their classic article, demonstrated the importance of an articular reduction of 2 mm or less (4). Patients whose articular reduction was greater than 2 mm at final follow up, had a significantly higher incidence of degenerative changes. Bradway and Amadio further substantiated these findings in their reported study (3).

Fernandez and Geissler in their series of 40 patients noted that the critical threshold may be as low as 1 mm or less (5). They reported that the incidence of complications was substantially lower when the articular reduction was within 1 mm. Trumble et al., in his review of 52 intra-articular fractures noted that factors that strongly correlated with successful outcomes include the amount of residual radial shortening and articular congruity (2). Edwards et al. described the advantage of the intra-articular reduction by wrist arthroscopy as compared to monitoring under fluoroscopy alone (6). In his report, 15 patients underwent arthroscopic evaluation of the articular surface following reduction and stabilization under fluoroscopy. They found that 33% of the patients had articular step-off of 1 mm or more as viewed arthroscopically. Frequently, the fragment was rotated. It was concluded that utilizing wrist arthroscopy as an adjunct may detect residual gapping not previously identified under fluoroscopy alone. Wrist arthroscopy is particularly useful in judging the rotation of fracture fragments, which is not readily identifiable under fluoroscopy.

A high incidence of associated intra-articular soft tissue lesions involving the triangular fibrocartilage complex and the interosseous ligaments has been shown by several authors (7–12). Mohanti and Fontes in two separate wrist arthrogram studies, noted a high incidence of tears of the triangular fibrocartilage complex associated with distal radius fractures (7,11). Fontes found a 66% incidence of tears of the triangular fibrocartilage complex in 58 patients (7). Similarly, Mohanti reported triangular fibrocartilage complex tears in 45% of 60 patients in his series (11).

Recently, several arthroscopic studies have documented the incidence of associated intercarpal soft tissue injuries with fractures of the distal radius. In three recent published studies, an injury to the triangular fibrocartilage complex seems to be the most common associated intra-articular soft tissue injury (8,10,13). Geissler et al. reported his experience in 60 patients with displaced intra-articular fractures of the distal radius undergoing arthroscopic-assisted reduction. In Geissler's series, 49% of the patients had a tear of the triangular fibrocartilage complex (13). An injury to the interosseous ligaments was less common. Injuries to the scapholunate interosseous ligament were present in 32% of his patients and a tear of the lunotriquetral interosseous ligament was identified in 15% of patients. Lindau in a similar arthroscopic study of 50 patients noted that tears of the triangular fibrocartilage complex was quite common and present in 78% of the patients (8). Injuries to the scapholunate interosseous ligament was identified in 54% of cases, and tears of the lunotriquetral interosseous ligament were less frequent and seen in 16% of patients. Hanker found that tears of the triangular fibrocartilage complex were very common and present in 55% of the 65 patients in his series (10).

RELEVANT ANATOMY AND CLASSIFICATION

Geissler et al. described an arthroscopic classification of tears of the interosseous ligament based on his work on arthroscopic management of distal radius fractures (13). He noted that a spectrum of injury occurs to the interosseous ligament.

TABLE 1 Geissler Arthroscopic Classification of Carpal Instability

Grade	Description	Management
I	Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. No incongruency of carpal alignment in the midcarpal space	Immobilization
II	Attenuation/hemorrhage of interosseous ligament as seen from the radiocarpal joint. Incongruency/step-off as seen from midcarpal space. A slight gap (less than the width of a probe) between the carpal bones may be present	Arthroscopic reduction and pinning
III	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. The probe may be passed through gap between the carpal bones	Arthroscopic/open reduction and pinning
IV	Incongruency/step-off of carpal alignment is seen in both the radiocarpal and midcarpal spaces. Gross instability with manipulation is noted. A 2.7 mm arthroscope may be passed through the gap between the carpal bones	Open reduction and repair

The ligament attenuates then eventually tears and the degree of rotation between the carpal bones increases. The scapholunate interosseous ligament appears to tear from volar to dorsal. Eventually the ligament completely tears, and a gap between the carpal bones is noted. This arthroscopic classification of carpal instability is based on observation of the interosseous ligaments both from the radiocarpal and midcarpal spaces (Table 1).

The normal scapholunate and lunotriquetral interosseous ligaments have a concave appearance between the carpal bones as viewed from the radiocarpal space. The scapholunate interosseous ligament is best seen with the arthroscope in the 3 to 4 portal. The lunotriquetral interosseous ligament is best observed with the arthroscope placed in either the 4 to 5 or 6-R portal. In the midcarpal space, the scapholunate ligament should be tight and congruent without any articular step-off. Similarly, the lunotriquetral interval should be congruent, but normally a 1-mm step-off or slight increased (play) between the lunate and triquetrum may be seen. A probe or needle may be inserted through the ulnar midcarpal portal to evaluate the amount of play between the carpal bones.

In Geissler Grade I injuries, there is loss of the normal concave appearance between the carpal bones as the interosseous ligament attenuates and becomes convex when seen in the radial carpal space. Hemorrhage may be seen within the ligament in acute situations, particularly associated with a fracture of the distal radius. In the midcarpal space, however, the interval between the carpal bones is still tight, congruent and no step-off is seen.

In Geissler Grade II injuries, the interosseous ligament continues to become attenuated and becomes convex as seen in the radial carpal space similar to Grade I injuries. There is no gap between the carpal bones when observed in the radial carpal space. In the midcarpal space, the interval between the involved carpal bones is no longer congruent and a step-off is seen. With scapholunate instability, there is slight palmar flexion of the dorsal edge of the scaphoid as compared to the lunate. In lunotriquetral instability, the interosseous ligament becomes attenuated as seen from the radiocarpal space. In the radial midcarpal space, there would be increased play when the triquetrum is palpated with a probe. Again, no gap is seen between the carpal bones with the arthroscope in the radiocarpal space.

In Geissler Grade III injuries, the interosseous ligament starts to tear and separate between the carpal bones. The ligament tears from volar to dorsal. A probe is frequently helpful to demonstrate a gap between the carpal bones. In the midcarpal space, a 2-mm probe may be placed between the carpal bones and twisted. However, the dorsal portion of the interosseous ligament is still intact, and a complete separation of the carpal bones is not seen.

In Geissler Grade IV injuries, the interosseous ligament is completely detached and the carpal bones separated. The arthroscope may be freely passed from the radiocarpal space through the tear to the midcarpal space. This is the so-called "drivethrough" sign.

Geissler Grade I injuries are consistent with a wrist sprain and usually respond to immobilization over a period of several weeks. In Geissler Grade II and III tears, these may be arthroscopically reduced and pinned in an acute situation. Following reduction of the distal radius fracture, the carpal bones are reduced and provisionally pinned. Usually three to four pins are placed between the involved carpal bones. In Geissler Grade IV injuries where there is a complete detachment of the interosseous ligament, it is felt that open repair will have the best prognosis in an acute situation (Figs 1–3).

■ OPERATING ROOM SETUP

Small joint arthroscopic instrumentation is essential for arthroscopic-assisted reduction of distal radius fractures. A small joint arthroscope is approximately 2.7 mm in diameter and even smaller arthroscopes may be utilized. When the arthroscope is initially placed in the wrist, it is usually full of hematoma and fracture debris. It is helpful to irrigate out the fracture debris and utilize a shaver (3.5 mm or less) to clear the remaining hematoma to improve visualization. A separate inflow is very

FIGURE 1 Posteroanterior radiograph showing an impacted scaphoid facet fracture of the distal radius with scapholunate instability.

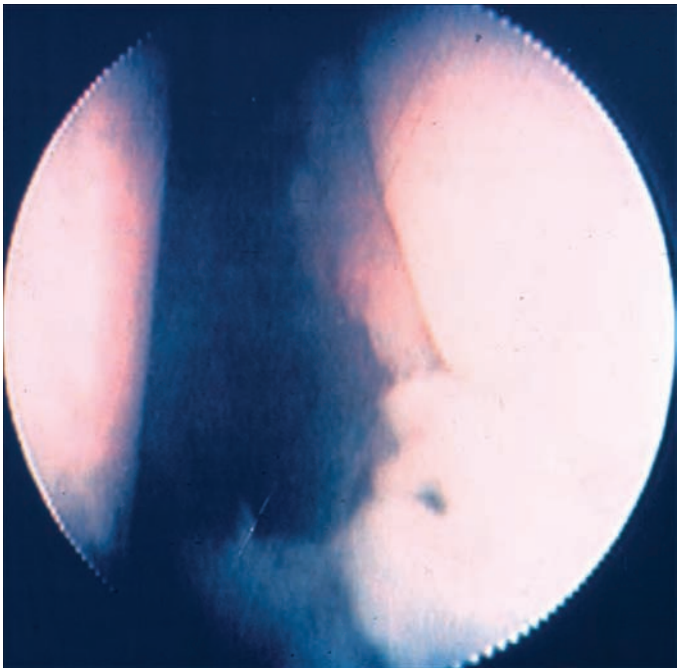

FIGURE 2 Arthroscopic evaluation of the wrist showing a Geissler Grade IV complete tear of the scapholunate interosseous ligament.

helpful to wash out the fracture debris. Inflow is placed through the 6-U portal and the hematoma is washed out with a cannula in the traditional 3 to 4 portal. Inflow through the arthroscope alone is usually not sufficient due to the small size of the cannulas, which restrict flow.

A traction tower is very useful in arthroscopic-assisted management of intra-articular distal radius fractures. A traction tower allows the surgeon to flex, extend, radially and ulnarly deviate the wrist to help reduce the fracture fragments while maintaining constant traction. A new traction tower from ARC Surgical (Hillsboro, Oregon, U.S.A) has been designed to allow the surgeon to simultaneously evaluate arthroscopically the articular reduction and monitor the reduction under fluoroscopy. The traction bar is placed at the side of the wrist rather than at its center so it does not block fluoroscopic evaluation and the surgeon does not need to work around a central bar. In addition, another advantage of having the traction bar at the side rather than centrally is that this allows the surgeon to simultaneously arthroscope the wrist dorsally and stabilizes

FIGURE 4 The ARC (Hillsboro, Oregon, U.S.A.) traction tower. The wrist may be suspended in the vertical position, and the traction bar at the side allows for fluoroscopic evaluation of the wrist as it is still in traction.

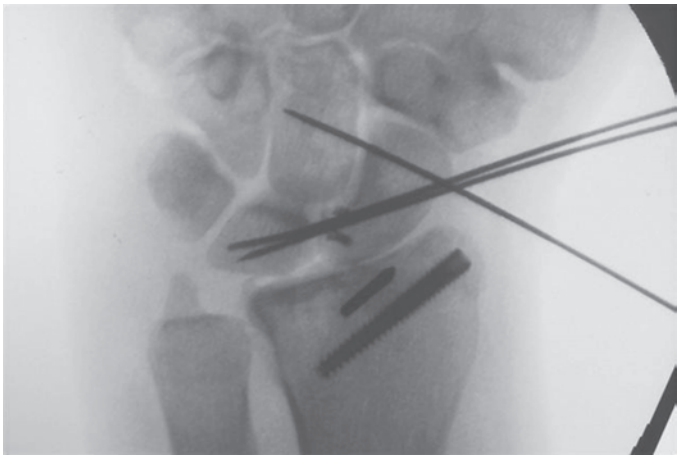

FIGURE 3 Posteroanterior radiograph following arthroscopic reduction and elevation of the impacted scaphoid facet fracture. In Geissler Grade IV injuries, it is recommended that a small incision is made for direct primary repair of a complete tear in the scapholunate interosseous ligament.

FIGURE 5 The ARC (Hillsboro, Oregon, U.S.A.) traction tower may be flexed so the wrist may be suspended in the horizontal position for wrist arthroscopy.

the fracture through a volar approach (Fig. 4). The surgeon can fluoroscopically evaluate the position of the plate and screw insertion during stabilization. This new traction tower also allows the surgeon to perform arthroscopic-assisted fixation in either the vertical or horizontal planes depending on the surgeon's preference (Fig. 5).

If the traction tower is not available, the wrist may be suspended by finger traps attached to a weight over the end of a hand table in the horizontal position, or with a shoulder holder in the vertical position. A small bump is useful to place under the wrist if weights are being utilized at the end of the table to obtain the wrist in slight palmar flexion.

Patients who sustain a high-energy injury to the distal radius frequently have swollen wrists. Because of this reason, it is difficult to palpate the traditional extensor tendon landmarks for wrist arthroscopy. Bony landmarks, however, usually can still be palpated and marked. The traditional viewing portal is the 3–4 portal, which is made between the third and fourth extensor compartments. The 3 to 4 portal is in line with the radial border of the long finger. The 4–5 working portal is made in line with the mid-axis of the ring finger. The extensor carpi ulnaris usually can be palpated. The 6-U portal is made ulnar to the tendon, and the 6-R working portal may be made radial to the extensor carpi ulnaris. Precise portal placement is mandatory for arthroscopic-assisted reduction of distal radius fractures. If the portal is placed too proximal, the arthroscope may be placed within the fracture itself, and if it is placed too distally can cause injury to either the articular surface of the carpus, or the interosseous ligaments. It is extremely useful to place an 18-gauge needle into the proposed portal location prior to making a skin incision (Fig. 6). A portal is made by pulling the skin with the surgeon's thumb against the tip of a No. 11 blade. This decreases the risk of injury to the cutaneous nerves. Blunt dissection is then continued with a hemostat to the level of the joint capsule. The arthroscope with a blunt trocar is initially introduced into the 3 to 4 portal, which is the primary viewing portal in wrist arthroscopy.

FIGURE 6 Patients who sustain a distal radius fracture frequently have swollen wrists. It is important to utilize the bony landmarks to identify the precise location of the wrist arthroscopy portals. It is helpful prior to committing to a skin incision to place a needle in the proposed portal location.

INDICATIONS

Ideal timing for arthroscopic-assisted reduction of distal radius fractures appears to be between 3 and 10 days. Earlier attempts at arthroscopic fixation may result in troublesome bleeding which obscures visualization. Fractures that are over 10 days old are difficult to disimpact and elevate up with percutaneous techniques.

LaFontaine has described several radiographic features that signify when a fracture of the distal radius is unstable (14). These features include initial dorsal angulation greater than 20°, extensive dorsal comminution, associated ulnar styloid fractures, significant intra-articular involvement, and patient age greater than 60 years.

Fractures without extensive metaphyseal comminution are most ideal for arthroscopic-assisted management. Radial styloid fractures, die punch fractures, three-part "T" fractures, and four-part fractures are all indicated for arthroscopic-assisted reduction and internal fixation (15). Three-part and four-part fractures are managed by a combination of arthroscopic-assisted fixation and open reduction. In these incidences, the fracture is stabilized by a volar plate through a volar approach. The joint capsule is not incised. The fracture is provisionally pinned and stabilized under fluoroscopy. Final articular reduction is then performed as the joint surface is arthroscopically visualized. The fracture fragments are manipulated arthroscopically, and then the distal screws are inserted through the plate to stabilize the fracture.

SURGICAL TECHNIQUE

Radial Styloid Fractures

A radial styloid fracture is the most ideal fracture pattern to manage arthroscopically, particularly if one is just beginning to gain experience with arthroscopic-assisted fixation of distal radius fractures (16). Closed reduction and percutaneous fixation of the radial styloid fragment may be attempted under fluoroscopy. The radial styloid fragment can almost always be closed reduced. Following percutaneous stabilization, the wrist may then be placed in traction and arthroscopically evaluated. This allows the fracture hematoma debris to be washed out and also to assess for any associated intra-articular soft tissue injuries. The arthroscope is initially placed in the 3 to 4 portal and the reduction of the radial styloid fracture is observed. However, with the arthroscope placed in the 3 to 4 portal, it comes directly over the fracture site. It is best then to place the arthroscope in the 4 to 5 or 6-R portal to look across the wrist to judge the rotation and reduction of the radial styloid fragment. Frequently, the articular reduction may look anatomic under fluoroscopy, but the radial styloid fragment may be still slightly rotated as viewed arthroscopically. The guidewires may be backed out of the shaft leaving them only in the radial styloid fragment if the radial styloid is rotated. The guidewires may then be utilized as joysticks to control the rotation of the radial styloid fragment and then advanced across the fracture site once the reduction is judged anatomic as viewed arthroscopically. A trocar may be introduced through the 3 to 4 portal to provide additional control of the radial styloid fragment as it is being manipulated with the joysticks. The positions of the guidewires are then checked under fluoroscopy. If the guidewires are in appropriate position, a cannulated screw may be placed over the guidewire through a cannula to stabilize the radial styloid fragment.

Early in the author's experience, only Kirschner wires were utilized to stabilize the radial styloid fragment. However, the

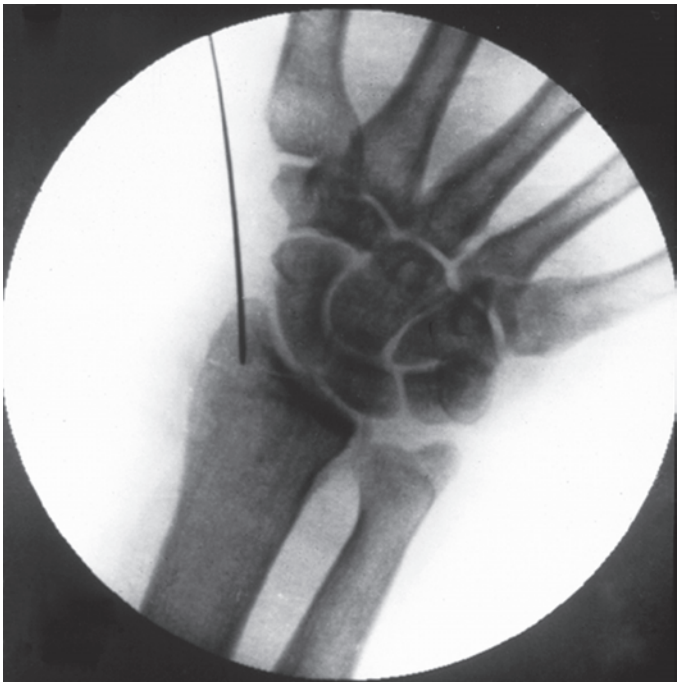

FIGURE 7 A guidewire may be placed in the radial styloid alone, but not across the fracture site to be utilized as a joystick.

protruding Kirschner wires frequently irritated the skin and potentially hampered rehabilitation. Now, headless cannulated screws are preferred to stabilize the radial styloid fragment. This eliminates any soft tissue irritation from the Kirschner wires protruding from the skin. Recently, new self-drilling headless screws have been introduced (Acutrak II-Acumed, Beaverton, Oregon, U.S.A.) which now eliminates the step of drilling and further simplifies the procedure. The headless screw decreases any metal prominence exiting from the bone, which decreases irritation of the thumb extensor tendons and helps promote an earlier range of motion.

An alternative technique to stabilize the radial styloid fragment is to place the guidewires under fluoroscopy in the radial styloid fragment alone and not cross the fracture site (Fig. 7). The position of the guidewire in the radial styloid fragment in relation to the fracture is viewed directly under fluoroscopy. The wrist is then suspended in a traction tower and the standard arthroscopy portals are made. Again, the best portal to judge rotation of the radial styloid fragment is with the arthroscope in the 6-R portal. The arthroscope is placed in the 6-R portal, and then the joysticks are used to manipulate and control rotation of the radial styloid fragment back to the articular surface of the distal radius (Figs. 8 and 9). Once the fracture is judged anatomic as viewed arthroscopically, the guidewires are advanced across the fracture site (Figs. 10–12). It is important when the guidewires are initially placed into the radial styloid to protect the surrounding soft tissues,

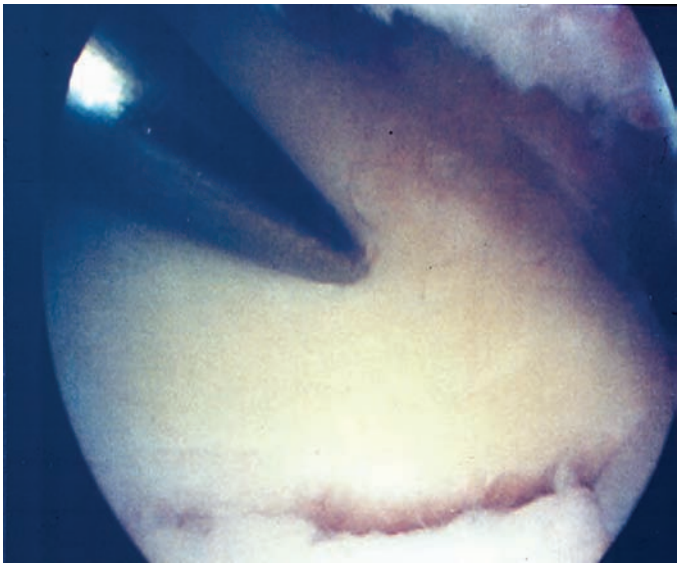

FIGURE 9 Arthroscopic view with the arthroscope in the 6-R portal showing anatomic reduction of the radial styloid fracture using a combination of the previously inserted guidewire and a trocar inserted into the 3 to 4 portal. The 6-R portal is the best portal to judge rotation of the radial styloid fracture.

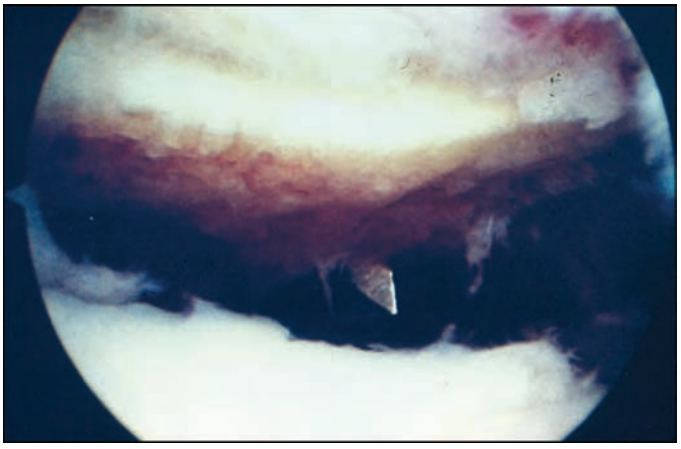

FIGURE 8 Arthroscopic view of a displaced radial styloid fracture with the scope in the 6-R portal. The previously inserted guidewire can be seen just into the radial styloid fragment to be used as a joystick.

FIGURE 10 Lateral radiograph showing a fracture dislocation of the radial styloid.

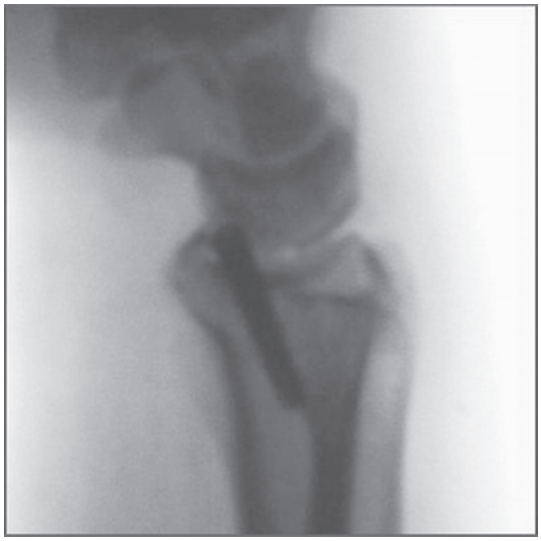

FIGURE 11 Lateral radiograph following arthroscopic reduction and stabilization with a headless cannulated screw. Notice how the carpus is reduced with the radial styloid fragment.

particularly the dorsal sensory branch of the radial nerve. The guidewires may be placed through a 14-gauge needle or, alternatively, an oscillating drill is used to insert the guidewires. The cutaneous nerves will not wrap around the Kirschner wires as they are being inserted with an oscillating drill.

Three-Part Fractures

Three-part fractures involve the displaced fracture of the radial styloid and lunate facet. In three-part fractures, the radial styloid may be closed reduced and percutaneously stabilized under fluoroscopic guidance. The radial styloid fragment may then be utilized as a landmark to which the depressed lunate facet fragment is reduced. Following percutaneous reduction and stabilization of the radial styloid fragment, the wrist is then suspended in the traction tower and fracture hematoma and debris are arthroscopically evacuated. The depressed lunate facet fragment is best seen with the arthroscope in the 3 to 4 portal. An 18-gauge needle may be placed percutaneously directly over the depressed fragment and utilized as a landmark. A large Steinmann pin is then placed approximately 2 cm proximal to the 18-gauge needle into the depressed lunate fragment, which is then elevated. Once the fragment is elevated back to the radial styloid fragment, a bone tenaculum is useful to reduce the fracture gap between the radial styloid fragment and the lunate facet fragment and to provide provisional stabilization. Once the fracture fragments are anatomically reduced as viewed arthroscopically, guidewires are then placed transversely from the radial styloid into the lunate facet fragment. The guidewires are placed into the subchondral bone. If a dorsal die punch fragment is present, it is important that the guidewires are aimed dorsally to capture this dorsal fragment. In addition, it is important to pronate and supinate the wrist to insure the transverse pins have not violated the DRUJ. The transverse pins may appear under fluoroscopy to not have penetrated the DRUJ, but because of the concave nature of the DRUJ, in actuality they may have protruded into the joint (Figs. 13 and 14). Headless cannulated screws are then placed over the transverse guidewire to stabilize the lunate facet fragment. One headless cannulated screw may be placed to stabilize the radial styloid fragment and a second screw is then placed transversely over the guidewire to support the impaction of the lunate facet fragment (Figs. 15–18). The headless cannulated screws again decrease soft tissue irritation when compared to protruding Kirschner wires, and promotes earlier range of motion and rehabilitation. A bone graft may be placed

FIGURE 12 Posteroanterior radiograph showing anatomic restoration of the articular surface following the fracture dislocation to the distal radius. A headless cannulated screw is utilized rather than multiple Kirschner wires as it facilitates rehabilitation.

FIGURE 13 Posteroanterior radiograph showing a displaced three-part fracture of the distal radius.

FIGURE 14 Posteroanterior radiograph following arthroscopic reduction with Kirschner wires of the three-part distal radius fracture.

FIGURE 15 Posteroanterior radiograph showing a displaced three-part fracture of the distal radius.

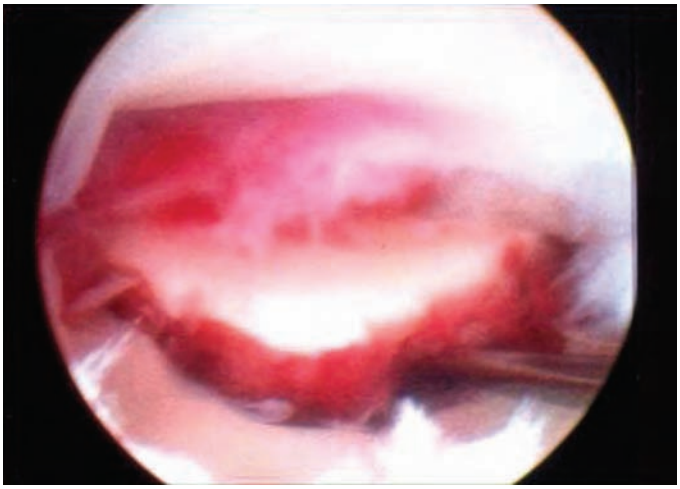

FIGURE 16 Arthroscopic view with the arthroscope in the 3 to 4 portal showing the displaced lunate facet fragment.

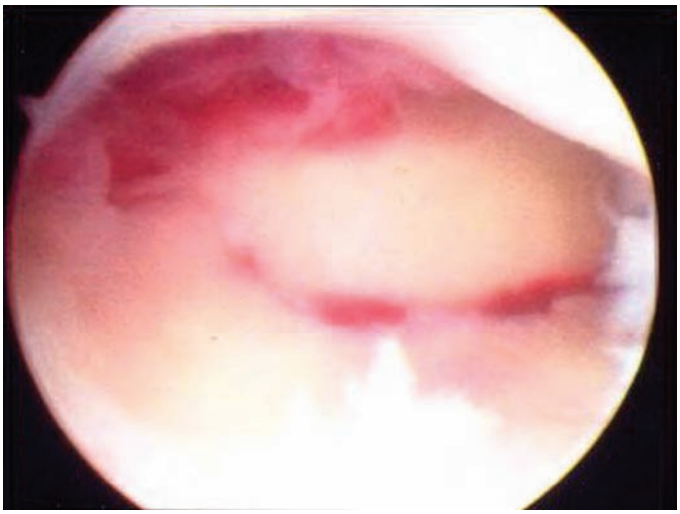

FIGURE 17 Arthroscopic view following reduction of the lunate facet fragment. The 3 to 4 portal is the best portal to view reduction and elevation of an impacted lunate facet fragment.

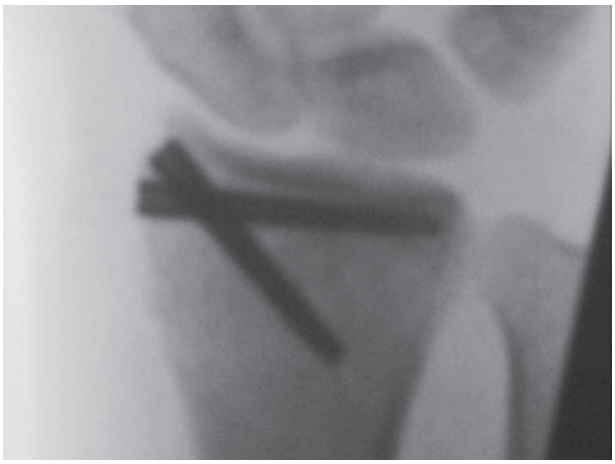

FIGURE 18 Two headless cannulated screws were utilized to support the reduction. One headless screw was placed through the radial styloid fragment and the second transversely in the subchondral bone to stabilize the impacted lunate facet fragment. Headless cannulated screws are preferred over Kirschner wires, which hamper rehabilitation.

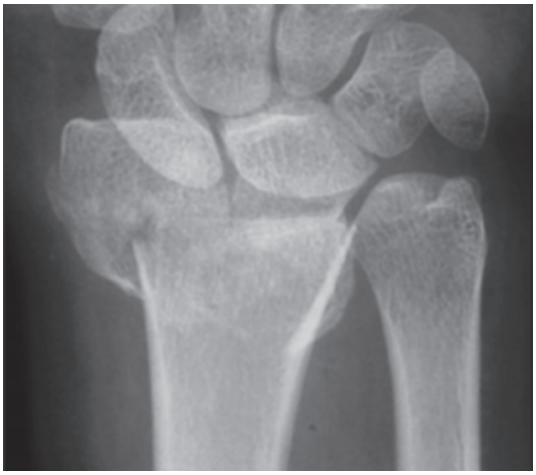

FIGURE 19 Displaced three-part fracture of the distal radius with metaphyseal comminution.

through a small dorsal incision between the fourth and fifth dorsal compartments to avoid late settling of fracture fragments if extensive metaphyseal comminution is present.

Three-Part Fractures with Extensive Metaphyseal Comminution

A volar plate may be utilized if extensive metaphyseal comminution is present (Fig. 19). Early in the author's experience, these fractures were stabilized with Kirschner wires and headless cannulated screws with additional bone graft. However, with the recent introduction and popularity of volar plate stabilization for fractures of the distal radius, a combined open and arthroscopic approach is now recommended. These strong volar plates have excellent fixation in patients with good bone stock, and promote earlier range of motion and rehabilitation.

In this scenario, a standard volar approach is made over the radial side of the flexor carpi radialis tendon. Dissection is continued down the sheath with the flexor pollicis longus

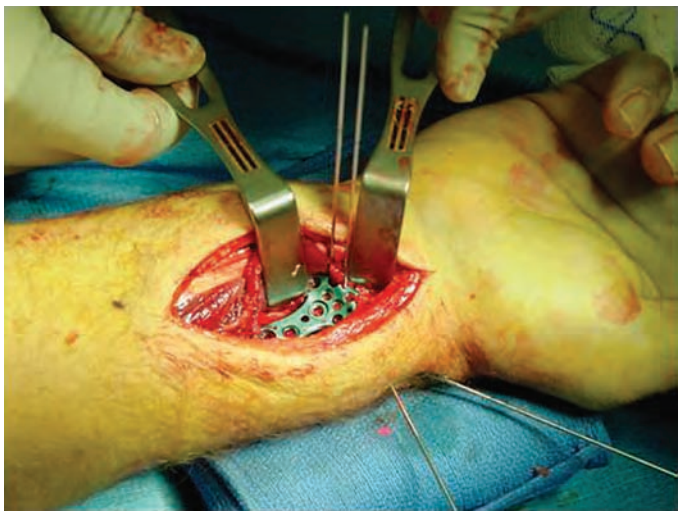

FIGURE 20 In three-part fractures with metaphyseal comminution, a combination of open surgery with arthroscopic surgery is preferred. An Acu-loc (Acumed, Beaverton, Oregon) volar distal radius plate is placed through a standard volar incision.

FIGURE 21 The fluoroscopic view following percutaneous stabilization of the fracture and provisional placement of the volar plate. An attempt is made to reduce the articular surface as closely as possible under fluoroscopic control.

FIGURE 22 The wrist is then suspended in the ARC (Beaverton, Oregon) traction tower where the articular reduction may then be fine tuned arthroscopically.

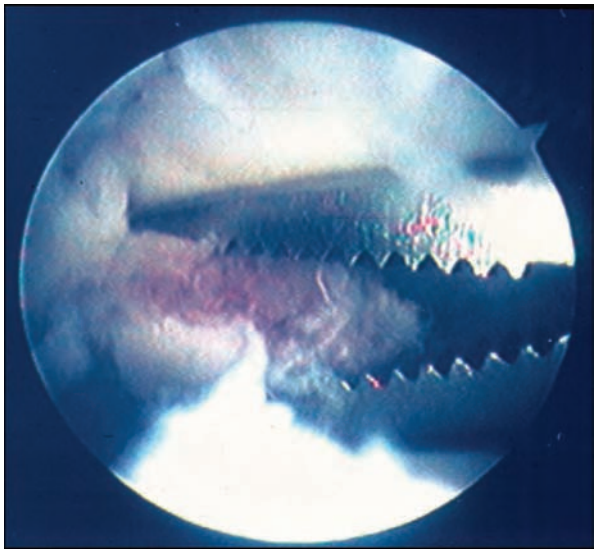

FIGURE 23 Frequently, multiple loose bodies may be identified in the joint. Sometimes these loose bodies may block reduction and are removed.

identified and retracted ulnarly. The pronator quadratus is released off its radial border exposing the fracture site. The radial styloid fragment can be anatomically reduced back to the shaft as viewed directly through the incision. It is frequently helpful to release the brachioradialis to facilitate reduction of the radial styloid fragment. The lunate facet fragment may be seen through the volar approach and can be anatomically reduced and pinned. A volar plate is placed and the fracture provisionally pinned through the plate as viewed fluoroscopically (Figs. 20 and 21). The wrist is then suspended in the traction tower and the articular reduction is viewed arthroscopically (Figs. 22–24). If the articular reduction is not anatomic, the pins may be removed from the plate and the articular reduction may be fine tuned as viewed arthroscopically. Once the reduction is felt to be anatomic, the pins are placed back through the plate to provisionally stabilize the fracture (Fig. 25). The most distal screws are then placed through the plate into the articular fragments.

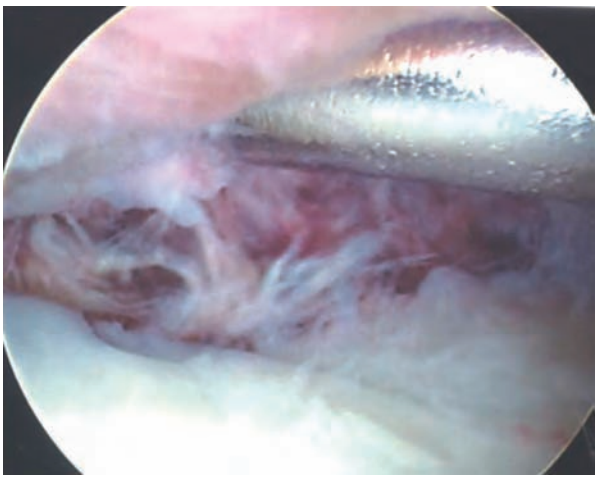

FIGURE 24 Arthroscopic view showing the volar wrist capsule to have pulled off the distal radius. In this case, the capsule was in the fracture site initially blocking reduction.

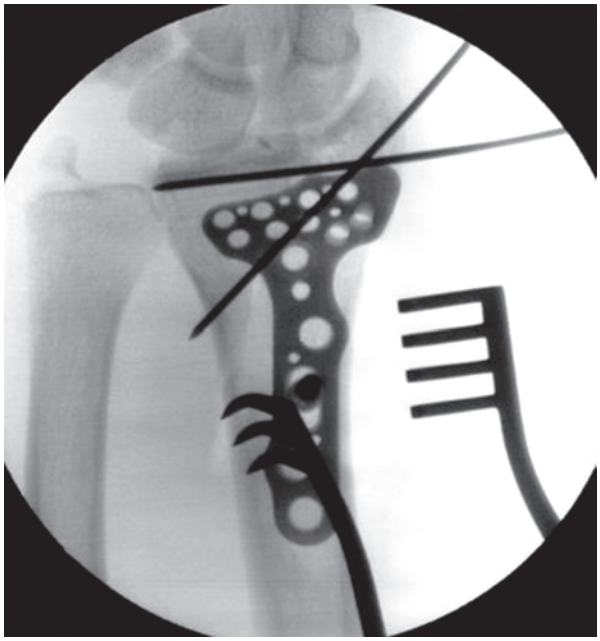

FIGURE 25 The volar capsule was arthroscopically removed from the fracture site, the fracture could then be anatomically reduced and stabilized. Once the articular reduction was judged to be anatomic under arthroscopy, the distal locking screws were placed into the plate. It is helpful to place the first screw in a non-locking mode to help reduce the bone to the plate. The remainder of the screws are then placed in a locking fashion.

In dorsal die punch fractures, arthroscopy is especially a useful adjunct (17). The dorsal die punch fragments are difficult to view frequently through a volar approach (Fig. 26). In these fractures, the volar plate is placed and the fracture is provisionally pinned under fluoroscopy. The wrist is then suspended in the traction tower, and the reduction of the dorsal die punch fragment is arthroscopically evaluated (Fig. 27). Frequently, it still needs to be further elevated. The dorsal die punch fragment is best visualized with the arthroscope either in the 6-R portal, or through the volar portal (18). The volar portal is made by placing the arthroscope with a blunt trocar between the radial

FIGURE 26 Computed tomography scan showing a distal-dorsal lip fracture of the distal radius.

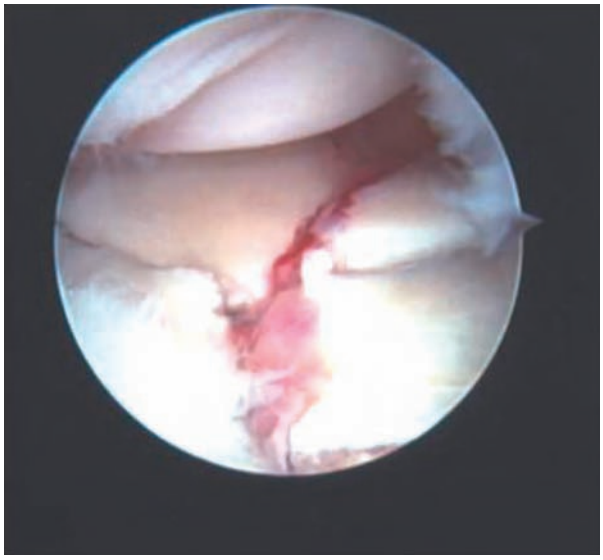

FIGURE 27 Arthroscopic view with the arthroscope in the 6-R portal to view the dorsal lip fracture following reduction. Arthroscopy can be a valuable adjunct in these very distal dorsal lip fractures. The pins through the plate may be visualized going into the fracture fragments directly, arthroscopically confirming secure fixation of the dorsal lip fragments when a plate is placed on the volar surface.

scaphocapitate and long radial lunate ligament. The cannula is pushed through this interval, and is then seen through the volar incision. A switching stick is then placed through the arthroscopic cannula into the volar incision. The arthroscopic cannula is then placed over the switching stick and the arthroscope may be placed into the volar portal to view the dorsal die punch fragment (Fig. 28). In the author's experience, the dorsal die punch fragment is usually well visualized with the arthroscope in the 6-R portal. This fragment is then further elevated percutaneously with a Steinmann pin. Once the articular surface is judged anatomic, the fracture fragment is pinned through the plate. As the distal screws are inserted into the plate, the screws may be seen arthroscopically to directly enter into the dorsal die punch fragment (Fig. 29). This ensures anatomic reduction and stabilization of the dorsal die punch fragment, which would be very difficult through a traditional open volar approach.

FIGURE 28 The articular reduction of the dorsal lip may be viewed either with the arthroscope in the 6-R portal or as demonstrated here with the arthroscope in the volar portal between the radial scaphocapitate and long radial lunate ligaments.

FIGURE 29 Fluoroscopic view confirming the locking screw is being placed into the distal dorsal lip fragment.

Four-Part Fractures

In four-part fractures, the lunate facet is divided into volar and dorsal fragments. The volar–ulnar fragment is unable to be reduced by closed manipulation. Traction causes the palmar wrist capsule to rotate the volar–ulnar fragment. In four-part fractures, a standard volar approach is made to the distal radius as described above. The radial styloid fragment is reduced under direct visualization through the open incision. The volar–ulnar fragment is then reduced under direct observation by reducing it back to the shaft and to the radial styloid fragment. It may then be provisionally pinned transversely. A volar distal radius plate is then placed and the fracture fragments are provisionally pinned.

The wrist is then suspended in the traction tower and the arthroscope is placed in the 3 to 4 portal. The dorsal–ulnar fragment is best viewed with the arthroscope either in the 6-R portal or through the volar portal. The dorsal–ulnar fragment is then percutaneously elevated back to the radial styloid and then the reduced volar–ulnar fragment, which are used as landmarks. The dorsal–ulnar fragment is then provisionally pinned, and the distal screws are placed through the plate to stabilize the dorsal fragments. Particularly in small dorsal fragments, the arthroscope is a usual adjunct to directly view the insertion of the screws into the dorsal fracture fragments.

Ulnar Styloid Fractures

Stabilization of an associated ulnar styloid fragment is quite controversial (19). Wrist arthroscopy provides some rationale as to when to stabilize an associated ulnar styloid fragment. The tension of the articular disc is palpated arthroscopically following anatomic reduction of the distal radius fracture. The articular disc is best viewed with the arthroscope in the 3 to 4 portal. A probe is then inserted through the 6-R portal to palpate the disc. If there is good tension to the articular disc when palpated, the majority of the fibers of the triangular fibrocartilage complex are felt to be still attached to the base of the ulna. A peripheral tear of the articular disc is suspected when the disc has lost its tension by palpation. A peripheral tear may be obscured by hematoma, and it is important to insert the shaver through the 6-R portal to debride any hematoma to view the ulna periphery of the articular disc. The articular disc may then be arthroscopically repaired to the base of the ulna with suture anchors if a peripheral tear is identified (20).

Stabilization of a large ulnar styloid fragment is considered when the articular disc is lax when palpated and no peripheral tear is identified. In this situation, the majority of the fibers of the articular disc are attached to the displaced ulnar styloid fragment. A small incision is made between the interval of the extensor carpi ulnaris and flexor carpi ulnaris. Blunt dissection is carried down to protect the dorsal sensory branch of the ulnar nerve, which is located volar to the incision. The ulnar styloid fragment is cleared of fracture debris and anatomically reduced. The fragment may be stabilized by either a tension band, Kirschner wire or preferably by a small headless cannulated screw.

OUTCOMES

The literature is relatively sparse regarding the results of arthroscopic-assisted fixation of displaced intra-articular fractures of the distal radius (6,16–18,21–24). Stewart et al. presented a comparison study of 12 open and 12 arthroscopic-assisted reductions of comminuted fractures of the distal radius (24). In his series, all fractures were classified as Frykman type VII or VIII. In the arthroscopic group, they had five excellent, six good, and one fair result. There were no excellent results in the open group. They also concluded that the arthroscopic group had a significantly increased range of motion as compared to that of the group that underwent open stabilization.

Doi et al. reported their results in a similar comparison study of 38 patients who underwent arthroscopic-assisted fixation in comparison with those patients who underwent open reduction (21). The authors similarly found that the arthroscopic group had improved range of motion as compared to the open group. Ruch reported his comparison study of 15 patients who underwent arthroscopic-assisted reduction and 15 patients who underwent closed reduction and stabilization by external fixation (23). In the 15 patients who underwent arthroscopic reduction, 10 patients had a tear of the triangular fibrocartilage complex. Seven of the 10 patients sustained a peripheral tear of the articular disc and underwent arthroscopic repair. No patients in the arthroscopic group had any signs of DRUJ instability at final follow-up. In the 15 patients who underwent closed reduction and external fixation, four patients presented with instability of the DRUJ at final follow-up visit. Potentially, these patients had a peripheral tear of the triangular fibrocartilage complex, which could have been acutely repaired at the time of fracture stabilization.

Geissler and Freeland reviewed their results of 33 patients who underwent arthroscopic-assisted reduction of comminuted intra-articular fractures of the distal radius (22). In their series, 25 patients had an anatomic reduction, and eight patients had a 1-mm articular step-off at final follow-up visit. The patients were evaluated utilizing the modified Mayo wrist score, and there were 20 excellent, 10 good, and three fair results in their series. In addition, they analyzed their final results based on associated injuries to the interosseous ligament. They noted when a Geissler Grade II injury to the scapholunate interosseous ligament was present, it did not affect the final prognosis in any fracture pattern. Geissler Grade II injuries were evenly distributed throughout their series, and did not correlate to the final prognosis. However, when a Geissler Grade III or IV tear was present combined with an AO Type C fracture, it significantly affected the final prognosis. In the five patients with AO Type C fracture without an interosseous ligament tear, all the five patients had an excellent result. However, in the five patients with an AO Type C fracture with a Geissler III or IV interosseous ligament tear, there were four good results and one fair result. It appeared that the presence of a Geissler Grade III or IV interosseous ligament tear significantly affected the final prognosis in AO Type C fractures in their study.

SUMMARY

Wrist arthroscopy is a valuable adjunct in the management of displaced intra-articular fractures of the distal radius. It allows for evaluation of articular reduction under bright light and magnified conditions. Particularly, wrist arthroscopy allows for detection of rotation of fracture fragments, which is very difficult to judge under fluoroscopy. It has been previously reported that restoration of the articular surface is important and affects the patient's final prognosis (2–5). In addition, evacuation of the fracture hematoma and debris may result in improved range of motion as previously documented by the comparison studies of Stewart and Doi (21,24).

Wrist arthroscopy also allows for the detection and management of associated intra-articular soft tissue injuries, which have been shown to occur frequently with intra-articular fractures of the distal radius. It is felt that management of acute soft tissue injuries has a better prognosis as compared to chronic reconstruction. Tears of the triangular fibrocartilage complex have been shown to be the most frequently associated soft tissue injury associated with fractures of the distal radius. This may explain why patients continue to complain of persistent ulnar-sided wrist pain despite an anatomically healed fracture of the distal radius (10,13,19). Chondral defects or loose bodies which frequently are not seen on plain radiographs are frequently identified arthroscopically and can be removed from both the radiocarpal and midcarpal spaces. Lastly, wrist arthroscopy provides a rationale of when to stabilize displaced ulnar styloid fragments when associated with a fracture of the distal radius (17).

SUMMATION POINTS

Indications

- One-, two-, three-, or four-part distal radius fractures.
- Ulnar styloid fracture when associated with DRUJ instability or laxity in the triangular fibrocartilage complex.
- When combined with a volar plate: fractures with metaphyseal comminution.

Outcomes

- Ninety percent good and excellent results (Geissler and Freeland)
- Detection of associated soft-tissue pathology
- Allows earlier range of motion (ROM) from evacuation of hematoma
- Early detection and treatment of associated DRUJ injury.

Complications

- Infection
- Swelling/compartment syndrome from fluid extravization
- Nerve and vessel injury.

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29

Arthroscopic Treatment of Metacarpophalangeal Joint Fractures in the Hand

Rocco A. Barbieri, Jr.
Southern Bone & Joint Specialists, Hattiesburg, Mississippi, U.S.A.

INTRODUCTION

Arthroscopic stabilization of intra-articular fractures is a technique that is widely accepted for the treatment of fractures of the knee, shoulder, and wrist. Very little has been published regarding the use of these techniques for the small joints in the hand. It has only been in the past decade that reports have surfaced regarding the use of arthroscopy to treat fractures in the hand (1). This has corresponded largely to the development of smaller arthroscopes (1.9 mm) and smaller instrumentation. Techniques to stabilize intra-articular fractures of the hand stress the importance of anatomically restoring the joint surface within less than 1 mm of step-off (2,3). For fractures of the metacarpophalangeal joint this traditionally has required an open approach that necessitated mobilization of the surrounding tendons and a capsulotomy to permit visualization. Unfortunately a common response to arthrotomy in the digits is stiffness, devitilization of bone fragments, and delayed healing (4). These adverse effects have focused attention towards alternative, less invasive ways to stabilize these uncommon but difficult fractures. The assistance of arthroscopy provides superior visualization through magnification and the ability to manipulate small articular fragments into place while limiting the insult to the surrounding soft tissue.

INDICATIONS

Simple two part fractures with displacement greater than 1 mm involving the metacarpal head or the base of the proximal phalanx are amenable to arthroscopic treatment. This includes both the adult and pediatric population since the growth plates can be stabilized without additional trauma. These indications are similar to those employed for comparable open techniques.

Contraindications to the use of metacarpophalangeal joint arthroscopy in fracture treatment include those cases with poor soft tissue coverage, open fractures, and active cellulitis. Other contraindications are fractures with three or more fragments or in which there is an associated diaphyseal component that cannot be reduced easily through percutaneous means. These fractures are extremely tedious and difficult to stabilize arthroscopically and are better suited for open techniques.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Preoperative assessment of surgical candidates initially focuses on the condition of the digit. There is typically tenderness and swelling of the involved joint and any lacerations present should lead to a high suspicion of an open articular injury. Often with displaced articular fragments there is a fair amount of rotational malalignment. In addition, one should note for the presence of very frail or "rice paper skin" as seen in patients with chronic disease or on steroids. In these individuals great care must be taken if small joint arthroscopy is performed since the traction forces may significantly disrupt the skin. X-rays are an essential component in determining the location of the fracture and in helping to decide how the particular fragments may be best stabilized. CT scans are occasionally useful as an adjunct to X-rays to assist in clarifying the degree of displacement and the size and number of the articular fragments.

SURGICAL TECHNIQUE

The patient is placed supine on the operating table and induced with regional or general anesthesia. A well-padded pneumatic tourniquet is applied to the arm and is often utilized. The affected arm is positioned on a radiolucent arm table and the surgeon is positioned at the cephalic side of the arm. The assistant is located adjacent to the surgeon allowing access to the lateral end of the hand table by C-arm. Finally, the video equipment is positioned at the foot of the table to permit easy visualization.

Special small joint instruments are required for arthroscopy of the metacarpophalangeal joints. Ideally a 1.9 mm 30° arthroscope is used in conjunction with a 2.2 mm cannula. It has also been possible to employ a 2.3 mm 30° scope but the extra 0.4 mm of diameter seems to limit one's ability to easily move around the metacarpophalangeal joint. Instruments and shavers generally used are between 2.0 mm and 2.5 mm. Inflow is provided via a gravity system utilizing a pinch pump and small joint tubing (Linvatec, Largo, FL).

Traction is critical and often the affected digit and each adjacent digit are supported in finger traps in a traction device. Anywhere between 8 and 12 pounds of traction is applied throughout the case. Care is taken to place the operative finger in the line of axis of traction with the other two surrounding digits providing mainly rotational control. Often it is difficult to get the finger traps to hold the digit and in most cases they can be prevented from slipping by wrapping the finger trap with Coban or in rare cases driving a 0.035 gauge Kirschner (K)-wire through the finger traps across the midaxial line of the middle phalanx. Traction time is treated identically to tourniquet time and should not exceed two hours.

Elevating the tourniquet to 250 mmHg begins the procedure. Exsanguination of the arm is often unnecessary as gravity alone is sufficient. The metacarpophalangeal joint is palpated and a 21-gauge needle is used to locate the portals and insufflate the joint with 3 ml of lactated ringers solution. In swollen hands it is occasionally difficult to enter the joint and one should not hesitate to use C-arm fluoroscopy to assist in localization.

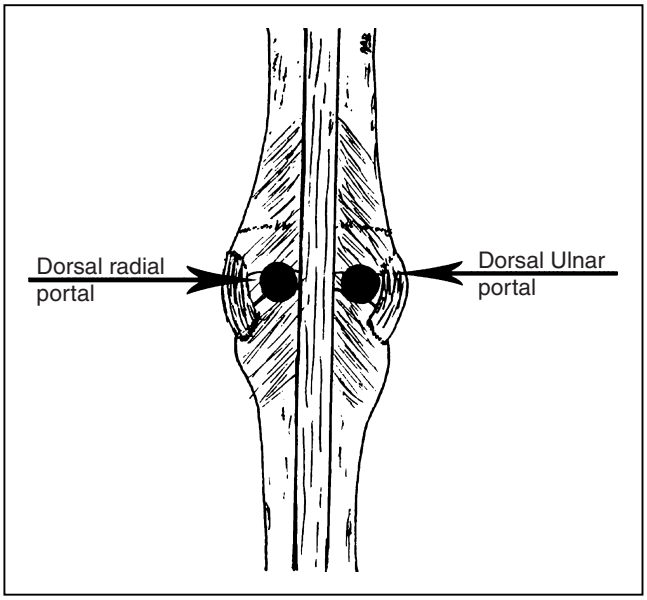

FIGURE 1 The relevant anatomy and location of portals for the metacarpophalangeal joint.

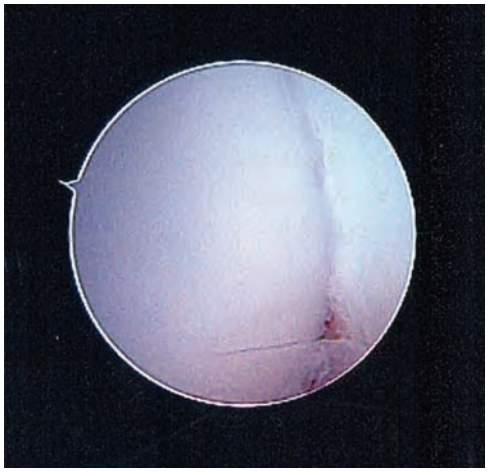

FIGURE 2 The articular surface of the proximal phalanx as seen arthroscopically after stabilization with a 0.035 gauge K-wire.

Two dorsal portals have been described for metacarpophalangeal joint arthroscopy (5). They are described as the dorsal radial and dorsal ulnar portals and are named for their relative location to the extensor tendons in the digits and the thumb (Fig. 1). The 21-gauge needle is used to identify both portals and a No. 11 blade is used to open the skin only. Care must be taken when incising the skin as dorsal branches of the sensory nerves cross the portal area. A blunt probe placed in the arthroscopic sheath is utilized to penetrate both the sagittal fibers and the joint capsule. The inflow is then hooked up to the arthroscopic cannula. The 1.9 mm arthroscope is inserted initially in the dorsal radial portal. While visualizing from within the joint the dorsal ulnar portal is then established with the blunt trocar alone. A 2.5 mm full radius shaver is then placed to clean out the joint and establish outflow. The arthroscopic and instrumentation portals are interchangeable. Instruments between 2.0 and 2.5 mm easily fit into the joint.

The procedure begins by using the 2.5 mm shaver to clean out any hematoma and to perform a partial synovectomy. Once adequate visualization has been established a systematic examination of the joint can be carried out. The surfaces of the joints are carefully examined to gain a better understanding of the fracture pattern. Note that the metacarpal head is wider at its volar aspect then the dorsal. In most joints the articular surface of the proximal phalanx is ringed by a fibrocartilagenous "meniscus" that may serve as a shock absorber for forces traveling across the metacarpophalangeal joint (6). Also easily visualized are the radial and ulnar collateral ligaments. These ligaments consist of three bundles of vertically oriented fibers that move relative to one another with joint motion. They originate in recesses just proximal to the metacarpal head and run to the base of the proximal phalanx. Visible just volar to these structures one can occasionally see less defined fibers extending to the volar plate. These thinner fibers form the accessory collateral ligaments. The volar plate is next observed by placing the digit in slight flexion if necessary. There is a small recess that exists between the metacarpal head and the volar plate. Occasionally loose bone fragments can be caught in this area that cannot be adequately inspected in full digital extension. Finally the dorsal capsule is inspected for any abnormalities.

The metacarpophalangeal joint of the thumb is similar to that of the digits with a few exceptions (7). The most notable difference is the presence of the articular surface of the two sesamoid bones embedded in the volar plate. These are only visible after removing a layer of synovium covering the volar plate. Another distinction is the absence of the fibrocartilagenous "meniscus" surrounding the articular surface of the proximal phalanx.

Once the joint has been cleaned, inspected, and probed attention is then focused on aligning the fracture fragments. This process begins with the act of cleaning out hematoma and debris between the fragments themselves. Mini curettes or small blunt probes are useful for this purpose. Occasionally traction can be reduced to allow for greater debridement between the fracture edges. Next the fragments themselves are manipulated into position. A 0.035 or 0.045 gauge K-wire is useful for this purpose and can be used as a joystick to reduce the articular fragments (Fig. 2). This author prefers to utilize the mini-acutrac system (Acumed, Beaverton, Oregon, U.S.A.), which employs a 3.0 headless screw on a 0.035 gauge wire. Once the fracture has been reduced the 0.035 gauge guide wire is inserted as perpendicular to the fracture plane as possible. A second 0.035 gauge K-wire is then inserted to maintain rotational control if screw fixation is going to be attempted. Next the proper length screw is inserted over the guide wire while visualizing the fracture to ensure that the joint remains well reduced and the hardware does not penetrate the joint. C-arm fluoroscopy is useful in assisting in both fracture reduction and hardware placement. After the fracture is stabilized traction is decreased and the arthroscope is used to confirm stability of the construct as the finger is taken through a partial arc of motion. This process is repeated with the digit out of the traction device and under C-arm fluoroscopy (Figs. 3 and 4). Once satisfied with the repair, the portals are closed with 4 to 0 nylon and the joint is injected with 10 ml of 0.25% marcaine without epinephrine for pain control. Postoperatively the digit is buddy taped to an adjacent finger and immediate unrestricted active motion protocol is started. Rarely, if there are concerns regarding compliance and stability the metacarpophalangeal joint is splinted in full extension when not exercising (Figs. 5 and 6).

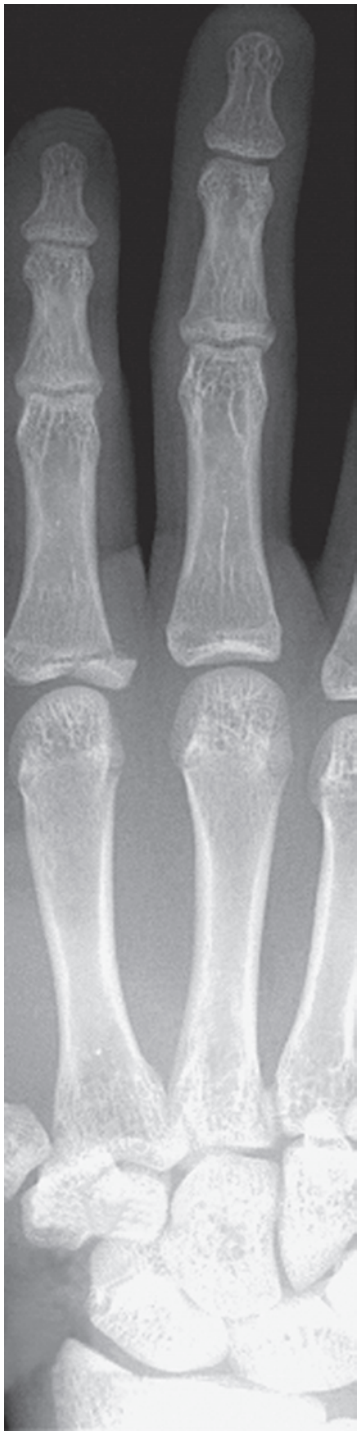

FIGURE 3 A pre-operative X-ray of a displaced, malrotated proximal phalanx fracture of the index finger. This is the patient seen in Figure 2.

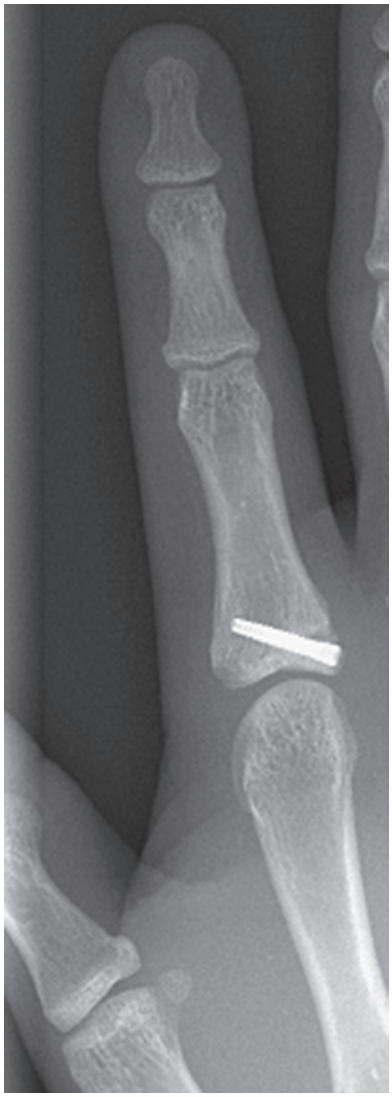

FIGURE 4 A postoperative X-ray demonstrating fixation of the proximal phalanx fracture of the same patient using a mini Acutrac screw.

■ COMPLICATIONS

Complications are rare and can be avoided in most instances by gentle operative technique and a thorough understanding of the anatomy of the metacarpophalangeal joint. The most common problem is iatrogenic cartilage injury caused by overzealous penetration into the joint. Ensuring there is adequate joint distraction, using blunt instruments, and employing C-arm fluoroscopy when needed to localize the joint can diminish the frequency of this problem. K-wire and screw placement around

FIGURE 5 A clinical view of the patient's digital extension four weeks postoperatively.

FIGURE 6 A clinical view of the patient's digital flexion four weeks postoperatively.

the joint can lead to sensory nerve and tendon injury. There has been a report of a delayed extensor tendon rupture secondary to a K-wire placed in the middle phalanx for traction (1). When establishing portals care must be taken to incise the skin only and to bluntly penetrate to the joint capsule in order to avoid injuries to the dorsal sensory nerves. This is especially true when performing arthroscopy on the thumb metacarpophalangeal joint since the dorsal sensory branch of the radial nerve travels in this region. Finally, when first beginning to master this technique one should not hesitate to convert the arthroscopic procedure to an open one if there are concerns regarding the quality of the reduction or the placement of the hardware.

OUTCOMES

Other than a few scattered case reports there is only one known series of metacarpophalangeal joint fractures treated arthroscopically (1,8). In this report the authors reviewed the outcomes of 14 consecutively treated patients and compared them to a matched set of similar injuries. In this series all fractures were closed injuries and involved six thumbs, two index, two long, three ring, and one little finger. The average operating time for arthroscopic-assisted reduction was 108 minutes. For the eight fingers the final metacarpophalangeal motion averaged 81° and the proximal interphalangeal motion averaged 99°. The only complication was a loss of fracture reduction two weeks postoperatively that was treated with successful repeat arthroscopic surgery. The average time to return to full activities including work and sports was eight weeks. This group of patients, when compared with a matched cohort treated via open techniques, had greater motion and earlier return to function.

SUMMARY

Metacarpophalangeal joint arthroscopy is in its infancy. At first glance its use may seem to be a triumph of technology over reason. However, as instrumentation becomes smaller and specific techniques are developed, arthroscopic treatment of disorders of the small joints of the hand will become more commonplace. The reduction and stabilization of fractures of the metacarpophalangeal joint arthroscopically is a technically demanding procedure. However, it has the potential to enhance the outcome of fracture treatment by limiting the exposure and the devitalization of small fragments while improving fracture reduction in a magnified operative field.

SUMMATION POINTS

Indications

Simple, closed two-part fracture of the metacarpal head or phalangeal base.

Outcomes

Have shown increased motion and an earlier return to function when compared to a similar cohort treated via conventional open means.

Complications

Involve damage to the surrounding structures of the metacarpophalangeal joint such as the extensor tendons, sensory nerves, and articular surface. For the most part these can be avoided with fastidious surgical technique.

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Triangular Fibrocartilage Tears and Ulnocarpal Impaction

Vincent Ruggiero
Staten Island University Hospital, Staten Island, New York, U.S.A.

INTRODUCTION

Acute triangular fibrocartilage complex (TFCC) tears and ulnocarpal impaction with associated chronic tears of the TFCC are two of the more common reasons for ulna-sided wrist pain. The use of the arthroscope as advanced the ability to diagnose and to treat these conditions. Prior to the widespread use of arthroscopy these conditions were treated with open surgical procedures. For TFCC tears these included excision or repair both of which required arthrotomy of the wrist (1). Ulnocarpal impaction was treated by ulnar shortening with plate fixation or with open wafer procedure (2–4). As the tools of arthroscopy have advanced and been made to accommodate the wrist joint, it is only natural that clever surgeons would devise methods to treat these disorders with the arthroscope. The arthroscope has allowed surgeons to visualize the tears of the TFCC better and we now possess the tools to repair or debride the tears and even resect portions of the ulna head with minimally-invasive techniques.

INDICATIONS

Ulna-sided wrist pain following trauma may be caused by a tear of the TFCC. With negative radiographs and no instability, a period of immobilization should be trialed. If the pain persists or if instability is present arthroscopy should be considered. A cortisone injection may be given as treatment prior to the use of surgery. This is usually when the condition is chronic.

TFCC tears, both acute, and chronic are common indications for wrist arthroscopy. Ulnocarpal impaction without associated lunotriquetral (LT) ligament tear is another indication that can be treated with wrist arthroscopy. When the LT ligament is torn along with ulnocarpal impaction and a TFCC tear, ulna shortening should be utilized as treatment. The diagnosis of the LT ligament tear is usually identified at the time of arthroscopy and can be a reason for failure of debridement of the TFCC alone (5). Open ulna shortening is used for these patients because it will tighten the ulnocarpal ligaments.

PREOPERATIVE PLANNING

The examination of the patient with ulna-sided wrist pain should include range of motion, stability of the distal radioulnar joint (DRUJ) in comparison with the opposite wrist and palpation for areas of focal tenderness. Pain elicited with palpation in fovea is consistent with a TFCC tear. Marked instability of the DRUJ is demonstrated by the "piano key" sign. The LT shuck test and ballottement test are consistent with a LT ligament tear (6). Evaluation of the wrist for extensor carpi ulnaris (ECU) subluxation should also be part of the examination. Any deformity should be noted as may be present secondary to distal radius malunion.

Imaging studies should include posteroanterior (PA) and lateral neutral rotation radiographs. This is the standard manner to determine ulna length. The elbow is at 90° of flexion with the shoulder in neutral and the forearm in neutral for the lateral. The PA radiograph places the shoulder in 90° of abduction with the forearm and elbow unchanged from the lateral radiograph position. If necessary radiographs of the opposite wrist for comparison should be obtained. Probated grip radiographs may aid in the diagnosis of ulnocarpal impaction. The radiograph is performed with the forearm pronated and maximal grip effort. The ulnar variance of the grip radiograph is compared to the neutral PA film. This has been shown to increase the ulnar variance by an average of 2.5 mm in symptomatic patients (Fig. 1A,B) (7). Magnetic resonance images (MRI) will show characteristic signs of edema in the ulna head and ulna aspect of the lunate in cases of ulnocarpal impaction. The MRI will assist in the confirmation of the diagnosis of a TFCC tear. The MRI testing with a high field magnet and an experienced radiologist can have an accuracy of 97% for detection of a tear and 92% for location (8). However, with less experienced radiologists and inadequate equipment, the sensitivity is much less (9). The MRI arthrogram may be shown in the future to make the sensitivity greater in the hands of all radiologists. The MRI is less sensitive for LT tears though it is improved by using arthrogram.

TFCC lesions have been classified into two classes. Class 1 is traumatic lesions and Class 2 is degenerative lesions. Within the traumatic class there are subdivisions based upon location of the tear and within the degenerative class and also it is based upon associated lesions (Table 1) (10).

SURGICAL TECHNIQUE

Anatomy

The TFCC originates on the ulnar border of the radius and attaches to the base of the ulna styloid. This central articular disk has a border of the radioulnar ligaments. These ligaments have a function to stabilize the DRUJ during forearm rotation. This is one of the TFCCs main functions. Palmarly the complex consists of the ulnolunate and ulnotriquetral ligaments which support the ulna carpus. On the dorsal side are the ECU and its subsheath which also stabilize the ulna carpus. The central disk is avascular with the blood supply to the TFCC coming from the periphery (Fig. 2). This allows for healing of peripheral tears but in converse the central tears will not heal (11). The TFCC absorbs 20% of the load across the wrist in the ulna neutral

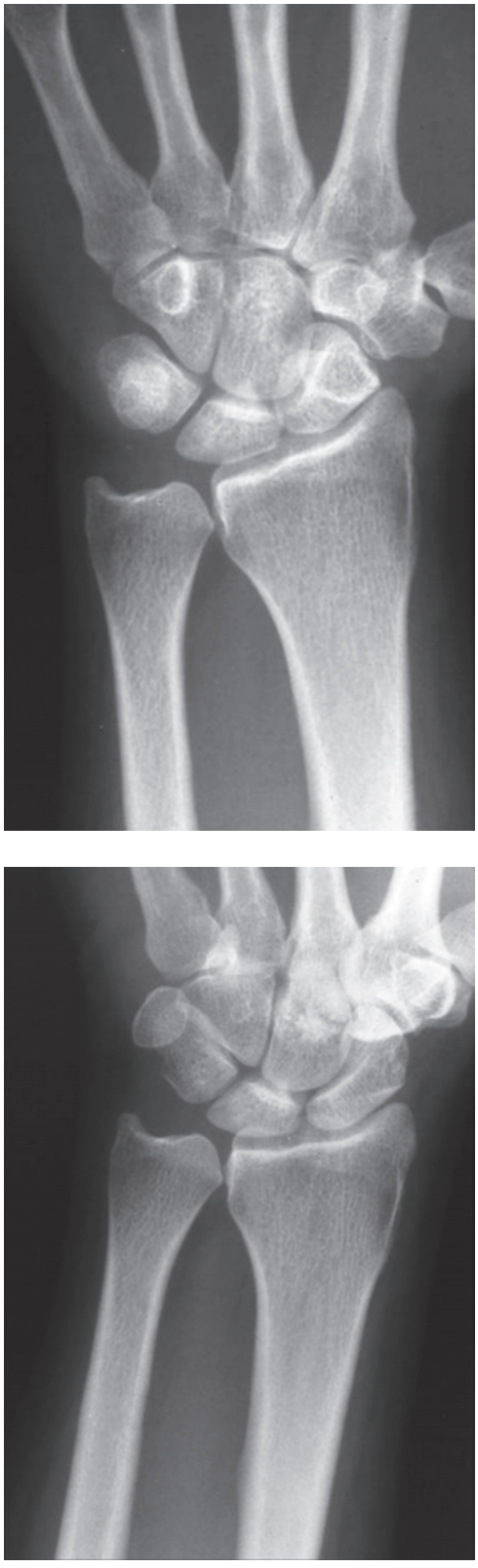

FIGURE 1 (**A**) Posteroanterior (PA) radiograph without grip. (**B**) PA radiograph of same patient with grip demonstrating a more positive ulnar variance.

patient. As the ulna variance becomes more positive the TFCC absorbs more of the load (10).

The extensor tendons at the level of the wrist joint are divided into six compartments. The portals for wrist arthroscopy are based on the location of the portal in comparison to the compartments (Fig. 3). The portals on the ulnar side of the wrist place the dorsal sensory branch of the ulna nerve at risk of injury. The portal with the highest risk is the 6U portal secondary to its proximity to the nerve.

TABLE 1 Palmer Classification of TFCC Tears

Class 1: Traumatic	A. Central perforation B. Ulnar-sided tear a. With distal ulnar fracture b. Without distal ulnar fracture C. Distal avulsion D. Radial avulsion a. With sigmoid notch fracture b. Without sigmoid notch fracture
Class 2: Degenerative	A. TFCC tear B. TFCC tear a. Lunate/ulnar chondromalacia C. TFCC perforation a. Lunate/ulnar chondromalacia D. TFCC perforation a. Lunate/ulnar chondromalacia b. LT ligament perforation E. TFCC perforation a. Lunate/ulnar chondromalacia b. LT ligament perforation c. Ulnocarpal arthritis

Abbreviations: LT, lunotriquetral; TFCC, triangular fibrocartilage complex.

Setup

The basic arthroscopy equipment is necessary for the procedures to be done. A 2.7 mm 30° angle arthroscope is standard. A motorized shaver with full radius shavers or burrs is needed as various punches including a suction punch. There are also thermal ablation devices that can be used and some surgeons utilize the laser with reported good results (12).

The surgery is performed under general anesthesia or an axillary block. The patient is supine on the operating room table. Various distraction devices are available. The devices will either

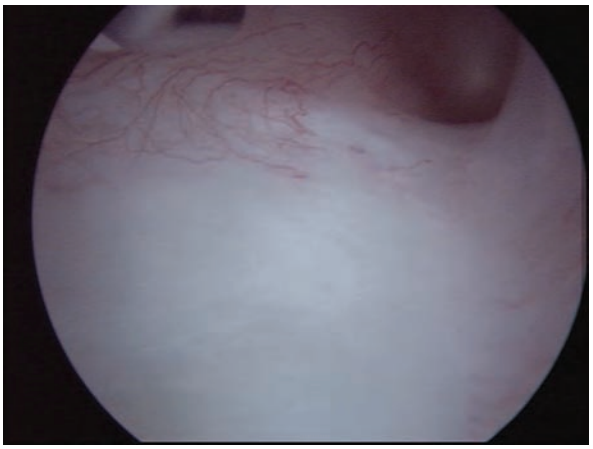

FIGURE 2 The peripheral blood supply to the triangular fibrocartilage complex looking from radial to ulna with the arthroscope in the 3–4 portal.

FIGURE 3 Common portals for wrist arthroscopy. Distraction is applied with the Traction Tower®.

be self-contained and sterile or will pull from overhead or off the end of the table. With the self-contained distraction device or the overhead traction, the wrist is in a neutral position simulating the neutral PA radiograph which was utilized to determine ulna length. The author prefers the self-contained distraction device. The arm is secured to the table after a tourniquet is applied. The method by which to secure the arm to the table is variable but one way is to place a towel over the tourniquet and secure the arm to the armboard with Coban® (3M Corporation, St. Paul, Minnesota, U.S.A.) wrap. This provides a tight hold to the upper arm which is vital to maintain the distraction and eliminate iatrogenic cartilage injury. Some surgeons prefer to secure the upper arm after the patient is prepped and draped. In the author's experience this has lead to loss of distraction during the procedure. The Traction Tower® (Conmed Linvatec, Largo, Florida, U.S.A.) is assembled per protocol after prepping and draping. Fingertraps are placed on the index and ring fingers and then they are attached to the tower. Ten pounds of traction is pulled by direct means. There is a dial on the device which can fine tune the distraction if it is necessary during the operative procedure.

Once the arm is in traction the portals are marked out. The portals for wrist arthroscopy are based on the position of the extensor compartments. Starting at Listers tubercle and advancing 1-cm distal is the 3–4 portal. It is between the crossing extensor pollicis longus and the extensor digitorum communius. Advancing another centimeter distal is the midcarpal radial portal. The ulnar edge of the fourth compartment can be palpated. Just ulnar to the fourth compartment and radial to the fifth compartment (extensor digiti minimi) is the 4–5 portal. One centimeter distal to that is the midcarpal ulna portal. This can also be palpated as a sulcus between the capitate, hamate, lunate, and triquetrum intersection. The ECU is palpated and a portal is marked just ulnar as the 6U and just radial as the 6R. The ECU is also marked out as is the articular surface of the distal radius and ulna (Fig. 3).

The limb is exsanguinated and the tourniquet inflated to 250-mm Hg. The 3–4 portal is localized with an 18-gauge needle and then the joint is filled with normal saline. If the fluid flows freely with no endpoint, it implies that a tear is allowing fluid to flow into either the midcarpal or DRUJ. This should be noted in the operative report. Then the skin is incised with an 11 blade scalpel and using a blunt hemostat the tissues are spread to the capsule. The blunt trocar is introduced into the radiocarpal joint and the wrist scope is placed into the cannula. Inflow is coming through the cannula. Various systems exist for maintaining distension. There are pumps that maintain constant pressure or manual devices using a syringe or pinch valve to keep the joint distended. To establish the 4–5 portal, an 18-gauge needle is used to localize its position under direct arthroscopic visualization. Again an 11 blade is used to open the skin and spread down to the capsule with a blunt hemostat and then enter into the joint with the blunt hemostat. At times, a 6U portal is utilized for outflow (if using thermal ablation devices). An angled probe is placed in the 4–5 portal and diagnostic arthroscopy is carried out.

Diagnostic arthroscopy is performed in the routine manner to examine all the intra-articular structures, but for the purpose of this chapter, discussion is limited to disorders on the ulnar side of the wrist. The TFCC is palpated with the probe and if a tear is found it can be further evaluated by making 6U portal for instrumentation and switching the scope to the 4–5 portal. This also allows for better visualization of the LT ligament just distal and ulnar to the TFCC. The author has found that the 6R portal is also of value and can be made instead of the 4–5 portal once again under direct vision using an 18-gauge needle to localize.

TFCC Debridement

After a diagnostic arthroscopy is performed, the debridement starts with the scope in the 3–4 portal and the 2.9 mm full radius shaver in the 4–5 (or 6R) portal. Up to two-third of the TFCC can be debrided without comprising DRUJ stability (13). Various small joint arthroscopy tools can be utilized to assist in the debridement depending on the size of the tear. Common tools are the side biters and a suction punch but whatever device works best for the surgeon and the tear should be used. After debridement is performed with the arthroscopy tools, the shaver is used to smooth the edges of the TFCC to a stable rim (Figs. 4 and 5). Various thermal ablation wands are now available to debride the TFCC. One must be careful with their use. It is important to make sure that the articular cartilage is not touched with the devices to prevent chondrolysis and outflow must be used to ensure that the temperature of the fluid in the joint does not go too high. If complete debridement cannot be carried out with the scope in the 3–4 and the instruments in the 4–5, then the scope can be switched to the 4–5 portal and the tools placed in the 6U portal.

No closure is performed on the portal sites. A dressing and short arm splint is applied allowing digital motion. The patient maintains elevation for 48 hours. At one week postoperative the dressing is removed and motion is begun supervised by a hand therapist.

FIGURE 4 Palmer 1A tear. Probe is in the central tear.

Case Example-TFCC Debridement

A fifty-six-year-old male sustained injury to right wrist in a fall three months prior to presentation to the office. He reported ulna-sided wrist pain with activity since the injury. His primary care physician treated him with nonsteroidal anti-inflammatory medications and splinting with no relief. His radiographs were negative and an ulnar neutral variant was present. A cortisone injection into the ulna side of his wrist gave temporary relief of symptoms. Eventually, he was taken to the operating room where arthroscopy was performed and a Palmer 1A TFCC tear was identified (Fig. 4). He had successful debridement performed (Fig. 5) and went back to preinjury activity status.

TFCC Repair

The setup and initial diagnostic arthroscopy is carried out as for the debridement. The TFCC is palpated with the probe and if it has lost its normal trampoline effect (Fig. 6) and if the ulnar edge is torn then a repair is performed (14). The author's preference is to perform an outside-in repair. The edges of the TFCC on the ulnar side are debrided with a full radius shaver so as to stimulate healing on that side (Fig. 7). There is a rich blood supply to the ulnar aspect of the TFCC which allows for healing in contrast to the avascular central portion. Once the debridement is complete a longitudinal skin incision is made over the ECU about 1 to 1.5 cm in length. The sheath is opened and the ECU is retracted either dorsal or volar whichever will allow for easier placement of the needles. There are various commercially available devices for repair of the TFCC. They all have in common a needle which will allow for a suture to be passed and a loop to withdraw the suture (Fig. 8). Once the needle is passed through the ECU sheath then it is passed through the TFCC from its undersurface while visualizing the passage with the arthroscope. A 2-0 polydioxanone (PDS) suture is threaded through the needle with the assistance of a Caspari suture wheel. The free end of the suture can be

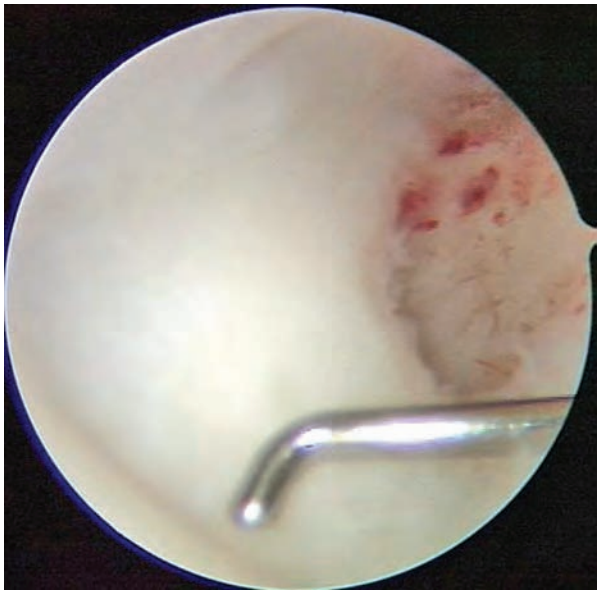

FIGURE 6 Lost trampoline effect of TFCC secondary to peripheral TFCC tear. *Abbreviations*: TFCC, triangular fibrocartilage complex.

FIGURE 5 Debrided Palmer 1A. Probe is on the triangular fibrocartilage complex and the ulna head is deep.

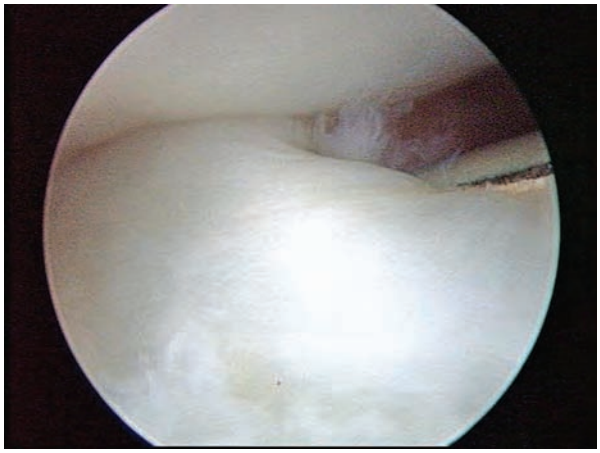

FIGURE 7 Palmer 1B triangular fibrocartilage complex tear with probe demonstrating unstable peripheral edge.

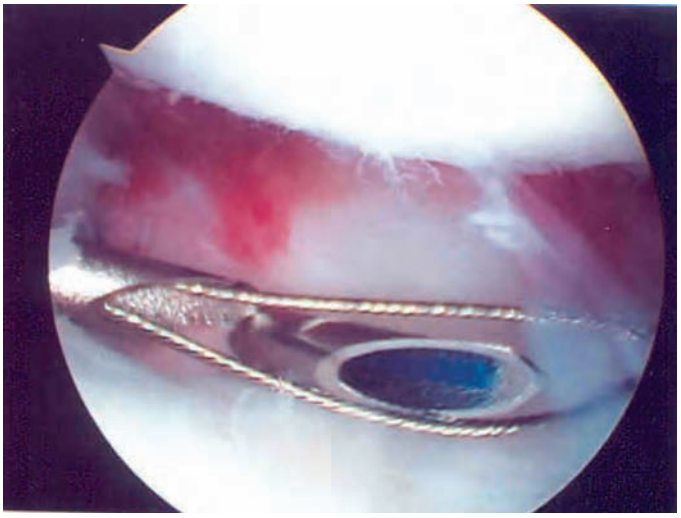

FIGURE 8 Suture being passed from the periphery through the suture passer.

withdrawn out of the wrist through the sheath with the loop. The loop may or may not have been passed through the TFCC. If it is passed through the TFCC then the suture will now be a U-stitch which is ideal otherwise it is a simple stitch that is made. If a simple stitch is passed it is ideal to pass two separate sutures. The ends of the suture are pulled tight and then while directly visualizing the TFCC the sutures are tied down to the ECU sheath (Fig. 9). The ECU is placed back in the sheath but the dorsal aspect of the sheath is not closed. The skin is closed over the open incision but the portals are not closed. No Kirschner (K) wires are used. A sugar tong splint with the forearm in neutral position is placed with the postoperative dressing. At the first postoperative visit, the dressing is removed and a Munster style cast is applied limiting supination/pronation for a total of six weeks from surgery. After the cast is removed, the patient is place into a hand therapy program to restore motion first and then to regain strength.

Palmer Type 1D TFCC tears can also be treated with the arthroscope. The setup and diagnostic arthroscopy are carried out as previously described. The free edge of the tear is debrided with an arthroscopic full radius shaver. The sigmoid notch of the radius is debrided with a burr taking care not to damage the articular surface of the radius or the carpus. Through the 6U portal and using a cannula, 0.062-inch K-wires are passed from the ulna side of the radius through the radial side. Once the wire has passed through the radial side it is withdrawn and then passed again. At least two passes are necessary but the repair is easier with more tunnels created. Then using a 2-0 PDS that is double armed with Tuohy needles the TFCC is sutured back to the radius. The needles are passed through the TFCC from the 6U portal through the cannula and into one of the drill holes in the radius. Both needles are passed through separate drill holes. The needles are passed out the radial side of the wrist and then with an open incision dissection is carried out to the exit from the radius. The sutures are brought into the same plane. One must avoid the sensory branch of the radial nerve and the extensor tendons. The sutures are tied down over the radius and the repair is complete (15).

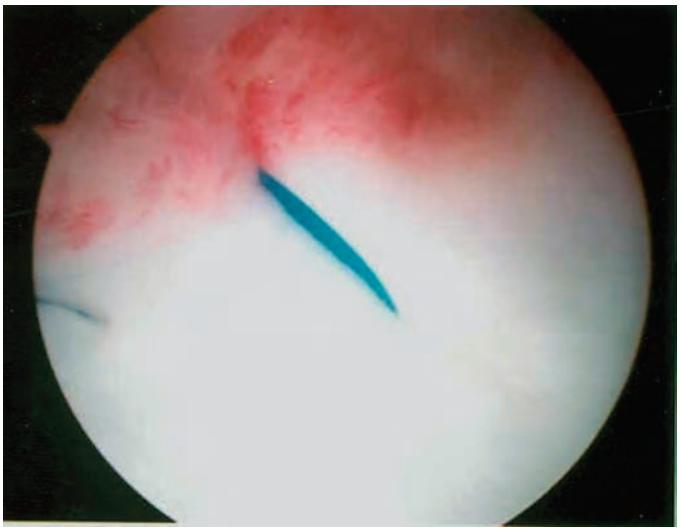

FIGURE 9 Repair of triangular fibrocartilage complex.

Case Example-Palmer 1B Tear

A thirty-nine-year-old right-hand dominant male carpenter reports an injury to his right wrist. He was using a drill when the bit bound and he sustained a torque injury to his right wrist. He ended up going to the emergency room but radiographs were negative with ulnar neutral variance. He had tenderness on examination in the fovea of the ulna side of the wrist. Mild instability was noted in comparison to the opposite side. A presumptive diagnosis of a TFCC tear was made. This was confirmed on MRI and at the time of arthroscopy a Palmer 1B tear was noted (Fig. 7). An outside-in repair was performed (Figs. 8 and 9), and the patient was immobilized in a Munster cast for six weeks. He did well in a postoperative therapy program and returned to work as a carpenter at three months from surgery.

Arthroscopic Wafer

The setup is the same as for the previous procedures except that a mini c-arm is also needed. This is positioned in a way to obtain radiographs to determine that enough bone has been resected. This can be difficult to arrange with all of the arthroscopy equipment being present. It is advisable to confirm that the image will be able to be brought in easily prior to prepping and draping the first times that the procedure is performed. Once sufficient skills are obtained with the resection, the use of fluoroscopy can be eliminated.

The TFCC tear is the access to the ulna head that is necessary to perform the resection. The first step is to debride the tear to a stable rim which will also allow better visualization of the ulnar head. Utilizing a small joint burr, 2 mm, the ulna head is abraded so the entire articular surface is removed. The known size of the burr can be used as a template to know how much bone is being removed. Starting on the radial side the ulnar head is debrided and then the burr is brought ulnar. At this time, the arthroscope is in the 3–4 portal and the burr is in the 6R portal. The arm must be brought through an arc of passive supination and pronation to see the entire ulna head so the resection can be adequately performed. The arthroscope must be passed into the 4–5 or 6R portal to check on the resection. The DRUJ portal may also need to be used to do a portion of the resection. Two portals for arthroscopy of the DRUJ are described. One is the proximal portal which is proximal to the sigmoid notch. The second portal is distal to the sigmoid notch. At times, the 2.7-mm arthroscope may be too larger to fit in the joint; therefore a smaller arthroscope is needed. Usually 2 mm of bone must be removed to create an ulna negative wrist (Fig. 10). The postoperative dressing included a short arm splint. Supervised hand therapy is

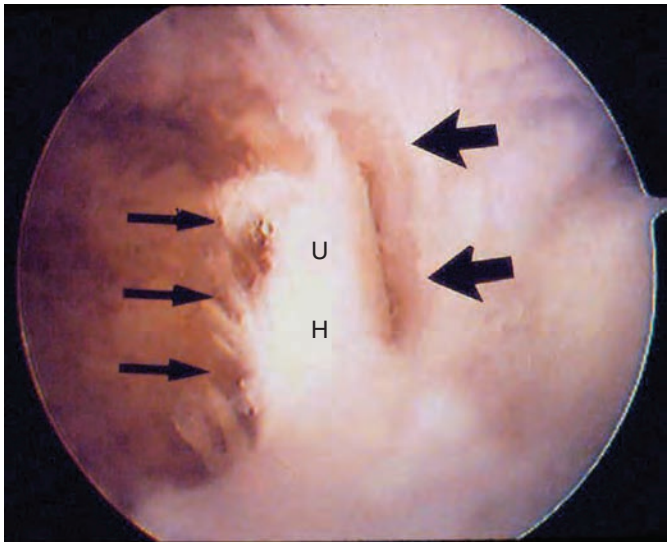

FIGURE 10 Arthroscopic wafer procedure demonstrating resected UH. *Small arrows* on the UH. *Large arrows* on the triangular fibrocartilage complex rim. *Abbreviations*: UH, ulnar head. *Source*: Courtesy of Andrew K. Palmer M.D.

begun at week 1 with an emphasis on motion. Once sufficient gains in motion are made then a strengthening program is begun.

Case Example-Arthroscopic Wafer

A forty-five-year-old right-hand dominant male police officer and avid golfer began having right-sided wrist pain about two months prior to presentation to the office. There was no discrete injury to the wrist but the pain was ulna sided and bothered him with activities including golf. Radiographs revealed 2 mm of ulnar positive variance. Diagnosis of ulna impaction was made. He failed conservative therapy and eventually underwent arthroscopy. At the time of surgery a degenerative TFCC tear was identified and an arthroscopic wafer procedure with TFCC debridement was carried out. The patient returned to normal law enforcement activity and golf with no pain.

■ COMPLICATIONS

Complications from these surgeries are uncommon. In one large study of 211 wrist arthroscopies, the major complication was 0.9% and the minor complication rate was 4.3%. However, 58% of these patients underwent subsequent open procedures, so it is difficult to conclude if the arthroscopy or the open procedure led to the complication. The most common complication was dorsal sensory ulnar nerve neuropraxia (16). The routine use of thermal ablation devices can be associated with burns or chondrolysis. Incomplete ulnar head resection leading to continued ulnar-sided pain is a technical error that can occur. Because the ulna head in an open resection comes out as one piece it can be judged to be completely removed.

■ OUTCOMES

Results from arthroscopic debridement of Palmer 1A TFCC are favorable. At average follow-up of three years 84% of patients have had relief of their symptoms (17). A study of patients combining degenerative and traumatic tears treated with debridement noted the traumatic tears did better. Patients that were ulna positive or had an associated LT ligament tear did worse (18). A more recent study had similar results. At follow-up of two to six years, 77% of patients had good to excellent results. Interestingly 18 of the 35 patients had associated chondral lesions (19).

Results from arthroscopic TFCC repair of Palmer 1B TFCC tears are also favorable. Satisfactory results of greater than 90% have been reported (20–22). Timing of the repair has also been examined. They theorized that delays over six months increased the incidence of degeneration of the TFCC. This was worse when there was an ulnar positive variant. Results when the repair was performed without six months demonstrated improvement in pain in all patients with 21 out of 24 achieving complete relief (23). More recent studies have confirmed the previous data with 34 out of 37 patients having good to excellent results. In this study, grip strength was noted to have diminished to 72% of normal (24).

Arthroscopic treatment of Palmer 1D tears is controversial. Because the radial side of the TFCC is avascular healing potential has been questioned. Good results with repair have been reported in the literature with 8 out of 13 patients returning to preinjury activity level. Postoperative studies including arthrogram, MRI, and arthroscopy demonstrated intact TFCC. This data clearly support the ability of the radial aspect of the TFCC to heal to the radius (23).

Arthroscopic wafer procedure as treatment for ulnocarpal impaction has had success. At three to five years results have had good to excellent results in 75% of cases (24). Debridement of 3 mm of bone in a cadaveric study lowered pressures on the ulna side of the wrist by 10.8% (25). The arthroscopic techniques give similar results as the open wafer procedure without the need for postoperative immbolization (3). Excellent results from combined arthroscopic TFCC debridement and wafer procedure have been recently reported with all patients being satisfied with the results and an improvement in grip strength by 36% (26). Patients with ulnocarpal impaction and associated LT instability should be treated with ulna shortening osteotomy and not the wafer procedure. The shortening will tighten the ligaments on the ulnar side of the carpus. Without the LT instability, the arthroscopic procedure has the benefit of no hardware complications and no risk of nonunion.

■ SUMMARY

Wrist arthroscopy is a minimally-invasive technique that has changed the way in which ulnar-sided wrist pain is treated. Pioneering work done on the anatomy, function, and injuries of the TFCC has been the stimulus to push the technology. As was true in the knee and the shoulder, the original use of the arthroscope was to assist in diagnosis. Treatments of the pathologies found were limited by the technology available. Surgeons pushed the advance of the instrumentation in the wrist which allowed for more treatment possibilities. There has been much advancement of the technology available for arthroscopy of the knee and the shoulder. The amount of new instrumentation in the wrist has lagged behind the changes in these other joints. One can envision a time in which repair techniques such as knotless anchors will be perfected in the wrist which would ease the repair of the radial-sided TFCC tear. Thermal devices for ablation and shrinkage are in their infancy and there future is unknown.

Indications for arthroscopic treatment of TFCC are tears in the setting of:

- Ulna-sided wrist pain failing conservative treatment
- Ulna positive deformity leading to pain
- LT ligament intact.

Advantages of the arthroscopy over open procedures are:

- Better visualization of the TFCC and associated chondral lesions
- Ease of repair of TFCC
- Less invasive for debridement of TFCC
- No risk of nonunion or hardware complication as in ulnar shortening.

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31

Minimally Invasive Treatment of Arthritis Associated with Scapholunate and Scaphoid Nonunion Advanced Collapse

Charles M. Jobin, Steven H. Goldberg, and Robert J. Strauch
Department of Orthopedic Surgery, Columbia University Medical Center, New York, New York, U.S.A.

INTRODUCTION

Scapholunate advanced collapse (SLAC) is a progressive pattern of arthritis that develops in the setting of a chronic scapholunate ligament tear. This ligamentous injury leads to abnormal carpal alignment, altered force transmission, and increased focal joint contact (1–3). Scapholunate instability is characterized radiographically by scapholunate joint widening, extension of the lunate, palmarflexion of the scaphoid, and capitate proximal and dorsal translation (4–6). In the normal wrist, pressure or load across the carpus is unevenly distributed and dependent on both the position of the wrist and on the direction of motion (7). One study demonstrated that with progressive scapholunate instability, contact area and pressure is concentrated at the radioscaphoid rather than the radiolunate joint (1,2). However, others found that with scapholunate ligament sectioning, the radiocarpal pressure shifts from the radioscaphoid to the radiolunate fossa (8). Additionally, scaphoid palmarflexion causes a decreased radioscaphoid contact area and changes contact to the dorsal lip of the radius (9). The greatest carpal shear forces lie between the distal radius and scaphoid and between the proximal capitate and the distal lunate. The above changes in carpal bone rotation and translation, force concentration, and contact area explain the radioscaphoid and lunocapitate arthritis (5,10,11).

SLAC wrist is classified into several stages that assists in determining which surgical intervention can alleviate symptoms (10). Stage I arthritis is limited to the radial styloid and scaphoid waist articulation with pointing of the styloid (Figs. 1 and 2) and joint space narrowing. Stage II arthritis advances proximally to involve the complete distal radius scaphoid fossa and scaphoid articular surfaces due to continued, chronic overload of this portion of the carpus (Fig. 3). In stage III midcarpal arthritis develops at the capitolunate joint from axial proximal collapse of the capitate between the dissociated scaphoid and lunate bones (Fig. 4). The proximal lunate articular surface and lunate facet of the distal radius have a concentric spherical articulation. Thus, the extended lunate in SLAC wrists does not result in abnormal shear forces at the radiolunate articulation, causing this joint to be spared from the arthritic process (10,12).

Scaphoid nonunion advanced collapse (SNAC) is a similar, but distinct, pattern of progressive arthritis with a comparable natural history and treatment options. Similar to SLAC wrists, pathologic carpal bone rotation occurs in SNAC wrists, particularly lunate extension. The nonunion site undergoes bone resorption and cystic changes in most patients after 18 months allowing the distal scaphoid fragment to translate proximally and contact the radial styloid (13). The distal scaphoid pole rotates and develops abnormal motion through its intact ligaments to the distal carpal row. This leads to radioscaphoid arthritis approximately five years after injury, which develops in all patients by 10 to 20 years (14,15). However, the proximal radioscaphoid joint is spared since the proximal pole has more normal kinematics through its continuity to the proximal row through the intact scapholunate ligament (13). Eventually, the distal pole rotation and radial styloid-scaphoid joint space narrowing allow proximal and radial migration of the capitate which causes scaphocapitate and capitolunate arthritis (13). This advanced arthritis typically develops after 20 years and is present in most patients 30 years after injury. The magnitude and a more diffuse pattern of arthritis correlate with increased scaphoid displacement and carpal malalignment (14,15).

Many patients with SLAC or SNAC wrists may have minimal symptoms for many years (16) and therefore operative intervention should be reserved for those patients with significant pain. The choice of surgical procedure is primarily dictated by the location and extent of the arthritis. Operative choices include arthroscopic debridement, radial styloidectomy (17), excision of the distal scaphoid pole for nonunion (18), proximal row carpectomy (19), limited intercarpal arthrodesis with scaphoid excision (10,19), total wrist arthrodesis (12), and total wrist arthroplasty. However, this chapter will focus on minimally invasive treatments for patients with early SLAC or SNAC wrist. Cases with stage III or diffuse arthritis require more extensive open procedures.

RADIAL STYLOIDECTOMY

Indications/Contraindications

Radial styloidectomy involves minimal surgery, immobilization, and rehabilitation, and eliminates the painful impingement between the distal scaphoid and the radial styloid in stage I SLAC or early SNAC wrist (17,20). It can be performed alone or in combination with other procedures (18). Additionally, styloidectomy may be performed at the time of procedures designed to treat scapholunate dissociation (21,22). Styloidectomy alone is contraindicated in stage II or III SLAC wrist since the arthritis extends proximal to the styloid.

Considerations for Preoperative Planning

Similar preoperative planning with respect to physical and radiographic examination is applicable for all the techniques in this chapter and will be described in detail in this section with specific points highlighted in subsequent sections. Patients must be counseled that styloidectomy or the other procedures may alleviate current symptoms, but they do not restore normal carpal kinematics or alter the natural history of progressive arthritis. Thus, patients may develop recurrent symptoms and

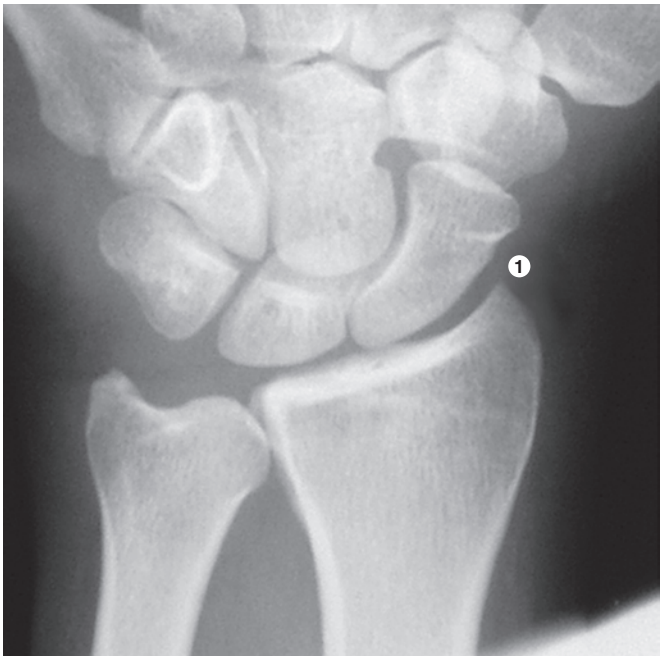

FIGURE 1 Posteroanterior radiograph demonstrating the beginning of radial styloid pointing (1) without radioscaphoid joint space narrowing. This indicates early stage I scapholunate advanced collapse wrist arthritis. Normal carpal alignment is present.

they may require additional surgery. Therefore, careful patient selection is crucial. Since isolated styloidectomy treats the painful radial wrist pain but does not address the chronic scapholunate instability, it is usually recommended in older

FIGURE 2 Chronic scapholunate instability is evident with a stress ulnar deviation, posteroanterior radiograph.

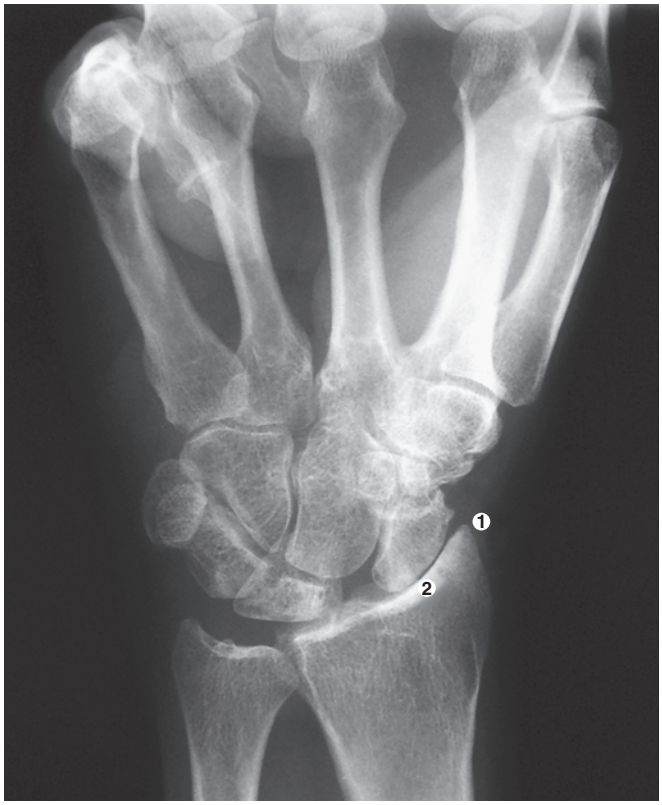

FIGURE 3 Posteroanterior clenched fist radiograph showing styloid pointing (1) and joint space narrowing at the radial styloid-scaphoid (2) and radial fossa-proximal scaphoid articulations. Note the widened scapholunate interval and preservation of the capitolunate joint space, making this stage II scapholunate advanced collapse wrist arthritis.

patients, patients with low-demands on wrist loading, patients with radial wrist pain during activities of daily living, and patients who do not wish to undergo more extensive rehabilitation and immobilization. It is not recommended as the definitive intervention in a young, athletic person who is likely to develop recurrent or progressive symptoms from repetitive loading of an untreated scapholunate injury.

Prior to performing styloidectomy, careful questioning and physical examination are critical to determine if the patient has focal radial wrist pain over the radial styloid and snuffbox area, or whether diffuse symptoms are present. Patients with focal symptoms may be candidates for an isolated open or arthroscopic styloidectomy. Patients who have diffuse wrist pain may have continued symptoms after styloidectomy alone.

Usually X-rays are the only imaging study needed prior to surgery. Routine radiographs include posteroanterior in neutral rotation, lateral, and oblique views. The presence of joint space narrowing should be specifically noted at the radial styloid-scaphoid waist, radial fossa-scaphoid proximal pole, and capitolunate articulations. Because joint space width can vary with wrist position, it is often useful to obtain bilateral wrist radiographs on the same film cassette to assess for asymmetry. The radiographs should confirm that arthritis appears to be limited to the radial styloid and scaphoid waist. A posteroanterior radiograph in radial deviation may help illustrate the point of maximal styloid-scaphoid contact. Please refer to chapter 15 "RASL reconstruction for scapholunate instability" for a detailed description of radiographic abnormalities in scapholunate tears.

FIGURE 4 Posteroanterior clenched fist radiograph showing styloid pointing (1) and diffuse radioscaphoid arthritis (2) with involvement of the capitolunate joint (3) indicating stage III scapholunate advanced collapse wrist arthritis.

However, since radiographic findings often underestimate the degree of articular cartilage injury and since SLAC wrist arthritis is secondary to other ligamentous carpal injuries, we recommend wrist arthroscopy be performed prior to styloidectomy, even if an open styloidectomy is planned in order to thoroughly evaluate the radiocarpal and midcarpal joints. If the arthritic changes are isolated to the radial styloid-scaphoid articulation, then the surgeon can proceed with styloidectomy. Additionally, debridement of inflamed synovium can eliminate synovitis and relieve diffuse dorsal wrist pain. Synovial debridement also removes redundant tissue that can eliminate pain emanating from mechanical impingement. Unstable flaps of a torn scapholunate ligament should also be debrided (23,24).

Surgical Technique

The patient is placed supine on the operating room table with the arm on an arm board and a sterile tourniquet is applied. The hand is suspended from a traction tower device with the index and middle fingers placed in finger traps under 10 to 15 pounds of traction. The radiocarpal joint is insufflated with normal saline to distend the joint. This protects the articular surface during portal establishment by moving the capsule away from the articular surface. During injection extravasation of fluid into the distal radioulnar joint or extensor carpi ulnaris sheath suggests a triangular fibrocartilage complex tear. A longitudinal incision is made just through the skin at the 3–4 portal, a soft spot distal and ulnar to Lister's tubercle between the extensor pollicis longus and extensor digitorum communis compartments. A fine, curved hemostat is used to bluntly spread down to the capsule to prevent cutaneous nerve or tendon injury and the capsule is penetrated in a controlled manner. A 2.7 mm arthroscope is placed through the portal and the radiocarpal compartment is visualized. An 18-gauge needle is placed in the 6U portal, which is located ulnar to the extensor carpi ulnaris, to allow outflow. Additionally, midcarpal arthroscopy should be performed using the radial midcarpal portal, 1 cm distal to the 3–4 portal to evaluate for capitolunate arthritis.

If no extensive midcarpal or radiocarpal arthritis is identified, the 1–2 portal is established between the extensor pollicis brevis and extensor carpi radialis tendons and a covered bur ranging in size from 2.9 to 4.0 mm is inserted. Alternatively the arthroscope may be placed in the 4–5 portal between the extensor digitorum communis and extensor digiti minimi with the bur placed through the 3–4 portal. Radiocarpal synovectomy should be performed to allow thorough observation of the radial styloid and volar ligaments. The amount of styloid removed should not be more than 4mm from the tip of the styloid and the width of the bur may be used as a reference. Post operatively patients should be placed in a volar short arm splint for 10 to 14 days after which sutures are removed. Gentle wrist motion is encouraged with restriction from vigorous activity for six weeks.

Complications

Arthroscopic styloidectomy may have less morbidity than open techniques as it avoids the need to identify and retract the dorsal sensory branches of the radial nerve and involves less capsular dissection. Failure to remove sufficient bone from the styloid may lead to persistent radiocarpal pain and loss of motion. Careful analysis of preoperative radiographs with measurement of the location of radioscaphoid impingement with respect to the styloid tip facilitates the determination of the amount of bone resection necessary to adequately decompress the joint. Additionally, arthroscopic visualization and intraoperative fluoroscopy provide a dynamic assessment of elimination of impingement. Alternatively, excessive resection must be avoided. Yao and Osterman (17) postulate that arthroscopic procedures may prevent excessive resection due to visualization of the styloid and volar ligaments during resection. Removal of styloid beyond 4 mm has a risk of sacrificing the radioscaphocapitate, dorsal radiocarpal, and long radiolunate ligaments which are integral in supporting the carpus and preventing ulnar and volar translocation (25,26). The distal radial and carpal articular surfaces should be protected from iatrogenic damage during the procedure. The comparison of complications following open versus arthroscopic styloidectomy has not been specifically studied.

Outcomes

The superiority of arthroscopy over open styloidectomy has not been shown with regard to functional outcome or rate of complications. There are very few reports on the outcome of isolated radial styloidectomy in the treatment of SLAC wrist. A report of isolated open styloidectomy for scaphoid nonunion was made with satisfactory pain relief in 10 out of 13 patients (20). Excellent or good results were reported in five out of eight patients with scaphoid nonunion at 11 months follow-up after open styloidectomy (27). Arthroscopic and open radial styloidectomy were discussed in relation to SLAC wrist in a study by Yao and Osterman (17), but clinical results were not mentioned. A case series of three patients who underwent arthroscopic styloidectomy and distal scaphoid excision was more recently described (18). At two year follow-up all patients were highly

satisfied, had pain relief, complete relief of mechanical symptoms (catching, popping), improvement of the Modified Mayo Wrist Scores from 60 to 88, improved grip strength from 73% to 87% of the contralateral hand, improved range of motion and no radiographic joint degeneration. No immobilization was necessary and patients returned to work within two weeks on light duty and four weeks for full duty.

DISTAL SCAPHOID EXCISION

Indications/Contraindications

Chronic scaphoid nonunion can be treated with excision of the distal scaphoid pole when radiographic changes are consistent with early SNAC wrist confined to the articulations between the scaphoid distal pole and the radial styloid and radial surface of the capitate (28,29). Distal pole scaphoidectomy is contraindicated in more advanced SNAC wrist in which the capitolunate or proximal radioscaphoid joint is involved. One author described excision of the radial styloid in combination with distal pole excision (18). In cases of SNAC wrist where the nonunion site is proximal to the scaphoid waist on a posteroanterior radiograph in ulnar deviation creating small proximal and large distal pole fragments, we believe these injuries are best treated by measures other than distal pole resection.

Considerations for Preoperative Planning

Despite treatment of scaphoid nonunions with vascularized or nonvascularized bone grafting stabilization and internal fixation (30–32), success is not guaranteed and postoperative immobilization is often necessary for a prolonged time. Patients may not wish to undergo multiple attempts to achieve scaphoid union and once arthritis has developed, union alone may not alleviate all symptoms. Thus, in patients with SNAC wrist and who have primarily radial wrist pain worsening in radial deviation, distal scaphoid pole excision can be performed. This is minimally invasive with a rapid rehabilitation making it a useful option for low demand individuals or individuals who cannot tolerate prolonged immobilization and lifting restrictions due to work or personal obligations. Preoperatively alternative treatment options should be discussed with the patient in the event that diffuse arthritis is found at the time of arthroscopy.

Surgical Technique

Standard wrist arthroscopy positioning and equipment is used as described in the previous section. The arthroscope is placed in the more ulnar 4–5 or 6R portal (radial to the extensor carpi ulnaris tendon) to gain wider perspective of the proximal scaphoid and distal radius scaphoid fossa articular surfaces (18). The midcarpal joint should also be examined. During the diagnostic arthroscopy it is often helpful to perform a thorough radial-sided synovectomy with debridement of any unstable chondral or ligamentous flaps of tissue using a 2.9 mm full-radius resector to establish a larger unobstructed field of view and working space in the region of the radioscaphoid joint and scaphoid nonunion site. Synovectomy allows enhanced visualization of the palmar radiocarpal ligaments that must be preserved to prevent postoperative ulnar carpal translocation. Depending on the patient's unique anatomy such as radial height and inclination, the arthroscope and bur can be alternately switched between multiple portals to improve visualization and working angles that permit styloidectomy and scaphoid excision without inducing new iatrogenic chondral injury. With the arthroscope in the 3–4 portal, insertion of the 2.9 mm bur through the more radial 1–2 portal facilitates removal of the radial styloid.

Sequential synovectomy and styloidectomy further opens the radiocarpal joint improving access to the distal pole of the scaphoid. This may also permit upsizing the bur to a 3.5 mm diameter which increases the efficiency of bone removal and decreases the frequency of instrument and line clogging by bone fragments. In an effort to improve working angles, attention should be paid to not removing more than 4 mm of the arthritic styloid to preserve the dorsal and palmar ligaments. The amount of resection can be judged based on the known bur diameter and marking the styloid articular surface 4 mm proximal to the tip at the initiation of styloidectomy. Finally, the distal scaphoid can be removed through the previously established portals, switching instrument, and arthroscope location as necessary. Adequate resection of the styloid and distal pole should be confirmed with intraoperative fluoroscopy.

Complications

Carpal instability could occur if extrinsic or intrinsic carpal ligaments are injured during bone resection. Articular cartilage or radial artery injury could also occur during the removal of the distal scaphoid pole.

Outcomes

In the largest series of open distal scaphoid resection, 19 patients were followed an average of 49 months (28). Flexion and extension arc improved from 49° to 92°. The radial and ulnar deviation arc improved from 23° to 41°. Postoperative grip strength improved to 75% of the opposite side. No radiographic carpal collapse was noted. Thirteen patients had complete pain relief and all but one returned to their prior job. In another series of open distal scaphoid excision four of the nine patients had no wrist pain and the remaining five patients had only mild pain with strenuous activity after surgery (29). The wrist range of motion improved from 70° to 140° (94% of the opposite wrist) and grip strength improved to 77% of the opposite wrist. There was no observed radiographic progression of arthritis in eight patients. The series of three patients who underwent arthroscopic styloidectomy and distal pole excision had good outcomes (see previous section for details) (18).

PROXIMAL ROW CARPECTOMY

Indications/Contraindications

Proximal row carpectomy (PRC) is a motion-sparing surgical procedure converting an unstable, painful SLAC or SNAC wrist into a simple hinge joint by removing the scaphoid, lunate and triquetrum and allowing the capitate to articulate with the lunate fossa of the distal radius. PRC is primarily indicated in chronic scapholunate ligament disruption with stage I or II arthritis and SNAC wrist confined to the radioscaphoid joint.

PRC is contraindicated in patients with degenerative changes on the lunate fossa of the distal radius, and inflammatory arthropathy which has a high failure rate because of progressive pancarpal arthritis (33). Loss of cartilage of the proximal capitate head can be a contraindication as well (SLAC stage III). However, PRC with proximal capitate resection and/or soft tissue interposition resulted in a good outcome in several patients with lunocapitate or radiolunate disease, which may slightly expand the indications for PRC (34,35). Others report that capitate focal chondral defects up to 3 mm are

amenable to PRC (33,36). If there is any question about the severity of capitate cartilage wear, an alternative procedure such as scaphoid excision and four corner fusion (lunate-triquetrum-capitate-hamate) should be considered. A relative contraindication is an active patient less than 35 years of age (37).

Considerations for Preoperative Planning

Since PRC is performed in patients with more advanced disease, physical examination should confirm diffuse, rather than focal wrist pain and radiographs should reveal diffuse radioscaphoid arthritis without significant capitolunate arthritis.

Arthroscopic Proximal Row Carpectomy Technique

Through standard radiocarpal and midcarpal portals, a PRC can be achieved (38,39). Use of a tourniquet and a mechanical infusion system establishes a clear visual field. The arthroscope is initially placed in the 3–4 portal to systematically examine the radiocarpal joint. If there is no significant radial-lunate fossa arthritis, the radial midcarpal portal is established and the arthroscope is introduced to confirm the absence of significant capitate arthritis. The arthroscope is then replaced in the 3–4 portal and a shaver is placed through the 4–5, 6U, and/or 6R portals depending on patient anatomy and surgeon preference and the scapholunate and lunotriquetral ligaments are removed. Then the center of the lunate is removed with a 2.9 or 3.5 mm bur. In order to protect the proximal capitate, the distal lunate is not resected with the bur, but rather a pituitary rongeur is used to carefully remove the remaining lunate shell. An assistant stabilizes the traction tower with one hand and places the other hand on the palmar wrist to apply palmar to dorsal counterpressure. The arthroscope and a small osteotome can be alternately switched between the previously established radiocarpal portals to fragment the scaphoid and triquetrum. The scaphoid and triquetral fragments can then be removed with a bur and pituitary rongeur. Occasionally, an anterior radiocarpal portal is useful to visualize the dorsal carpal bones. It is established by placing a switching stick through the 3–4 portal and between the radioscaphocapitate and long radiolunate ligaments (40). Then a volar incision is made over the switching stick and the flexor carpi radialis is retracted. The arthroscopic cannula is placed over the switching stick, the stick is removed, and the arthroscope is introduced into the cannula. Care must be taken to avoid injuring the volar capsule or radiocarpal ligaments.

Digital motion is encouraged immediately after surgery. The first dressing change is performed at 10 or 14 days to remove the sutures. The wrist remains immobilized in a splint for three to four weeks to allow ligamentous and capsular healing. Then occupational therapy for wrist range of motion is initiated. A removable neutral wrist splint is continued when not in therapy. After six weeks no immobilization is needed and at eight weeks a strengthening program is initiated. By three months postoperatively, the patient may return to full unrestricted activities.

Complications

Complications of proximal row carpectomy are relatively infrequent. During either open or arthroscopic approaches injury to the dorsal sensory branches of the radial or ulnar nerve can occur. Iatrogenic damage to the articular surface of the proximal capitate or the lunate fossa of the distal radius could occur during carpectomy. Damage to volar radiocarpal ligaments during carpectomy can result in unrestrained ulnar translation of the carpus. Recognized ligament injury should be primarily repaired with suture or bone anchors depending on the location of injury. Finger weakness theoretically could occur from loss of carpal height leading to laxity of extrinsic tendons. Relative incongruity between the capitate head and lunate fossa could result in capitate changes, which has been reported in two studies in 6 out of 20 and 14 out of 17 patients an average of 13 years after open surgery (36,37). Both groups found radiocapitate joint space narrowing to be often asymptomatic in these patients. Complications from the arthroscopic technique have not been well-studied and the risk-benefit profile of arthroscopic versus open PRC is unknown.

Outcomes

Only two studies describing arthroscopic PRC could be found. Culp et al. (39) reported a qualitative description of seven patients who all experienced pain relief, good grip strength, and a functional range of motion. However, the authors did not state length of follow-up, preoperative symptoms and physical exam findings, or quantify postoperative parameters such as pain relief, grip strength, or range of motion. No validated outcome measures were used. Roth and Poehling also described a single patient in which arthroscopic PRC was performed, but did not state the postoperative outcome (38). Thus, further studies documenting the safety and efficacy of arthroscopic PRC are needed before routine use can be recommended.

Open Proximal Row Carpectomy Technique

Since open PRC is a much more commonly performed procedure than the recently described arthroscopic method and has been proven effective over the past four decades (41), we will briefly discuss the open approach. We believe the open approach is a minimally invasive technique since long-term immobilization is not necessary and careful preservation of the nerves, tendon, capsule, and ligaments is performed. Either regional or general anesthesia is used with the patient placed supine and the affected arm abducted 90° on a hand table.

Under tourniquet control a transverse incision is made centered over the proximal carpal row, providing excellent exposure with a cosmetic scar (Fig. 5). Dissection is carried down to the extensor retinaculum (Fig. 6) with care taken to protect the sensory branches of the radial and ulnar nerves. The extensor pollicis longus (EPL) tendon is retracted radially out of the opened third dorsal compartment. The extensor carpi radialis brevis (ECRB) is also then identified and retracted radially and the fourth compartment tendons are retracted ulnarly. The posterior interosseous nerve is identified and a 1-cm segment is resected. The dorsal capsule is longitudinally incised parallel to the ECRB. Staying within the subperiosteal plane, to avoid entering the dorsal compartments, the dorsal capsule is elevated (Fig. 7). The integrity of the articular surfaces of the head of the capitate and the lunate facet of the distal radius are inspected for chondromalacia. If significant eburnation is found on the capitate head, PRC should be abandoned and either a total wrist fusion or scaphoidectomy with four corner fusion performed.

There are various techniques for excision of the scaphoid, lunate, and triquetrum. The scaphoid can be removed first by sharply dividing any remaining fibers of the scapholunate interosseous ligament and then inserting a Steinmann pin into the scaphoid to use as a joystick (Fig. 8). The scaphoid is removed intact by sharply reflecting the volar capsular and ligamentous attachments to the scaphoid, although the distal

FIGURE 5 A dorsal horizontal incision, 4 to 5 cm in length, is made centered over the proximal carpal row. Lister's tubercle (L) is marked.

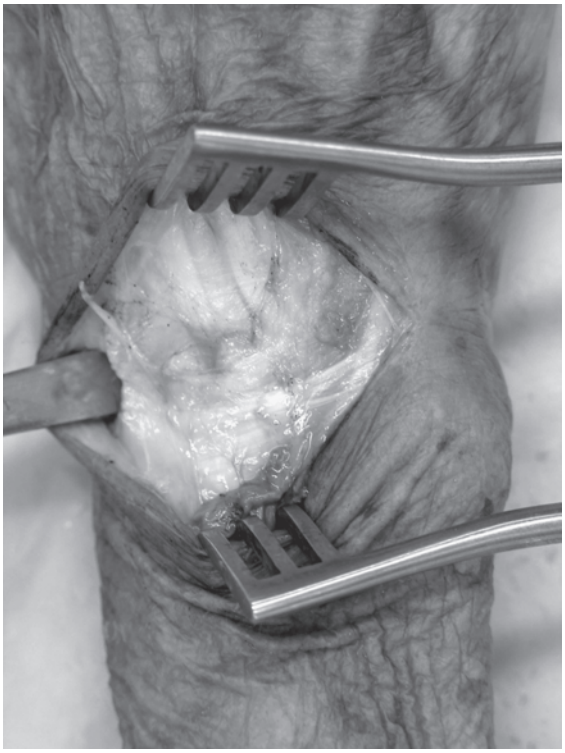

FIGURE 6 Dissection is carried down to the extensor retinaculum (horizontal fibers) with care taken to protect the sensory branches of the radial and ulnar nerves.

scaphoid tubercle need not be completely removed in order to preserve distal ligaments (Fig. 9). The lunate and triquetrum may be removed en-bloc or piecemeal, often with a joystick to rotate the bones to facilitate removal of the investing ligaments.

After the proximal row carpal bones are removed, the capitate settles into the lunate fossa of the distal radius. The capsule is closed with interrupted sutures after which orthogonal radiographs are taken to ensure that all of the proximal carpal-row bones are removed, and that the head of the capitate is seated in the lunate fossa of the distal radius (Figs. 10–12). The EPL is left out of the third dorsal compartment and the retinaculum is approximated with a 3–0 absorbable suture. The skin is closed in standard fashion. A volar plaster splint is applied. Postoperative immobilization and rehabilitation are similar to the arthroscopic technique described above.

Open Proximal Row Carpectomy Outcomes

Two well designed studies analyzed the long-term clinical and radiographic results in a total of 42 patients an average of 13 years after open PRC (36,37). The wrists had an average flexion-extension arc of 72° and 77° and an average grip strength of 83% to 91% of the contralateral side. Fourteen out of 18 and 17 out of 20 patients were satisfied. Radiographs revealed radiocapitate joint space narrowing, but there was no significant association between loss of joint space and subjective or objective function. There were four failures (18%) in patients under 35 years of age, in one of the studies that required fusion at an average of seven years after PRC (37). A summary of long-term outcomes after proximal row carpectomy is reported (Table 1).

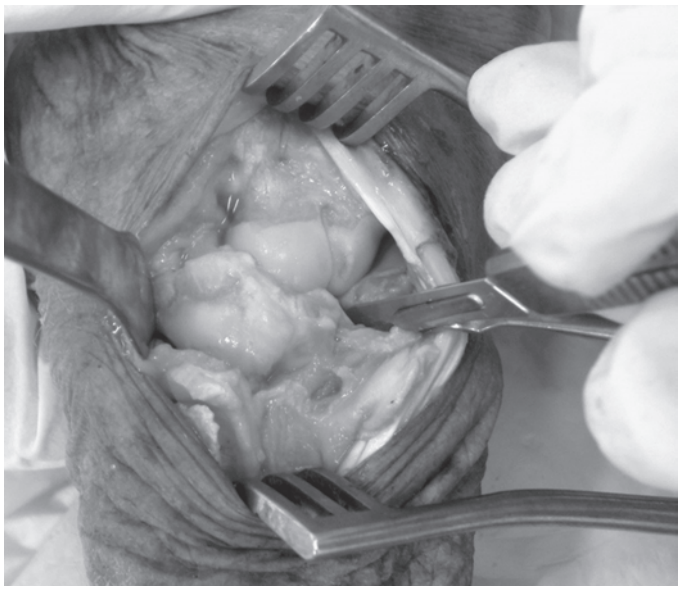

FIGURE 7 The tendons of the extensor digitorum communis are retracted ulnarly and the extensor pollicis longus and radial wrist extensors are retracted radially to expose the dorsal capsule that has been incised vertically. Radial and ulnar capsular flaps have been elevated and retracted, exposing the carpal bones. If the proximal pole of the capitate has no or minimal chondromalacia, proximal row carpectomy is initiated by sectioning the lunotriquetral (scalpel) and scapholunate ligaments to facilitate mobilization of the proximal carpal bones.

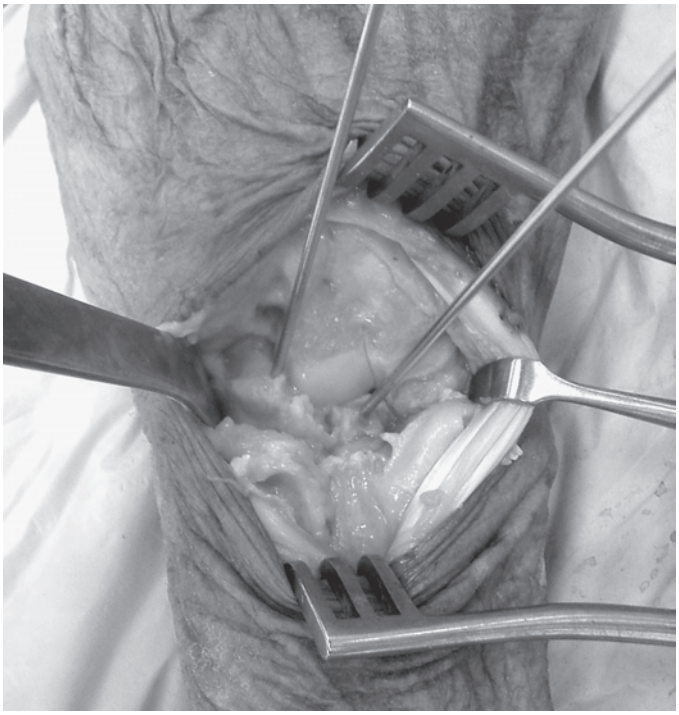

FIGURE 8 Kirschner wires are inserted into the scaphoid and lunate to be used as joysticks to facilitate carpal bone rotation, permitting direct visualization during careful reflection of the capsuloligamentous attachments.

FIGURE 10 Intraoperative fluoroscopic posteroanterior image of the completed proximal row carpectomy.

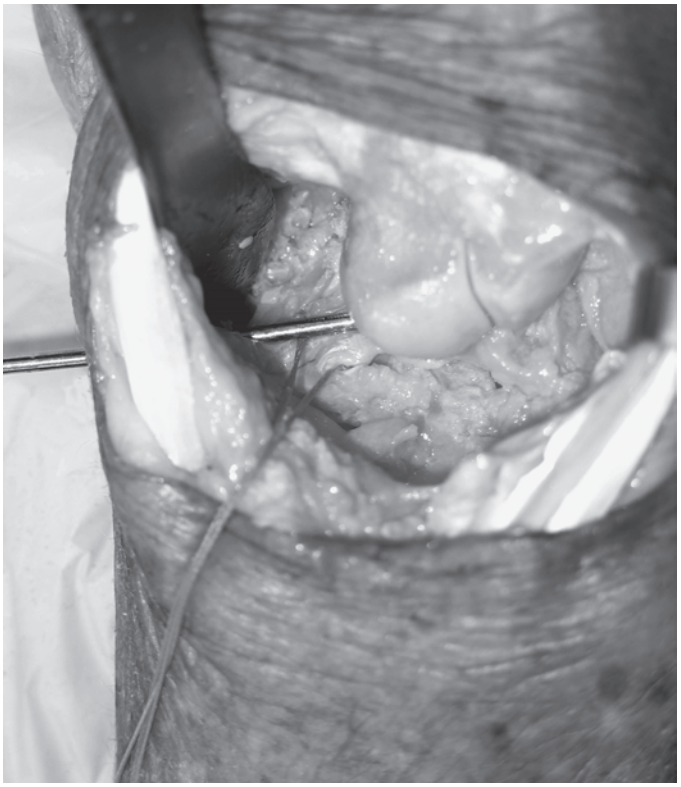

FIGURE 9 The Kirschner wire is placed percutaneously just distal to the level of the radial styloid to illustrate the location of the RSC ligament. After proximal row carpectomy has been completed, the intact RSC ligament (suture) is important to preserve carpal stability. *Abbreviation*: RSC, radioscaphocapitate.

FIGURE 11 Follow up posteroanterior radiograph six months after proximal row carpectomy in a 34-year-old man who developed Kienbock's disease with a fractured, collapsed lunate with avascular necrosis.

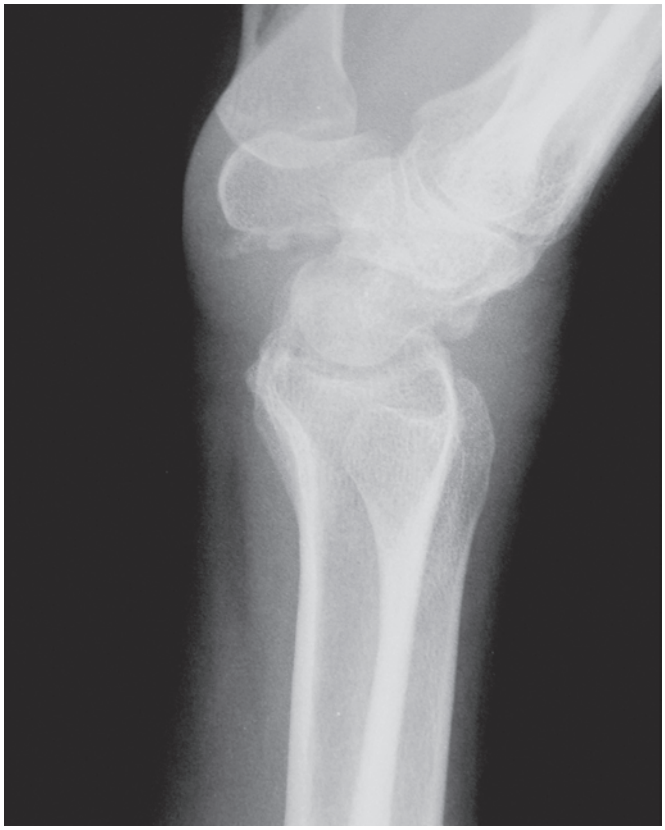

FIGURE 12 Five month follow-up lateral radiograph of the same patient in Figure 11 with proper coronal alignment of the new radiocapital articulation. The patient had 90% wrist extension and 50% wrist flexion in the operated hand compared to the unaffected hand.

SUMMATION POINTS

SLAC and SNAC wrists occur years after chronic wrist injuries. Based on careful preoperative assessment and discussion with the patient about the natural history of the disorder and their activity level and goals, individualized treatment plans can be established. Future studies are needed to formally compare arthroscopic and open approaches in order to directly compare safety and efficacy. This chapter describes several minimally invasive techniques and delineates their indications, outcomes, and complications. These are summarized below:

Arthroscopic or Open Radial Styloidectomy

Indications

- Limited radial styloid and scaphoid arthritis in SLAC or early SNAC wrist
- No midcarpal arthritis (capitolunate arthritis)

Outcomes

- Limited reports of open or arthroscopic isolated styloidectomy, but short-term pain relief seems good and length of improvement is unclear

Complications

- Excessive resection: Ulnar carpal translation with radioscaphocapitate ligament injury
- Too little resection: recurrent symptoms

Distal Scaphoid Excision

Indications

- Early radial styloid-scaphoid, radial-capitate arthritis after scaphoid nonunion

Outcomes

- Limited reports of open and arthroscopic distal scaphoid excision with good pain relief and improved range of motion and grip strength

Complications

- Risk of injury to radial artery, carpal ligaments, or articular surface during resection

Proximal Row Carpectomy

Indications

- More extensive radioscaphoid arthritis with minimal to no arthritis at the capitolunate joint

Outcomes

- Two case series with a total of eight patients undergoing arthroscopic PRC showing relief of pain

TABLE 1 Open Proximal Row Carpectomy Long-Term Outcomes

Proximal row carpectomy	No. of wrists	Follow-up (years)	Flexion (degree)	Extension (degree)	Radial deviation (degree)	Ulnar deviation (degree)	Grip strength (%) contralateral wrist	Failures requiring salvage arthodesis
Culp (42)	17	3.5	28	35	9	23	67	2 of 17
Green (43)	15	2.5	40	39	5	31	64	2 of 15
Imbriglia (33)	27	4.0	42[a]	42[a]	—[a]	23	80	1 of 27
Tomiano (44)	23	6.0	37	37	8	19	79	1 of 24
Wyrick (45)	11	3.0	47	38	4	27	94	0 of 11
Baumeister (46)	30	2.3	38	37	10	23	50	1 of 23
Jebson (36)	18	13.1	36	40	12	22	83	2 of 20
Didonna (37)	18	13.2	36	36	9	31	91	4 of 22
Krakauer (12)	12	3.3	33	39	14	18	66	2 of 12
Cohen (19)	19	1.5	36	45	7	24	71	1 of 19
Nevaiser (47)	22	3.0[b]	38	45	5	30	100	2 of 24
Overall study data	212	5.0	37	39	8	24	76	18 of 212 (8.5%)

[a] Average flexion/extension arc reported as 84°, radial deviation not reported.
[b] Follow-up reported as a range from 3 to 10 years with no average follow up reported.

- Many open series with long-term follow-up indicate excellent results

Complications

- Potential for injury to carpal ligaments leading to instability and radiocapitate arthritis or damage to the radiocapitate joint during carpectomy

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Arthroscopic Treatment of Wrist Ganglion Cysts

Scott R. Hadley
Peripheral Nerve Research Laboratory, Department of Orthopedic Surgery, University of California, Irvine, Irvine, California, U.S.A.

Ranjan Gupta
Peripheral Nerve Research Laboratory, Department of Orthopedic Surgery, Anatomy & Neurobiology, and Biomedical Engineering, University of California, Irvine, Irvine, California, U.S.A.

INTRODUCTION

Ganglion cysts are the most commonly diagnosed and treated soft tissue tumor in the hand and wrist (1). They are defined as cyst-like masses closely associated with either joint or tendon sheaths that contain a mucinous or jellylike fluid. The occurrence of these masses is greater in women than in men, with a female to male ratio ranging from 2:1 to 4:1 (2). They most commonly present in the second to fifth decades of life (1). Ganglion cysts may arise almost anywhere on the wrist and hand, but the majority (60–70%) of ganglia present at the dorsum of the wrist (1,3). The volar wrist is the second most common location of ganglion cysts accounting for 18% to 20% (1).

The cause, natural history, and pathogenesis of wrist ganglion cysts remain controversial (3–5). Etiologic explanations include synovial herniation, displaced germ cells resulting in dermoid cysts, overgrowth of synovial tissue, and mucoid degeneration (1). The prevailing theory is that ganglia develop from connective tissue by myxoid degeneration and disintegration of collagen fibers, with mucinous fluid accumulation by the progressive liquefaction of collagen fibers (4,6). Histologic analysis shows dense collagen bundles which form a delimiting capsule around the mucinous fluid that communicates with the adjacent joint through a ganglion stalk (3). The cyst fluid is primarily composed of hyaluranic acid, with significant amounts of albumin, globulin, and glucosamine (3). The mucin is typically clear, but may be blood tinged. Despite the microscopic evidence of the mucoid theory, it inadequately explains several important aspects of ganglion cyst pathology, including why the masses have a tendency to spontaneously resolve or recur, and the predilection for cysts development in adolescents and adults populations (1).

It also has been hypothesized that wrist ganglia are a secondary manifestation of underlying ligamentous pathology and joint instability (5,7). Previous history of trauma to the wrist has been correlated in 10% to 50% of wrist ganglion cases (5). Damage to the scapholunate ligament (SL) ligament is believed to be the origin for most dorsal wrist ganglia, while volar ganglia are thought to arise from injury to the scaphotrapezial joint or the radiocarpal joint (3,5). In support of this idea, histology of the ganglion stalk has revealed a complex interconnected series of cysts that form a one-way valve between the dorsal capsule and SL ligament, presumably as a response to tissue trauma (1). This one-way valve stalk allows the wrist joint to pump fluid into the overlying ganglion cyst, thus explaining the activity related increase in ganglion size. A recent study reported a high association of ganglia with types II and III scapholunate and type III lunatotriquetral instabilities (8). Further evidence is provided by a retrospective study that found 17 patients who had undergone dorsal ganglion resection required subsequently treatment for rotary subluxation of the scaphoid (5).

Ganglion cysts of the wrist are varied in their presentation. Many patients complain of a palpable mass up to several centimeters in diameter, while other patients have cysts that can only be appreciated with the wrist in flexion. An even smaller patient population suffer from occult ganglion that may cause persistent wrist pain without a palpable mass (2). The myriad of symptoms associated with ganglion cysts of the wrist are explained by the mass effect of the ganglia on surrounding structures. The most common symptom of dorsal wrist ganglia is a dull ache, which is believed to be a result of compression of the terminal branch of the posterior interosseous nerve. Other frequent complaints include subjective weakness, localized swelling, and limited range of motion.

Current treatment options for ganglion cysts of the wrist include patient reassurance (benign neglect), aspiration, injections of corticosteroid, hyaluronidase or sclerosing agents, and surgical excision (4,6,9–11). All of these treatments have inherent advantages and disadvantages, and variable degrees of success (3,7,11–14). Currently, the mainstay of surgical treatment remains open ganglion excision (1,3,7,15), but the minimally-invasive arthroscopic approach is gaining popularity because it's a safe procedure that also permits the inspection of the SL and surrounding structures to rule out joint instability (2).

Arthroscopic removal of dorsal ganglion of the wrist was first described in 1995 by Osterman and Raphael (13), and has become an accepted technique in many institutions. Conversely, an arthroscopic technique for resection of volar ganglion of the wrist has been described only twice in the English peer-reviewed literature and has not gained widespread appeal secondary to the potential high risk of neurovascular damage (16,17). Regardless of the surgical approach, the goals of ganglion surgery should be: (*i*) ganglion excision through a cosmetically acceptable scar, (*ii*) minimizing injury to surrounding structures, (*iii*) evaluation of carpal ligament complex, and (*iv*) maintain wrist range of motion.

INDICATIONS

It is important to consider the patients expectations in developing a management plan for wrist ganglions. Many

need the mass to be removed because of functional limitations, discomfort, cosmesis, or fear that it could be something worse. Others seek only assurance of a benign process. The indications for surgical treatment of wrist ganglions whether open or arthroscopic, are relative and based on the patient's symptoms, expectations and failure of conservative treatment. The following clinical situations are most amendable to arthroscopic ganglion cyst excision:

- primary, unoperated wrist ganglion,
- suspected intracarpal pathology, such as scapholunate instability, and
- cosmetic concerns, such as hypertrophic scarring or patient's preference.

General contraindications are patients who are unable to tolerate anesthesia or wrist surgery. Recurrent or occult ganglion cysts may be better treated with open excision.

CONSIDERATION FOR PREOPERATIVE PLANNING

A key consideration in management is the fact that ganglion cysts have a spontaneous resolution rate of 28% to 58% (2). All nonoperative treatments are associated with high cyst recurrence. For example, needle aspiration of the cystic fluid, with or without steroid injection, has a recurrence rate of 60% (18). On the other hand, surgical excision of wrist ganglion cysts using either an open or arthroscopic technique has a reported recurrence rate of less than 10%.

It is important to obtain a good patient history and perform a thorough physical exam to exclude the rare possibility of a malignancy. Other conditions that may cause diffuse swelling of the dorsum of the wrist, such as extensor tenosynovitis, lipomas, and other hand tumors should also be considered. Patients with a ganglion cyst will usually report a mass that waxes and wanes in size, along with an achiness of the wrist. A key to diagnosis is a mass that can be transilluminated with a light, which indicate its fluid content. Aspiration of a gelatinous material confirms the diagnosis.

Wrist radiographs are usually obtained prior to any planned surgical procedure to rule out SL dissociation and arthritis. Occasionally, MRI are indicated for occult ganglions or suspected solid tumor.

The anatomical location of the ganglion cysts is important to correlate with symptoms and to guide surgical treatment. Dorsal ganglia usually project between the extensor pollicus longus and the extensor digitorum communis ligaments, with or without a pearly-white stalk that extends to the SL and dorsal capsule (2). The most common volar ganglion lesion site is the interval between the radioscaphocapitate and the long radiolunate ligaments, with a stalk extending to the radiocarpal joint (16,19). Surgical excision of the cyst decompresses the affected area and in most cases alleviates the symptoms of pain and weakness (2,10–12,14).

SURGICAL TECHNIQUE

The surgical setup and equipment for arthroscopic treatment of wrist ganglion cysts is the same as for general wrist arthroscopy (Fig. 1). An axillary block or general anesthesia is used with a tourniquet for better visualization (20). Before wrist distraction, a thorough wrist examination under anesthesia should be performed. With the hand and wrist placed in 3–4 kg of distraction, the ganglion and portal sites are identified and marked.

FIGURE 1 Typical surgical setup for arthroscopic dorsal wrist ganglionectomy. The cyst is outlined and is just distal to the 3-4 portal. *Source*: Courtesy of Virak Tan, MD.

In dorsal wrist ganglionectomy there are several techniques described in the literature. Osterman and Raphael's original technique is done by first establishing the 6R portal to evaluate the proximal carpal row, capsular and interosseous ligaments for concomitant pathology. The arthroscope is then pointed radially and dorsally towards the dorsum of the SL to view the ganglion base. External pressure on the cyst can accentuate the bulge of the cyst into the joint. Once the pathologic tissue is clearly identified, an 18-gauge needle is introduced through the 3-4 portal, as visualized by the 6R portal, to determine the correct position for instruments. Commonly, the needle is passed through the ganglion and into the stalk.

Following the same principles, recent surgical reports of arthroscopic dorsal wrist ganglion resection have abandoned the use of a needle to guide instrument placements and instead start directly with either the 3-4 or 4-5 portal for inspection of the joint and identification of the ganglion (11,12,14). All techniques use an arthroscopic full-radius resector to remove a 1-cm^2 area of capsule at the ganglion base along with the entire ganglion and stalk. Often times, the mucinous cyst fluid can be seen decompressing into the joint during resection. Circumferential resection from a portal created directly over the cyst is sometimes helpful to ensure complete excision of the pathologic tissue. When there is a region of synovitis close to the ganglion stalk it is also debrided. Completion of the dorsal wrist ganglion excision and partial capsulectomy is signaled when the extensor pollicus longus or extensor digitorum communis tendons, which lie superficial to the dorsal capsule, are visualized. Care should be taken to avoid injury to the extensor tendons, carpal articular surfaces, and scapholunate interosseous ligament by working with the shaver facing away from the joint. When there is doubt about the complete arthroscopic resection of the ganglion, it is appropriate to convert to an open approach (11,12). The portal sites are closed with a single 4-0 nylon suture.

Postoperatively, the wrist can be immobilized for one week. At 7 to 10 days postoperatively, the sutures are removed and the patient is allowed activity as tolerated with avoidance of strenuous activity or weight bearing for six weeks.

Alternatively, some surgeons prefer no immobilization and allow activity as tolerated.

The surgical approach for arthroscopic volar ganglion resection is based on the same principles for dorsal ganglions but with an added emphasis on avoiding critical neurovascular structures because the 1-2 portal is often used. Placement of this portal puts branches of the dorsal radial sensory nerve and radial artery at risk for injury. The indications for this technique are limited and, accordingly, no consensus on the arthroscopic surgical approach has been established.

The key to low recurrence of ganglion cysts is complete resection of the ganglion with the connecting stalk and associated capsule. However, arthroscopic identification of the stalk ranges from 29% to 79% (11–14). Consequently, whether or not the stalk is visualized, a 1-cm^2 area of the dorsal capsule adjacent to the ganglion should be resected (2,11–14). Alternatively, Nishikawa et al. argue that the area of resection should be as small as possible and developed a new arthroscopic classification of ganglia based on the degree of stalk visualization, which minimizes the required amount of dorsal capsular resection (11).

Case Example

A thirty-eight-year-old right-hand dominant woman who has failed aspiration and methylprednisilone injection of a dorsal ganglion cyst elected to undergo an arthroscopic ganglionectomy. The arthroscope was inserted through the 4-5 portal and routine diagnostic wrist arthroscopy was performed. The SL interosseous ligament (Fig. 2) was intact but there was fraying of the dorsal capsule over the SL ligament (Fig. 3). An 18-gauge needle was inserted at the 3-4 portal, through the cyst into the radiocarpal joint, where is corresponded to the area of capsular fraying. External pressure on the cyst caused the ganglion to bulge into the joint (Fig. 4). The arthroscopic shaver, inserted through the 3-4 portal, was used to excise about 1 cm^2 of dorsal capsule (Fig. 5). Care was taken to avoid injuring the overlying extensor tendons which can be easily seen after the capsular excision (Figs. 6 and 7). Postoperatively, the wrist was not immobilized and activity was progressed as tolerated.

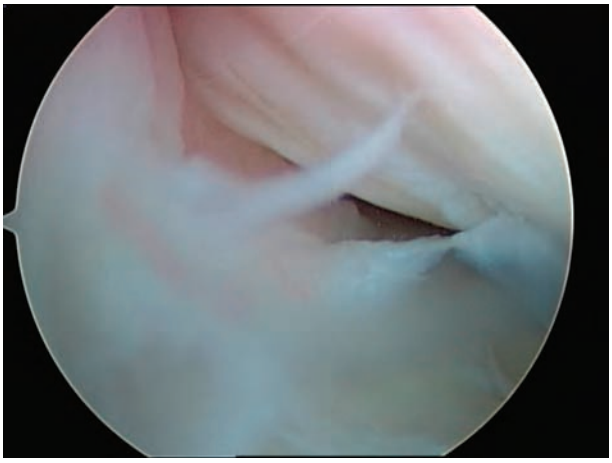

FIGURE 3 Fraying of the dorsal capsule in the region of the scapholunate ligament interval, as seen with the arthroscope in the 4-5 portal. *Source*: Courtesy of Virak Tan, MD.

COMPLICATIONS

There are no published reports of intraoperative complications during wrist arthroscopic ganglionectomy (14); however, it has been reported that failure to completely excise the ganglion stalk and capsular attachment during surgical excision lead to a 30% to 60% recurrence (2). The postoperative complaints are rare and usually resolve spontaneously or with minimal treatment. In the first postoperative visit, several cases of dorsal wrist swelling have been reported, presumably due to arthroscopic fluid, and were successfully treated with aspiration (12,21). One patient had a neuropraxia of the superficial branch of the radial nerve which resolved with neurolysis (21). Wrist stiffness is another common postoperative complaint that subsides with wrist range of motion exercises (14).

Persistent wrist symptoms after ganglion excision should lead one to suspect underlying instability at the scapholunate interval (5).

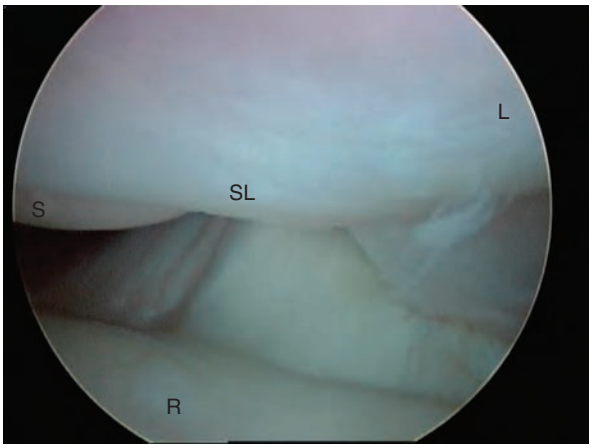

FIGURE 2 Intra-articular view through the 4-5 showing the scapholunate ligament (SL) interval with an intact SL ligament. *Abbreviations*: S, scaphoid; L, lunate; R, radius. *Source*: Courtesy of Virak Tan, MD.

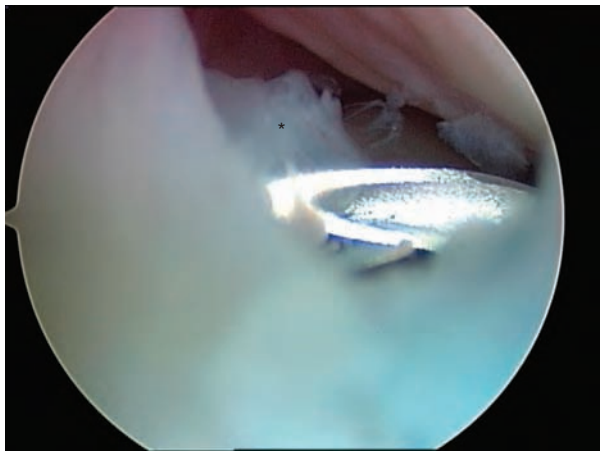

FIGURE 4 An 18-gauge needle inserted through the cyst into the radiocarpal joint. The needle entered the joint in the area of capsular fraying. External pressure on the cyst caused the ganglion to bulge into the joint (*). *Source*: Courtesy of Virak Tan, MD.

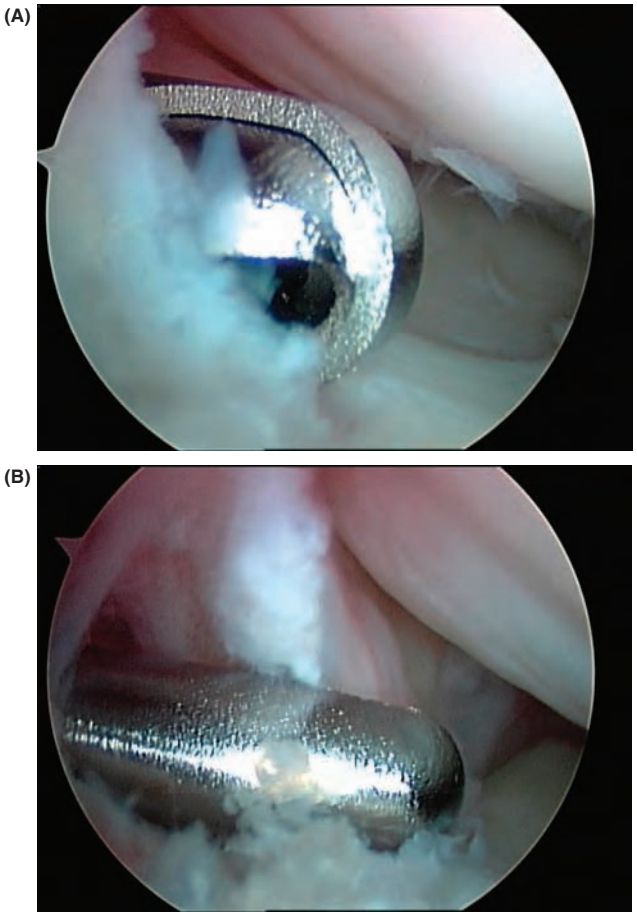

FIGURE 5 (**A**) Debridement of the capsular fraying with an arthroscopic shaver through the 3-4 portal. (**B**) After debridement and decompression of the ganglion cyst, a 1-cm^2 area of dorsal capsule is excised. *Source*: Courtesy of Virak Tan, MD.

OUTCOME

Open resection of wrist ganglion is currently the more widely used surgical technique and is the gold standard by which all other approaches are compared. The outcome variable that is most commonly reported in the literature is recurrence rate. In their initial arthroscopic study, Osterman and Raphael reported only 1 recurrence in over 150 arthroscopic ganglionectomies (13). Subsequent evaluations of arthroscopic cyst removal have reported recurrence rates at or less than 5% (8,11,12,14).

The first prospective, randomized comparison of recurrence rates for open and arthroscopic surgical dorsal ganglia excision found a recurrence rate of 8.7% (2/23) in the open surgical group and a rate of 10.7% (3/28) in the arthroscopic group (21). The slightly higher arthroscopic recurrence rate conflicts with previously published data. It is important to note that the technique used in this study did not include an additional midcarpal portal site to rule out additional wrist pathology (21). Whether arthroscopic technique is superior to open surgery in the incidence of postoperative cyst recurrence rates is still ambiguous but the studies to date indicate that the rates are at least comparable.

Other key measures of ganglia excision outcome are return of wrist motion and pain relief. Most arthroscopic studies report an overall postoperative improvement in range of wrist motion, average grip strength, and pain scores (8,12,14). Alternatively, the randomized comparison study noted greater complaints of scar discomfort and residual pain in the arthroscopic group at the two month point (21). This unexpected finding is tempered by the fact that the long-term follow-up indicated less reports of occasional or mild pain in the arthroscopic treated patients (21). Overall patients who undergo arthroscopic ganglia surgery are satisfied with the results of their surgery (8,11–14).

The most recent report on outcome of arthroscopic resection of wrist ganglia is by Mathoulin et al. in 2004 (17). These authors performed 96 dorsal and 32 volar ganglionectomies. At an average follow-up of greater than two years, there were four recurrences in the dorsal and none in the volar group. There was one patient in the volar group that had moderate hematoma which resolved after three days. Range of motion and grip strength were reported to be the same or better than the unoperated side.

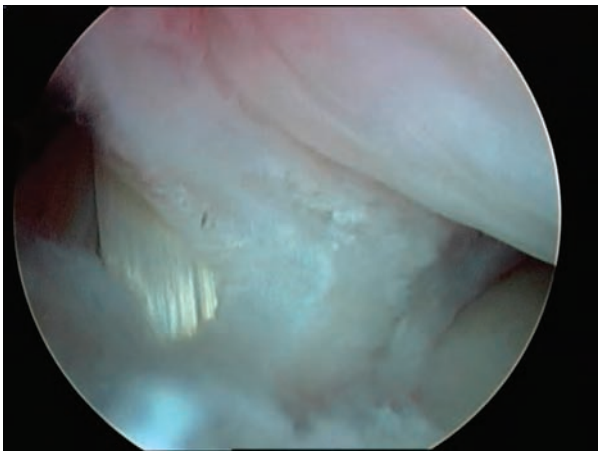

FIGURE 6 At completion of the procedure, the extensor tendons can be visualized through the hole in the dorsal capsule. *Source*: Courtesy of Virak Tan, MD.

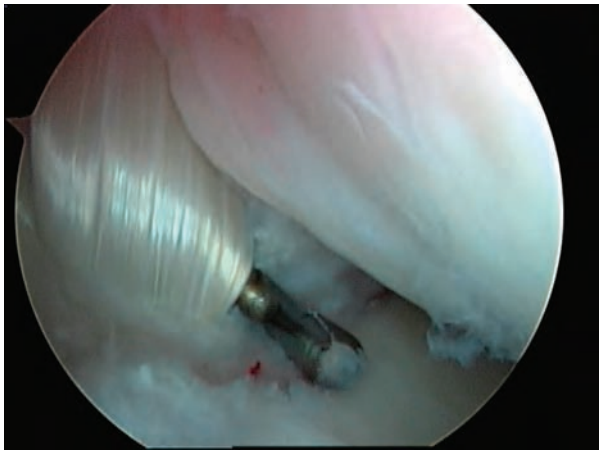

FIGURE 7 A probe is used to deliver the extensor tendons into the joint to ensure that injury has not occurred. *Source*: Courtesy of Virak Tan, MD.

SUMMARY

Ganglia of the wrist and hand are common occurrences that often require surgical intervention for definitive treatment.

Open cyst excision has been described as trading a lump for a scar (13). Proponents of the arthroscopic ganglionectomy point to the advantages of this minimally-invasive procedure which include less postoperative pain and earlier return to function. The arthroscopic technique is performed using smaller portal incisions and usually creates a better cosmetic outcome (2). It also provides a more controlled excision of the ganglion while protecting the SL (14). Finally, the arthroscopic technique allows the surgeon the ability to thoroughly examine the surrounding anatomical structures, evaluating possible causes of the ganglion as well as associated intra-articular pathology.

Fortunately, surgical excision of wrist ganglia is a highly successful treatment that is rarely associated with any serious complications. Although the arthroscopic technique has not yet been clearly proven to be uniformly superior to open surgical resection in incidence of cyst recurrence, it is at least equivalent (1,7,11–14). It compares favorably with open excision when evaluating the outcome parameters of motion, wrist strength, and residual pain (14). Accordingly, arthroscopic excision for wrist ganglion is an acceptable minimally-invasive surgical alternative for treating ganglion cysts of the wrist.

SUMMATION POINTS

Indications

- Primary, unoperated wrist ganglion,
- Suspected associated intracarpal pathology
- Cosmetic concerns, such as hypertrophic scarring
- Patient's preference

Outcomes

- 90% to 95% success rate
- Recurrence rate similar to open technique

Complications

- No reports of intraoperative complications
- Temporary wrist swelling
- Neuropraxia

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Basal Joint Arthritis-Arthroscopy/Debridement

Jay T. Bridgeman and Sanjiv H. Naidu
Department of Orthopedics and Rehabilitation, Penn State University College of Medicine, Hershey, Pennsylvania, U.S.A.

INTRODUCTION

The thumb basal joint is the second most commonly involved site of osteoarthritis in the hand, after the distal interphalangeal joint. It causes significant disability due to painful, weakened pinch and grip (1). Women develop basal joint arthritis 10 to 15 times more often than men. Geographical and racial differences also have an influence on the prevalence of osteoarthritis in the hand. Basal joint arthritis is less frequently observed in Asian individuals when compared to caucasians (2).

PATHOGENESIS

The etiology of basal joint arthritis is multifactorial. Synovial derived cytokines such as interleukin-1 have been shown to activate degradative enzyme synthesis in the chondrocyte, which results in breakdown of the proteoglycan matrix components (1). Neutral proteases and metalloproteoglycanases play a central role in catabolism of the matrix, resulting in decreased hydrophilic properties and less hydration of the matrix. These biochemical events significantly alter the mechanical properties of hyaline cartilage, making it more susceptible to failure under load (2).

Pellegrini analyzed surgical and postmortem specimen of the basal joint and identified chondromalacia in the dorsal compartment and eburnated bone of the palmar joint surfaces (3). Palmar cartilage degeneration was closely associated with degeneration of the beak ligament from the articular margin of the metacarpal. The ligament acts as a checkrein to dorsal migration of the metacarpal on the trapezium during dynamic flexion-adduction of the thumb. Functional incompetence of the beak ligament results in pathologic laxity, abnormal translation of the metacarpal on the trapezium, and generation of excessive shear forces between the joint surfaces, particularly within the palmar portion of the joint during grip and pinch activity (3,4). Pellegrini also identified that the primary loading areas during lateral pinch are in the same palmar regions of the joint as the eburnated surfaces in diseased joints (5).

INDICATIONS

The indications for arthroscopic debridement of the basal joint are post-traumatic arthritis and idiopathic arthritis (Eaton stage 1 and 2) which have failed nonoperative treatment (1). We offer this to patients who due to life/work requirements want to delay ligament reconstruction and tendon interposition. Culp's indications are stage 1 or 2 osteoarthritis, post-traumatic osteoarthritis, end-stage osteoarthritis (hemi or complete trapeziectomy for stage 3 or 4 disease). His contraindications are metacarpal phalangeal hyperextension and Ehlers-Danlos syndrome (6).

CONSIDERATIONS FOR PREOPERATIVE PLANNING

History and Physical Exam

Patients typically present with pain at the basal joint, especially with pinch and grip. With disease progression, breadth of grasp and forceful lateral pinch are limited. Patients complain of pain at the base of the thumb and symptoms of instability.

Inspection

An enlarging prominence described as a "shoulder sign" occurs at the base of the thumb. This is due to dorsal metacarpal subluxation on the trapezium and metacarpal adduction with disease progression.

Palpation

Tenderness is elicited with palpation along the thumb trapeziometacarpal joint. As the disease progresses, patients develop instability, subluxation, and crepitance.

Provocative Tests

The grind test combines axial compression, flexion, extension, and circumduction, which reproduce pain at the basal joint.

A thorough exam of the hand is necessary to identify other conditions such as stenosing flexor tenosynovitis and de Quervain's tenosynovitis, which if left untreated may make postoperative therapy difficult (2).

PREOPERATIVE IMAGING

The three radiographic views obtained to evaluate the basal joint include a posterior anterior, lateral, as well as the pronated anterior posterior view. A spectrum of disease progression, from isolated trapezial-metacarpal joint to pantrapezial joint complex can be affected. Eaton and Littler described four stages (7):

Stage 1:	A normal joint with the exception of possible widening from synovitis
Stage 2:	Joint space narrowing with debris/osteophytes less than 2 mm in size
Stage 3:	Joint space narrowing with debris/osteophytes greater than 2 mm in size
Stage 4:	Scaphotrapezial joint space involvement in addition to narrowing of the trapezial-metacarpal joint.

Irwin et al. and Tomaino have identified concomitant scaphotrapezoidal joint arthritis, which if left untreated can lead to residual pain (1,8). This is poorly identified with radiographs and Tomaino recommends intraoperative assessment. Radiographic findings do not always correlate with patient's

clinical symptoms, which necessitate a good physical exam before considering operative treatment.

NONOPERATIVE TREATMENT

Nonsteroidal anti-inflammatory medications, intra-articular steroid injection, hand or forearm based thumb spica splint immobilization, and thenar muscle isometric conditioning are hallmarks of nonoperative treatment (2). These treatment modalities are usually effective for a limited period of time, but always should be initiated before operative treatment is offered.

SURGICAL TECHNIQUE

Equipment

Berger described a technique for arthroscopic evaluation of the basal joint. A short barrel 1.9 mm arthroscope connected to standard arthroscopic electronic equipment, including a small color camera, focusing connector, video monitor, video recorder, printer, and light source is used in this procedure. Normal saline is used to irrigate the joint through the arthroscope sheath. The size of the joint often limits full distention to 2 ml of fluid. Normal saline is delivered using a pump-assisted system. The pressure is set to 50 to 75 mmHg throughout the procedure. The thenar eminence is observed for swelling indicating extravasation. If this occurs the pressure is lessened to gravity. An outflow cannula may be placed, or an in-line three-way stopcock may be implemented, but one may rely upon the suction provided by a shaver system for intermittent fluid exchange. For debridement, a 2.0 mm full-radius side shaver and 2.0 mm burr are used with the power shaver system. Additional equipment available for immediate use includes a small probe, a variety of small arthroscopic grabbers, a suction punch, and a power wire driver with a standard assortment of Kirschner wires (K-wires). A commercially available sterile self-contained distraction device that is positioned directly on the operating hand table can be used; however, any method of applying the desired level of traction in a sterile environment can be used (9).

Anatomic Landmarks

Palpation is used to identify the landmarks of the arthroscopic portals. Berger described two portals: the 1R (radial) and the 1U (ulnar) portals. They allow visualization of most of the distal articular surface of the trapezium and the proximal articular surface of the first metacarpal. The lateral most joint surface and joint capsule are difficult to view through either portal (9).

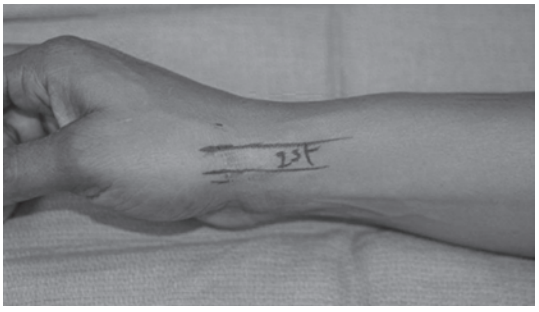

FIGURE 1 Portal landmarks.

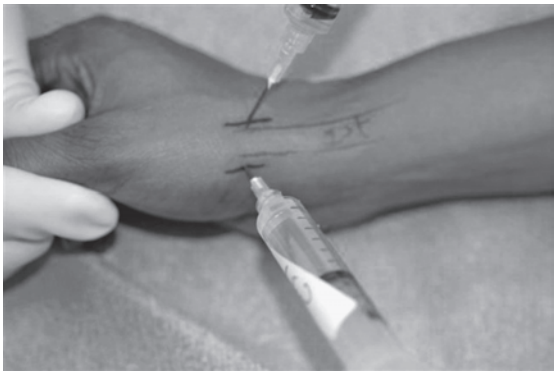

FIGURE 2 Insufflation of joint.

1R Portal

The incision is located just anterior to the abductor pollicis longus tendon. The plane of this portal passes through the nonligamentous capsule just lateral to the anterior oblique ligament. The dorsoradial ligament (DRL), posterior oblique ligament(POL), and ulnar collateral ligament are well visualized through this portal (9).

1U Portal

The incision is located just posterioulnar to the extensor pollicis brevis tendon. The plane passes between the DRL and POL. The anterior oblique ligament and ulnar collateral ligament are well visualized through this portal (Fig. 1) (9).

Procedure

Regional or general anesthesia is administered as for other upper-extremity arthroscopic procedures. A single dose of parenteral antibiotics is generally administered prior to starting

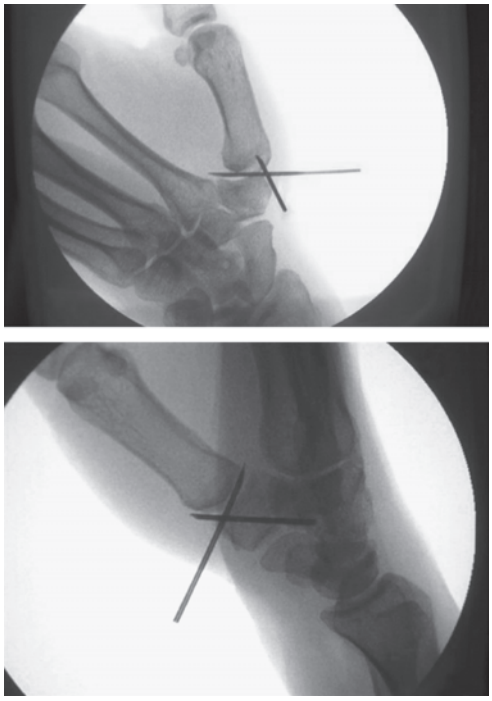

FIGURE 3 Verification of needle placement in joint with anterior posterior and lateral fluoroscopic images.

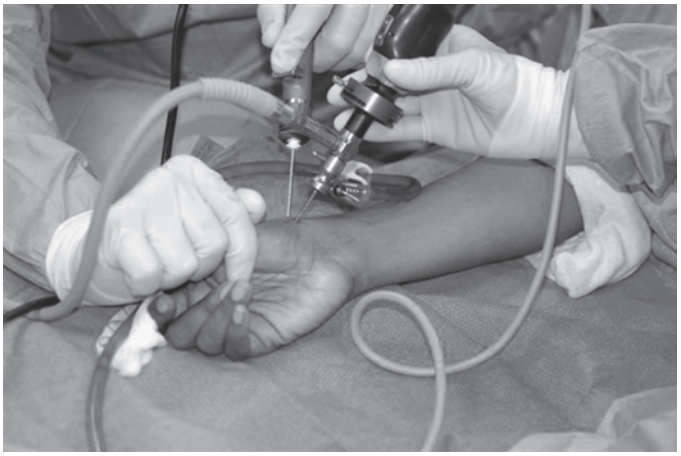

FIGURE 4 Arthroscopic instrument placement into carpometacarpal joint.

the procedure. A pneumatic tourniquet is applied to the limb. The limb is prepared and draped in a standard sterile fashion. The extremity is placed in traction using a single thumb finger trap. Five to eight pounds of longitudinal traction is applied. Pertinent landmarks: the proximo-posterior edge of the base of the first metacarpal, the radial artery, and the tendons of abductor pollicis longusand extensor pollicis brevis are palpated and marked. The extremity is then exsanguinated and the pneumatic tourniquet is inflated (9).

A 20-guage needle is advanced into the joint just proximal to the base of the first metacarpal through the planned portal site. This confirms the appropriate entry angle for the arthroscope and allows insufflation of 1of 2 ml of fluid into the joint (Fig. 2). We then confirm intra-articular needle placement with fluoroscopy (Fig. 3). A single 3-mm longitudinal incision is made over each portal site. Blunt subcutaneous tissue dissection is performed to avoid branches of the superficial radial nerve as well as the deep and superficial branches of the radial artery. After entering the joint capsule, a 1.9 mm tapered trocar and its sheath are introduced through each portal site, generally with a slightly distal inclination. Berger describes using a gentle sweeping motion to find a natural division between the ligaments in the fibers of the joint capsule, particularly the 1U portal (9). The probe or shaver is easily introduced in the portal opposing the arthroscope (Fig. 4).

At this point, arthroscopic observations and procedures may begin. When the synovial lining of the joint capsule obscures a detailed visualization of the capsular ligaments, a synovectomy with the 2.0-mm shaver may assist the surgeon in viewing specific structures. Hypertrophic synovium and cartilage lesions are debrided (Figs. 5 and 6). The joint is irrigated. The portals are closed with nylon suture (9).

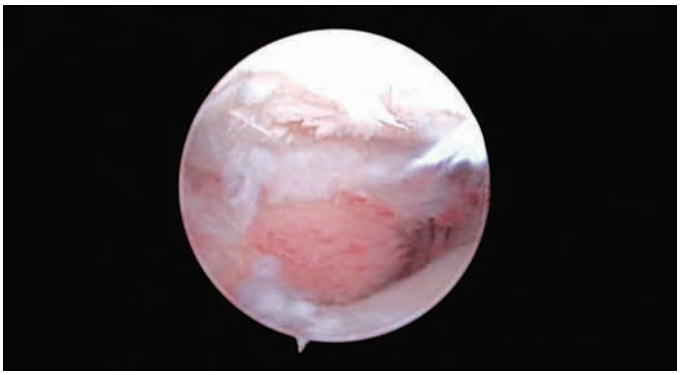

FIGURE 5 Hypertrophic synovium and chondromalacia upon joint entry.

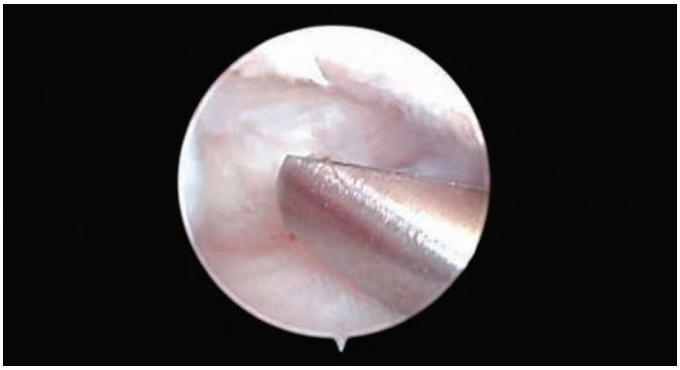

FIGURE 6 Debridement of joint debris and synovium.

COMPLICATIONS

The branches of the superficial radial nerve surround the arthroscopic field. One or both branches may be damaged with the approach to the joint capsule. Development of altered sensation or a painful neuroma is possible. This can be avoided by using a needle to confirm intra-articular placement and blunt dissection as described. The radial artery courses immediately posterior and ulnar to the arthroscopic field and may inadvertently be damaged during the procedure. This may lead to loss of perfusion to the thumb or other digits in a hand where dominant blood supply is through the radial artery. Knowledge of the anatomy of the region and awareness of the location of the branches of the superficial radial nerve and the radial artery, along with careful blunt dissection as the joint capsule is approached will minimize the risk of injury. Inadvertent entry into the wrong joint is possible due to the close proximity of the radioscaphoid and scaphotrapezial joints. Careful palpation of soft tissue landmarks and confirmation with fluoroscopy should minimize these risk as well (9).

OUTCOMES

Culp described arthroscopic debridement, synovectomy, and thermal capsular shrinkage for trapeziometacarpal arthritis of the thumb (6). This series described 24 thumbs in 22 patients, with 88% good to excellent results with 1.2 to 4 years follow-up. Pinch strength improved 22%. There are no studies that report long-term results of this procedure (6).

SUMMATION POINTS

Indications

- post-traumatic arthritis
- idiopathic arthritis (Eaton stage 1 and 2).

Outcomes

- Short term results for debridement are good
- No long term results are published.

Complications

- superficial radial nerve injury
- radial artery injury
- inappropriate joint entry.

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Arthroscopy of the Basal Joint: Treatment of Arthritis with Soft-Tissue Interposition

Julie E. Adams and Scott P. Steinmann
Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota, U.S.A.

INTRODUCTION

Arthritis of the basal joint of the thumb is commonly treated with open techniques involving total or subtotal trapeziectomy and interposition arthroplasty. Multiple procedures and variations have been described and good data are available regarding the outcomes of these techniques. Many are open procedures; however, an arthroscopic technique is advantageous to minimize morbidity and has been shown to have outcomes comparable to open procedures (1–4).

Arthroscopy allows for preservation of the joint capsule while facilitating visualization and debridement or excision of an arthritic trapeziometacarpal joint. Although some have described acceptable results following simple arthroscopic debridement (5), bony impingement and metacarpal migration may occur. Interposition arthroplasty prevents bony impingement and buttresses the first metacarpus to prevent these problems. We favor a minimal resection of the trapeziometacarpal joint by performing an arthroscopic bony recontouring which effectively fulfills the role of performing a partial trapeziectomy but preserves bone stock. This obviates the problems associated with total trapeziectomy, namely, reduced pinch strength and proximal migration of the first metacarpus, and maximizes options for future surgical procedures if symptoms recur. Arthroscopy of the basilar joint of the thumb is performed using a modification of the techniques first described independently by Berger (6) and Menon (3,7).

Following adequate arthroscopic debridement, interposition arthroplasty may be performed with a variety of materials. Published studies have documented clinical outcomes as well as the histological, radiological, and vascular characteristics following open or arthroscopic interposition of allogenic or autologous tissue, xenografts, or synthetic materials (7–17). A diverse variety of materials, including tendon, fascia lata, costochondral graft, Gore-Tex, Gelfoam, and silicone, have been utilized (10,11,13,16). Silicone and Gore-Tex have fallen out of favor due to poor outcomes (11,18,19). Adverse immune effects have been noted with some xenografts (20). Others have used hematoma arthroplasty (21) or tendon interposition with good results (15,18,19).

Recently, other options for interposition materials have been introduced. Both xenograft and human dermal grafts can now be processed to yield an acellular collagen scaffold that can be used as an interposition tissue or for tendon and soft-tissue repairs (22). Because the material is rendered acellular during processing, it lacks many of the disadvantages of standard allograft or xenograft tissue. Previous in vivo studies have demonstrated rapid infiltration of native cellular agents, including fibroblasts and vascular tissue, with minimal host inflammatory response (22–24). Because of these advantageous characteristics, use of this material for interposition arthroplasty following trapeziectomy was proposed. We currently use a commercially available acellular allograft dermal matrix material and have noted satisfactory patient outcomes with minimal complications. The minimally invasive nature allowed by use of this material is advantageous. However, results of traditional autograft interposition, such as palmaris or plantaris tendon, remain the standard by which these newer materials should be measured.

INDICATIONS

Patients with Eaton (15) stages II or III symptomatic trapeziometacarpal joint arthritis recalcitrant to nonsurgical management are candidates for the procedure. The procedure is contraindicated in the presence of significant pantrapezial arthritis, as this will not be adequately addressed by the arthroscopic procedures. Such patients may be better served with an open procedure such as total trapeziectomy. Ligamentous instability is another contraindication, as this procedure will not address this pathology.

PREOPERATIVE PLANNING

Diagnosis of trapeziometacarpal arthritis should confirmed by appropriate physical examination and radiographic studies. In addition, all patients should have had a trial of nonoperative therapy, such as splinting or injections, prior to consideration of surgical management.

Preoperative physical examination should document pinch strength, grip strength, and range of motion. Preoperative questionnaires, such as the Disability of Arm, Shoulder and Hand score, may be helpful to document outcomes. Concomitant conditions, such as carpal tunnel syndrome, should be investigated for and excluded.

A standard radiographic series, including anteroposterior, lateral, and oblique films, should be obtained. Radiographs should exclude pantrapezial arthritis. Some authorities use radiographic measurements to estimate the magnitude of disease (14); however, others have found these measurements to have poor reliability and correlation with intraoperative findings (25).

SURGICAL TECHNIQUE

The procedure may be performed under either general or regional anesthesia. The patient is placed supine and the operative extremity is prepared and draped in the usual

FIGURE 1 Operative setup. The hand is suspended in traction via the thumb and/or index finger, and prepped and draped in the usual sterile fashion. In this figure, the graft is prepared for insertion into one of the portals.

sterile fashion. A sterile tourniquet is applied, and the thumb is placed in sterile finger traps with 5 to 8 pounds of traction applied. A standard vertical traction tower as used for wrist arthroscopy is preferred, although a horizontally applied traction system may be used. A traction sleeve to the index finger may be applied to give additional support to the wrist (Fig. 1). Landmarks, including the flexor carpi radialis (FCR), abductor pollicis longus (APL), and extensor pollicis longus (EPL), are marked prior to insufflation of the joint (Fig. 2). Prior to skin incision, the tourniquet is inflated to 250 mmHg.

Fluoroscopy is useful to identify the exact locations of the two main portals particularly if the surgeon has limited experience with first carpometacarpal (CMC) joint arthroscopy. In patients with significant arthritis and partial subluxation, the surgeon may inadvertently enter the scaphotrapeziotrapezoid joint rather than the CMC joint.

The two standard portals are the 1-R (radial) and the 1-U (ulnar) portals (Figs. 3–5). The 1-R portal is made just radial to the FCR tendon at the level of the CMC joint. This portal transverses the nonligamentous capsular tissue dorsoradial to the anterior oblique ligament (AOL; Fig. 6A,B) and is furthest from the radial artery and the branches of the superficial radial nerve. The branches of the superficial radial nerve are most commonly found overlying the APL. Consequently, if the 1-R portal is placed in a more ulnar position, closer to the FCR, risk of injury to a branch of the superficial radial nerve is less likely (26). The 1-R portal is useful to examine the dorsal radial ligament (DRL), palmar oblique ligament (POL), and ulnar collateral ligament (UCL), and provides a view of the radial aspect of the joint (6,27). It also allows for visualization of the intermetacarpal ligament and the distal insertions of the AOL into the first metacarpal (Fig. 6A,B).

The 1-U portal is placed just ulnar to the extensor pollicis brevis (EPB) tendon (Fig. 7). This area can have a higher incidence of superficial radial nerve branches crossing the portal site than the 1-R portal area. Likewise, the radial artery is located only a few millimeters from the ulnar side of the portal. It is safest to make the 1-U portal close to the EPB tendon, as placing the portal in close proximity to the EPL tendon results in a greater chance of radial artery or superficial radial nerve injury. To establish the portal, the skin should be carefully incised and a small hemostat used to gently dissect and spread down to the capsular tissue. This will help avoid traumatic injury to either branches of the superficial radial nerve or the

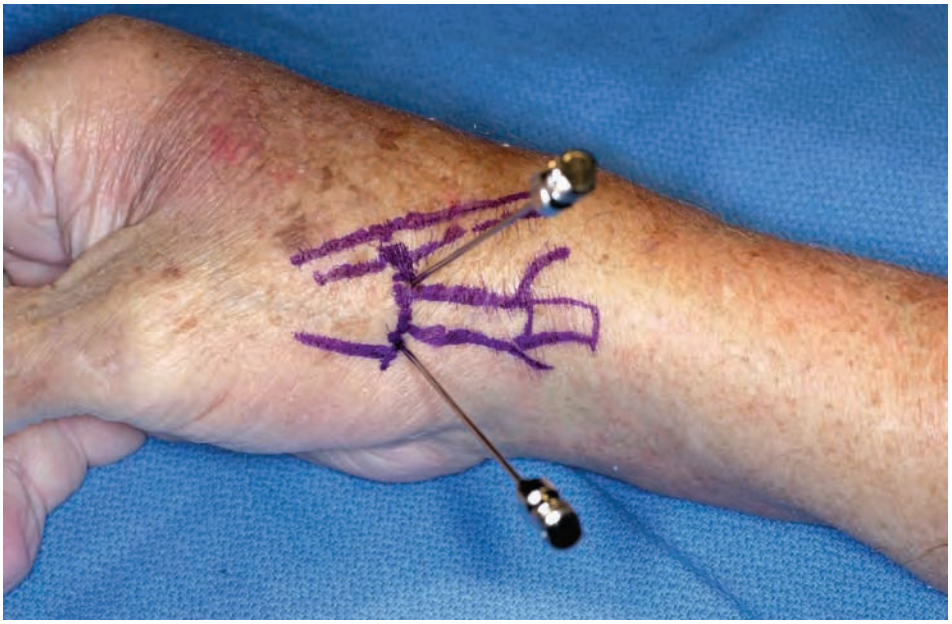

FIGURE 2 The location of subcutaneous landmarks for portal placement have been indicated by a marking pen on the skin. Spinal needles have been inserted into the 1-R and 1-U portal sites. *Source*: From Ref. 3.

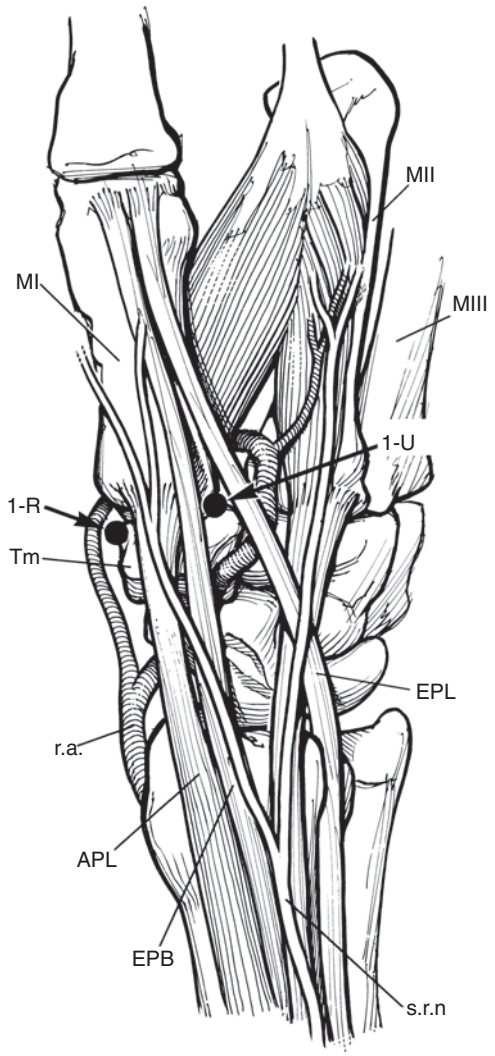

FIGURE 3 Artist's depiction of the first carpometacarpal joint detailing portal sites (1-R and 1-U) and local anatomic structures. The r.a. and the s.r.n. are in close proximity to the portal sites. *Abbreviations*: APL, abductor pollicis longus; EPB, extensor pollicis brevis tendon; EPL, extensor pollicis longus tendon; MI, first metacarpal; MII, second metacarpal; MIII, third metacarpal; r.a., radial artery; s.r.n., superficial radial nerve; Tm, trapezium. *Source*: From Refs. 3, 6. Courtesy of Mayo.

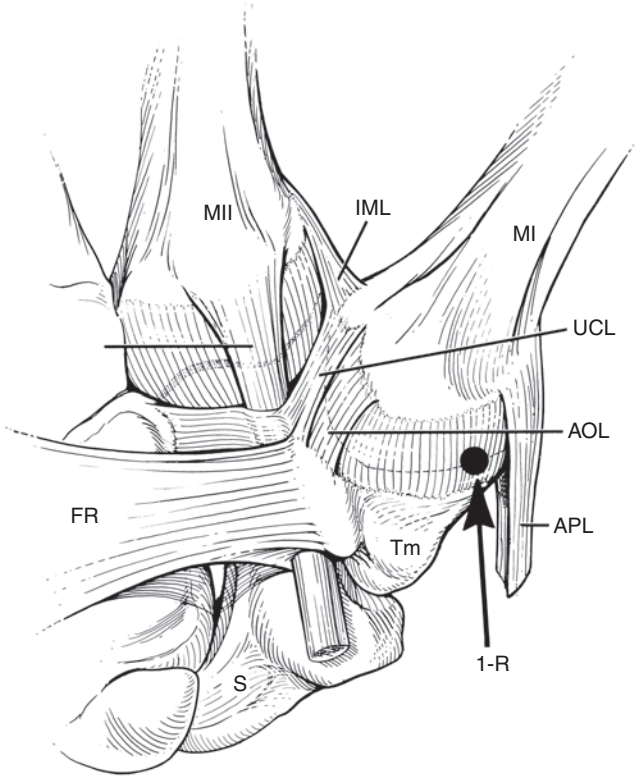

FIGURE 4 Palmar view of the first CMC joint showing the relationship of the 1-R portal and the volar stabilizing ligaments of the thumb: the UCL, AOL, and IML. *Abbreviation*: AOL, anterior oblique ligament; FR, flexor retinaculum; IML, intermetacarpal ligament; MI, first metacarpal; MII, second metacarpal; S, scaphoid; Tm, trapezium; UCL, ulnar collateral ligament. *Source*: From Refs. 3, 6. Courtesy of Mayo.

radial artery. The 1-U portal tends to enter the joint either through the DRL or between the DRL and the POL. This portal allows for excellent visualization of the AOL and the UCL (Fig. 8A,B). It may also be utilized as the main working portal for interventions following diagnostic arthroscopy (3,6,26,27).

A standard 2.7-mm wrist arthroscope is used to visualize the CMC joint. The camera and working portal can be switched back and forth between the 1-R and the 1-U portals as the arthroscopy progresses. It is helpful to sweep the trocar back and forth in the joint prior to placement of the arthroscope since this will tend to help create an initial space for visualization within the joint. An electrocautery or radiofrequency ablation probe is helpful to use initially for debridement of soft tissue prior to performing any bony work.

Once adequate visualization of the joint is achieved, a small joint shaver (3.5 mm) can be used to further debride the joint. Smaller diameter arthroscopic shavers tend to not work as well. Likewise, although it is possible to use a smaller arthroscope such as a 1.9 mm, the visual field tends to be limited and consequently the pace of the procedure is slowed. Visualization is also enhanced by use of a standard arthroscopic mechanical pump to continuously irrigate the joint with saline. A dedicated outflow cannula is usually not needed if both working portals are large enough to allow egress of fluid.

Once adequate visualization has been achieved, the bony work is addressed. Typically, an arthritic biconcave trapezium is observed. An arthroscopic burr (3.5 mm) is then used to remove 3 to 4 mm of distal trapezium (Fig. 9). A smooth bony surface is then carefully created. Viewing from both the 1-R and the 1-U portals is required to be sure accurate planning of the trapezium has been performed.

After bony recontouring has been performed, the joint is then ready for placement of the interposition tissue. Interposition tissue depends on the surgeon's preference. Arthroscopic utilization of autograft tissue, such as the FCR or the palmaris longus tendon, has been described by some authors (7,11). Allograft or xenograft materials may be manufactured to be approximately 1-mm thick, but can

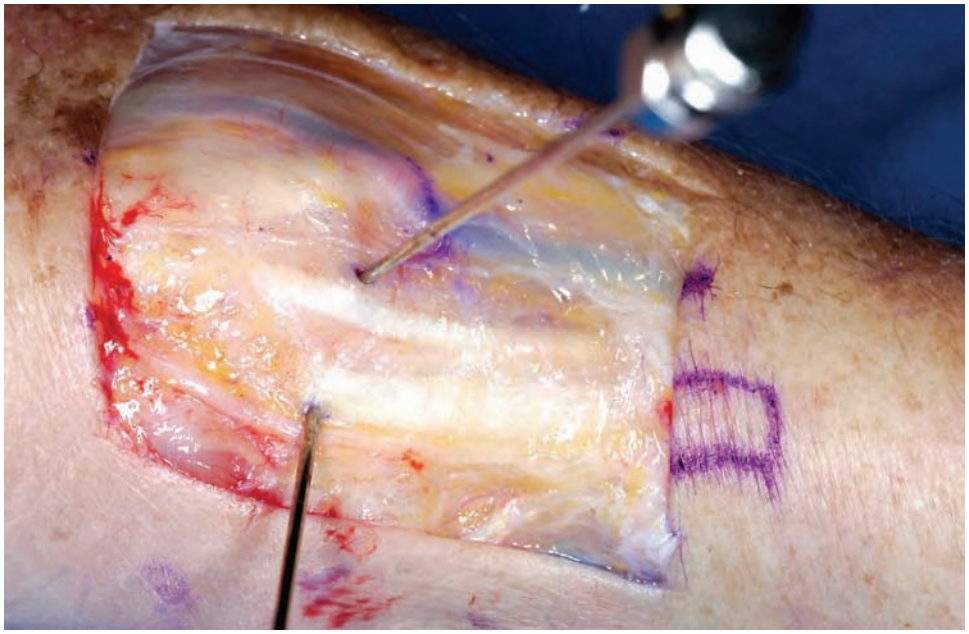

FIGURE 5 In this cadaveric dissection, the skin has been removed to reveal subcutaneous structures, including branches of the superficial radial nerve, the APL tendon, and the EPB tendon. *Abbreviation*: APL, abductor pollicis longus; EPB, extensor pollicis brevis tendon. *Source*: From Ref. 3.

then be folded to double the thickness and cut to match the articular surface area of the joint. This may be sutured with absorbable sutures to maintain the implant in a double layer; however, this step is usually not necessary. The tissue is then placed into the joint by passing a small curved hemostat into a portal and then manipulated until it exits out the opposite portal. A corner of the folded graft is then placed into the grip of the hemostat and pulled into the joint (Fig. 1). Once the graft has been placed into the joint, the arthroscope is replaced into the joint and a probe used to "spread out" the graft to completely cover the cancellous surface of the trapezium. The portals are then closed and the thumb maintained in an abducted position as the traction is removed. Portals should be closed carefully to prevent potential dislocation of the graft. A sterile thumb spica abduction splint is then applied while carefully holding the thumb in an abducted position. Alternatively, a 0.45-Kirchner wire can be passed through the base of the first metacarpal into the trapezium to help maintain stability; however, in most cases, a thumb spica splint alone is adequate to maintain reduction. After splinting, a fluoroscopic view can be obtained to confirm restoration of joint space with the interposition graft. This can then be saved and compared to preoperative and subsequent radiographs obtained during follow-up visits (Fig. 10A,B).

The splint is changed to a cast at two weeks, at which time the portal sutures are removed. A forearm-based thumb spica abduction cast is then maintained for an additional four weeks, for a total of six weeks of immobilization. After cast removal, the patient should be seen by a hand therapist and instructed in exercises for progressive mobilization. Full activity as tolerated is permitted after the cast is removed. Patients are seen in routine follow-up with radiographs obtained at three months (Fig. 10B).

■ COMPLICATIONS

During the surgical approach, there is a risk of injury to the branches of the superficial radial nerve. Neuroma formation may occur and may require excision. To minimize risk of nerve injury, incisions should be made through skin only, with deeper blunt spreading of tissue to establish the portals. Extrusion of the graft may occur, requiring removal. Adverse reaction to the interposition material has been demonstrated by other authors, ultimately requiring conversion to another procedure. Most poor outcomes relate to poor patient selection and are due to performing this minimally invasive procedure in patients who require a more extensive surgery to address their pathology such as in those with significant ligamentous laxity or those with pantrapezial arthritis.

■ OUTCOMES

Outcomes of arthroscopic debridement and resurfacing have been demonstrated to be comparable to those obtained by traditional procedures (1,2,4). We previously reported on 17 patients who underwent the described procedure with interposition of a human acellular dermal matrix graft (Graftjacket®, Wright Medical Technology, Arlington, Tennessee, U.S.A.). At an average follow-up of 14 months, all patients reported improvements in the level of pain symptoms, and 94% stated that they were satisfied or somewhat satisfied with the procedure. No major complications were observed, and no radiographic evidence of subsidence was noted. Postoperatively one patient was dissatisfied. This patient had a postoperative ulnar neuropathy presumed to be related to his axillary block anesthesia. Likewise, Swafford (4) described his experience with a similar technique, which differs by pin fixation longitudinally through the implant

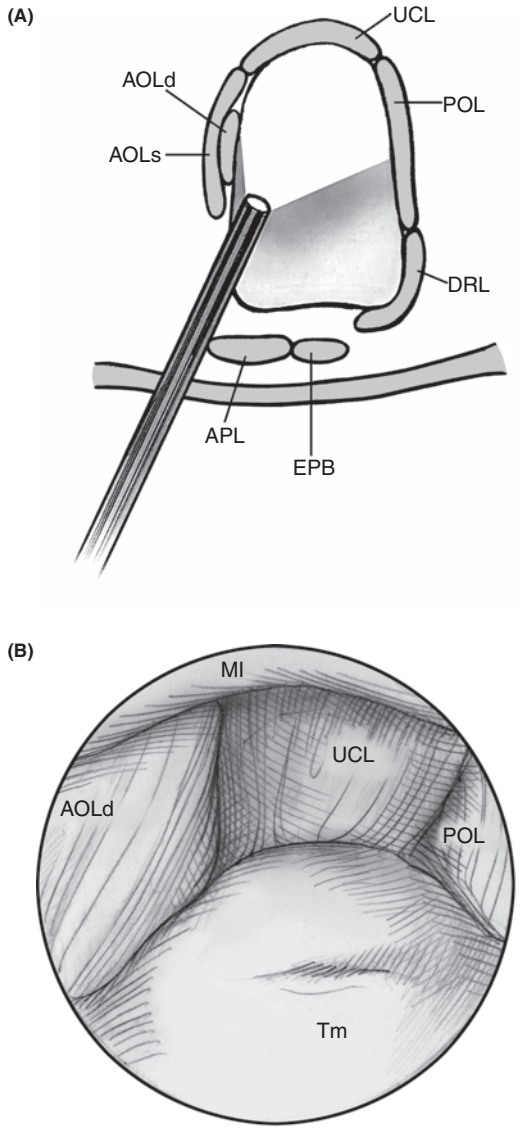

FIGURE 6 (**A**) Schematic of the 1-R portal and the viewing area. (**B**) Artist's rendition of the arthroscopic view from the 1-R portal. *Abbreviations*: AOLd, deep anterior oblique ligament; AOLs, superficial anterior oblique ligament; APL, abductor pollicis longus tendon; DRL, dorsoradial ligament; EPB, extensor pollicis brevis tendon; MI, first metacarpus; POL, posterior oblique ligament; Tm, trapezium; UCL, ulnar collateral ligament. *Source*: From Refs. 3, 6. Courtesy of Mayo.

and joint, and thermal capsular plication. In his series, 90% of patients had good to excellent results.

SUMMARY

In conclusion, the described technique of arthroscopic interposition arthroplasty is a minimally invasive technique that represents a viable surgical option for management of the appropriate patient with refractory trapeziometacarpal arthritis.

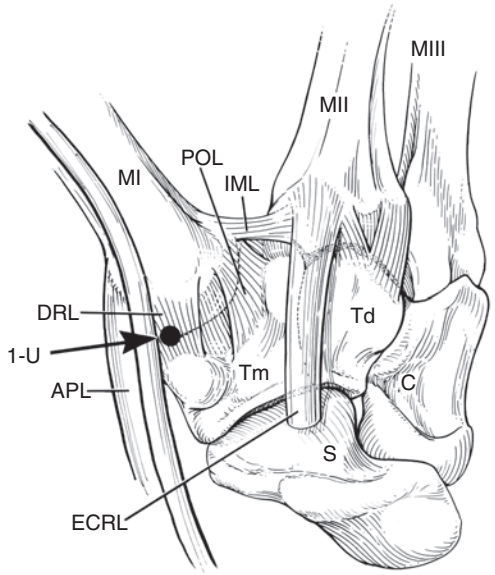

FIGURE 7 Artist's rendition demonstrates the 1-U portal and the anatomic features viewed from the dorsal aspect of the first CMC joint. *Abbreviations*: APL, abductor pollicis longus tendon; C, capitate bone; DRL, dorsoradial ligament; ECRL, extensor carpi radialis longus tendon; IML, intermetacarpal ligament; MI, first metacarpal; MII, second metacarpal; MIII, third metacarpals; POL, posterior oblique ligament; Td, trapezoid; Tm, trapezium. *Source*: From Refs. 3, 6. Courtesy of Mayo.

SUMMATION POINTS

Indications

- Patients with Eaton stages II or III symptomatic trapeziometacarpal joint arthritis recalcitrant to nonsurgical management
- Significant ligamentous laxity and pantrapezial arthritis should be absent

Outcomes

- Comparable to those previously documented in open procedures such as ligament reconstruction and tendon interposition
- Advantages include preserving capsular and ligamentous structures, preserving bone stock, and the minimally invasive nature of the technique

Complications

- Generally rare, but may include graft reaction and graft extrusion
- Infrequent nerve or vessel injury
- Failure due to inappropriate patient selection

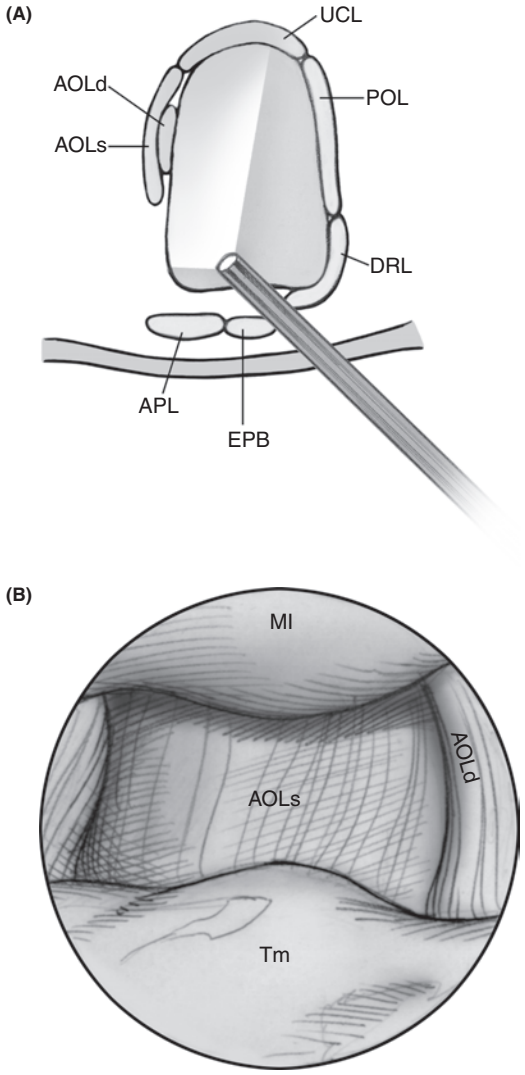

FIGURE 8 (**A**) Schematic of the 1-U portal and the viewing area. (**B**) Artist's rendition of the arthroscopic view from the 1-U portal. *Abbreviations*: AOLd, deep anterior oblique ligament; AOLs, superficial anterior oblique ligament; APL, abductor pollicis longus tendon; DRL, dorsoradial ligament; EPB, extensor pollicis brevis tendon; MI, first metacarpus; POL, posterior oblique ligament; Tm, trapezium; UCL, ulnar collateral ligament. *Source*: From Refs. 3, 6. Courtesy of Mayo.

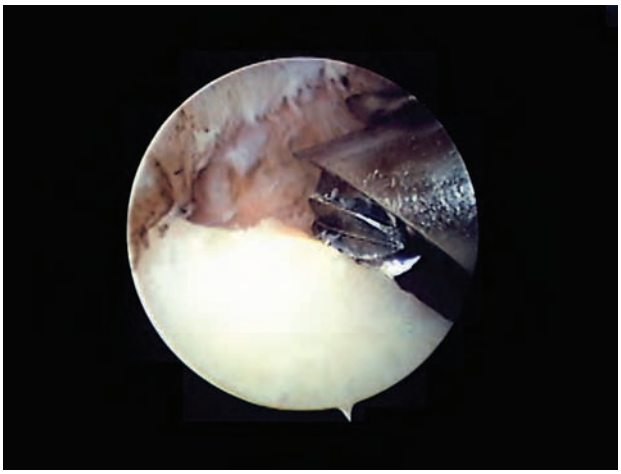

FIGURE 9 Intraoperative view of the biconcave arthritic trapezium. The 3.5-mm arthroscopic burr is utilized to resect the distal trapezium.

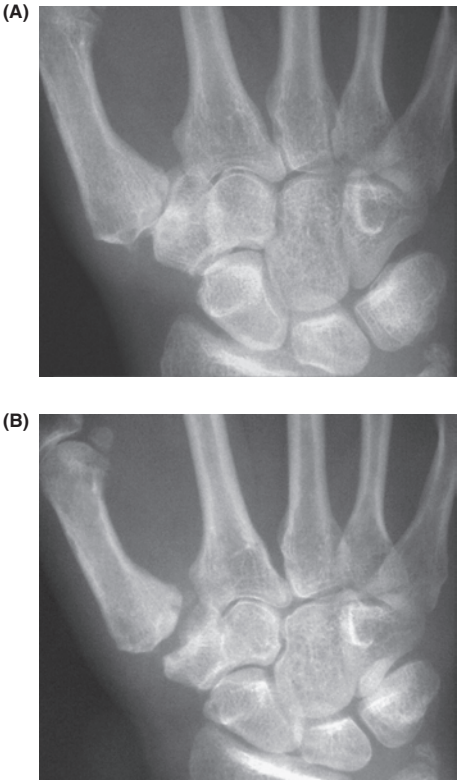

FIGURE 10 (**A**) Preoperative radiograph demonstrating the arthritic first CMC joint. (**B**) Postoperative radiograph at three months follow-up shows preservation of the joint space.

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Endoscopic Carpal Tunnel Release: The Single-Portal Mirza Technique

Tamara D. Rozental, Charles S. Day, and Orrin I. Franko
Department of Orthopedic Surgery, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts, U.S.A.

INTRODUCTION

Carpal tunnel syndrome is the most common compression neuropathy in the upper extremity. Patients failing conservative treatment with splinting and/or corticosteroid injection often require surgical release to alleviate the paresthesias and numbness which characterize the disease. The first carpal tunnel release was performed in 1924 by Herbert Galloway (1). Since then, a variety of incisions have been described to visualize the transverse carpal ligament (TCL) and avoid injury to the underlying median nerve. Open carpal tunnel release continues to be the gold standard for decompression of the median nerve but reports of pillar pain and prolonged discomfort over the palmar incision have led to the development of endoscopic techniques. There are two main endoscopic approaches for carpal tunnel release: single- or double-portal techniques. This chapter reviews endoscopic carpal tunnel release through the Mirza single-portal distal entry technique. This uniportal technique was developed after reports of injuries to anatomic structures at the distal aspect of the TCL and allows direct visualization of the superficial palmar arch, median nerve, and flexor tendons (2).

INDICATIONS

The indications for the Mirza carpal tunnel release technique are generally the same as those open carpal tunnel surgery. They include a clinical diagnosis of median nerve compression at the carpal tunnel in patients (1) failing conservative treatment or (2) with thenar weakness or atrophy.

Authors disagree on absolute contraindications to endoscopic carpal tunnel release. Reported contraindications to date include:

- Need for extensive neurolysis or tenosynovectomy
- Mass in the carpal canal
- Inflammatory arthritis (due to increased risk of aggravating the inflammatory process)
- Peripheral neuropathy
- Anatomic abnormalities
- Vasospastic disorders
- Prior carpal tunnel release
- Thenar weakness requiring tendon transfer
- Pregnancy (due to excessive weight gain and edema)
- Dupuytren's contracture or other conditions limiting finger or wrist extension
- Patients on anticoagulant therapy.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

See discussion in Chapter 36.

SURGICAL TECHNIQUE

Positioning

The patient is positioned supine with the wrist in neutral position. Two initial lines of incisions are drawn: one longitudinal in line with the third web space and the other transversely across the radially abducted thumb. A 1.5 cm incision is marked from the intersection of these two lines proximally. An additional marker for the incision is the ulnar border of the flexed ring finger which should lie within the 1.5 cm incision. Two additional longitudinal lines are drawn in the distal forearm: one radial to the flexor carpi ulnaris tendon and the other along the palmaris longus tendon. The midpoint between these lines is marked with an "x" to aim the cannula between the median and ulnar neurovascular bundles (Fig. 1).

Technique

The skin is incised and the edges are undermined. A Ragnell retractor is placed on either side of the incision and the skin edges are retracted, pulling the palmar fascia away from the underlying neurovascular bundle. The palmar fascia is divided longitudinally to expose the midpalmar fat. The median nerve, superficial palmar arch, and TCL are then identified (Fig. 2). The retractors are repositioned to include the palmar fascia. A path is then created by blunt dissection (with a blunt hemostat) between the TCL and the contents of the carpal canal, aiming ulnarly towards the "x" in the distal forearm. The forearm is then elevated and the wrist extended over a bolster to introduce the dissector (A.M. Surgical, Smithtown, New York). The dissector is aimed between the two lines marked on the forearm. Once the pathway is created with the dissector, a dissecting obturator is introduced (Fig. 3). The tip of the obturator should rest against the undersurface of the TCL at all times. Once the cannula tip is palpable through the skin beneath the "x", the obturator is removed and the cannula is left in place with the slot facing slightly ulnar. A standard 4 mm 30° endoscope is introduced through the slotted cannula and oriented toward the slot (Fig. 4A,B). The TCL is visualized through the endoscope and any remaining tenosynovium is removed with the dissecting obturator (Fig. 5). The median nerve is visualized by rotating the cannula radially (Fig. 6).

FIGURE 1 The 1.5 cm incision is marked and two additional longitudinal lines are drawn in the distal forearm. The midpoint between these lines is marked with an "x" to aim the cannula between the median and ulnar neurovascular bundles.

Once proper cannula placement is verified, the cannula is once again rotated ulnarly to visualize the TCL and the flexor tendons (Fig. 7). Once a clear view of the TCL is obtained, the endoscope is removed and a mounting blade is attached to the end of the scope with a locking device (Fig. 8). The TCL is divided by advancing the blade under direct endoscopic visualization through the cannula from distal to proximal (Fig. 9A,B). The TCL division is complete when the blade is palpable through the skin in the distal forearm, proximal to the wrist flexion crease. The blade can then be removed and the endoscope reinserted to visualize the divided edges of the TCL (Fig. 10). The median nerve and flexor tendons can also be visualized by rotating the cannula radially and ulnarly, respectively. Finally, the endoscope is removed and the obturator re-inserted. The entire assembly is then brought out together.

Closure

Following irrigation and hemostasis, the skin is closed with interrupted sutures. A soft compressive dressing is then applied.

OUTCOMES AND RESULTS

Since the introduction of endoscopic carpal tunnel release, the hand surgery literature has seen the proliferation of articles reporting on the results, outcomes, and complications of the technique. Enthusiasts emphasize lower postoperative morbidity, better functional outcomes in the short term, and a reduced period of disability. Opponents have focused on the higher rates of complications encountered with the endoscopic technique, particularly in its early stages. Mirza initially reported on 280 cases of endoscopic releases using the above described technique. Mean grip strength approached preoperative values by the fourth postoperative week and patients returned to work at a mean of 14 days after surgery. No patients reported pillar pain or scar tenderness (2).

Multiple prospective randomized trials comparing open with endoscopic carpal tunnel release have since been performed. Trumble et al. performed a multicenter randomized trial using the single-portal Agee technique and a traditional open carpal tunnel release (3). They found that patients treated with the endoscopic release had better functional outcomes in the first three months after surgery and returned to work at a faster rate. These findings, however, have not been consistent throughout the literature. Other randomized trials have reported similar outcomes and return to work times in both patient groups (4,5). In addition, some series have reported higher rates of reoperation in patients treated with endoscopic carpal tunnel release, negating the positive effect of a faster return to activities of daily living. A meta-analysis of 13 randomized controlled trials was published in 2004 (6). The study supported the conclusion that scar tenderness and grip strength were better in patients treated with endoscopic techniques. They also found a higher rate of reversible nerve injuries among these patients. The results in terms of pain and return to work were inconclusive (6). To date, no randomized studies have been published comparing the Mirza technique with open carpal tunnel release.

COMPLICATIONS

Reported complication rates using the endoscopic technique range from 0.2% to 5% (7). Many of the more dramatic complications, however, occurred during the early development stages of the technique and have been addressed by changes in the design of the instrumentation.

The original Agee technique resulted in several cases of nerve transection (8). Since then, the blade assembly has been redesigned and a large multicenter trial using the new device found a complication rate of 1.8% (9). Due to incomplete visualization of the TCL, Chow modified his original transbursal technique to an extrabursal insertion point. Nagle compared the two methods and found that the complication rate of 11% using the original technique dropped to 2.2% once the new insertion point was utilized (10).

Injury to anatomic structures at the distal aspect of the TCL lead Mirza to develop a uniportal technique allowing direct visualization of the superficial palmar arch, median nerve, and flexor tendons. During his early experience, Mirza reported two cases of transient ulnar nerve neuropraxia. In addition, one patient sustained a partial transaction of the median nerve repaired at the time of surgery and the other patient had an incomplete release of the TCL requiring reoperation. After redesigning the instrumentation, a more recent report of 475 patients revealed one case of reflex sympathetic dystrophy, one transient neuropraxia, and one blade failure (11).

There are varying reports in the literature regarding conversion of endoscopic carpal tunnel release to open procedures. Saw et al. reported a 12% conversion rate secondary to fogging of the lens during the procedure and incomplete visualization of the TCL (8). Other authors have reported a conversion rate of 2% (Mirza).

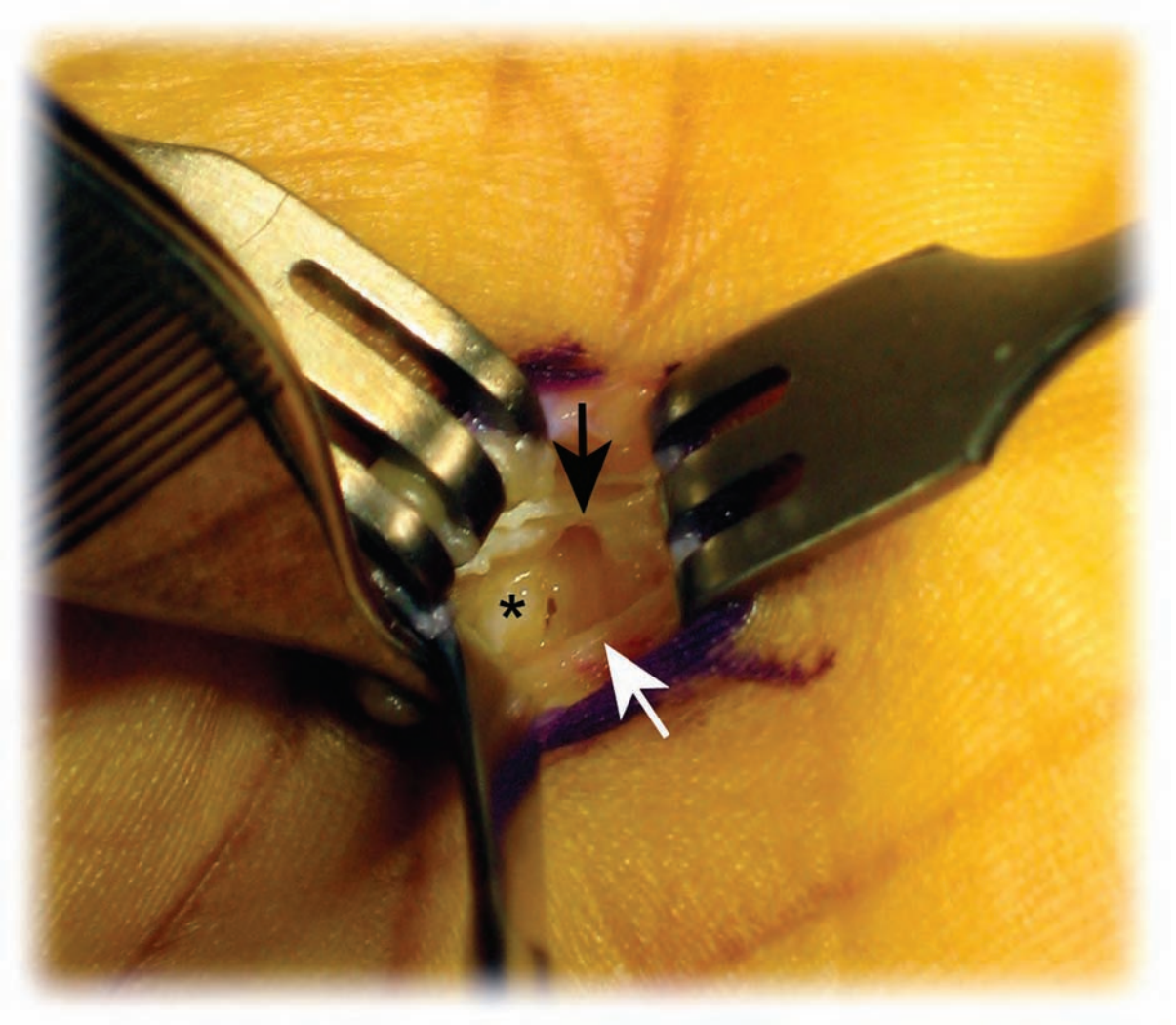


FIGURE 2 Following skin incision, the skin edges are retracted, pulling the palmar fascia away from the underlying neurovascular bundle. The median nerve (*asterisk*), superficial palmar arch (*white arrow*) and transverse carpal ligament (*black arrow*) are then identified.

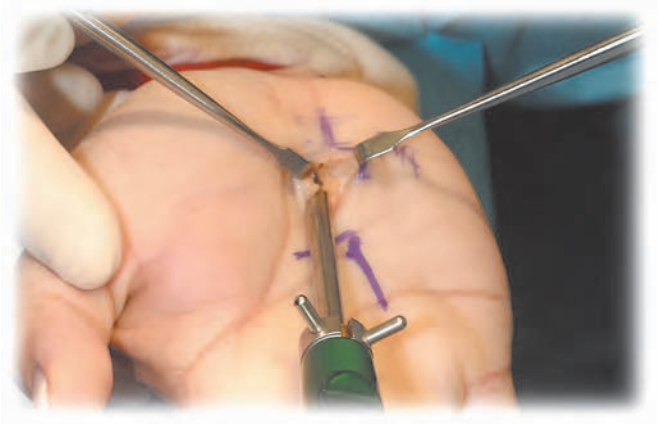


FIGURE 3 The dissector is aimed between the two lines marked on the forearm. Once the pathway is created with the dissector, a dissecting obturator is introduced.

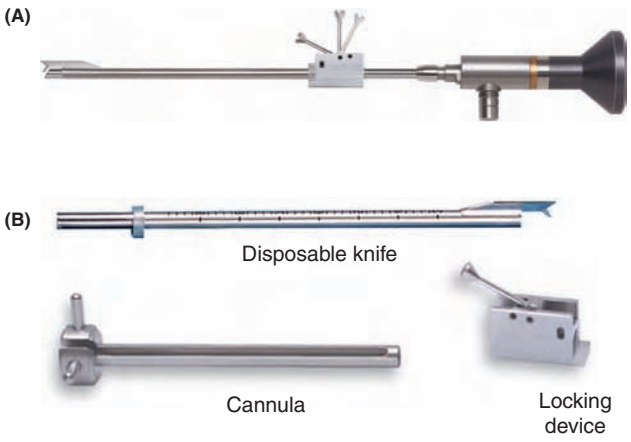


FIGURE 4 (**A**) A standard 4 mm 30° endoscope is introduced through the cannula. (**B**) The disposable knife, cannula, and locking device unassembled.

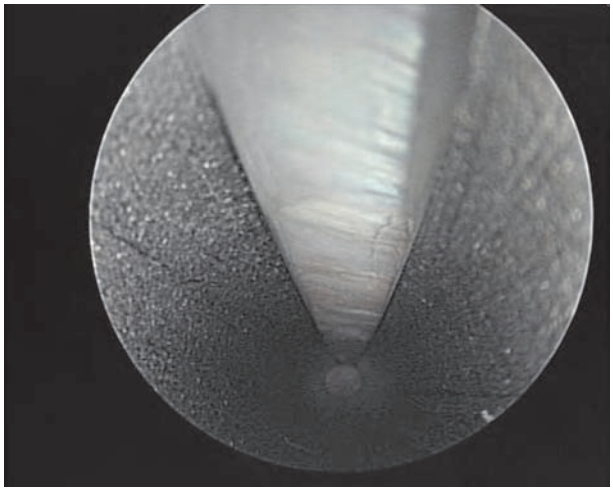


FIGURE 5 The transverse carpal ligament is visualized through the endoscope.

FIGURE 6 The median nerve is visualized by rotating the cannula radially.

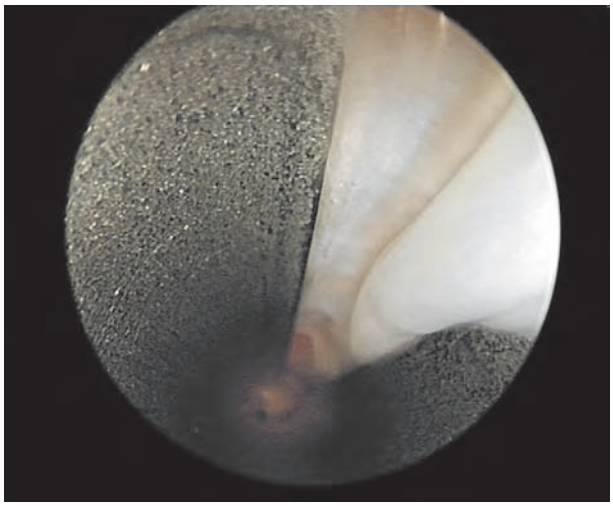


FIGURE 7 The cannula can be rotated ulnarly to visualize the transverse carpal ligament and the flexor tendons.

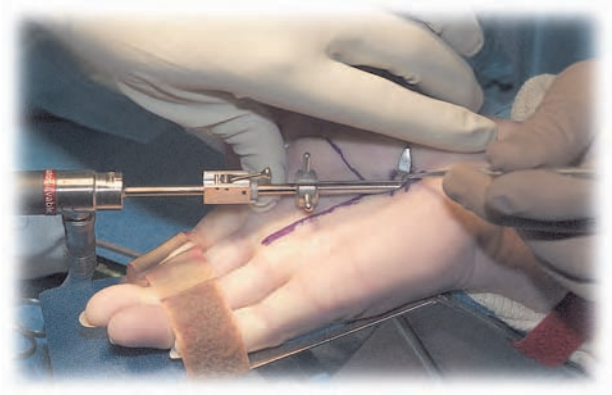
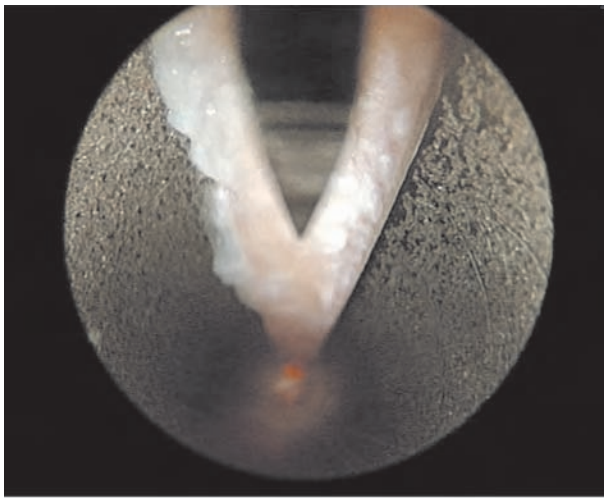


FIGURE 8 The mounting blade is attached to the end of the scope with a locking device.

(A)



(B)

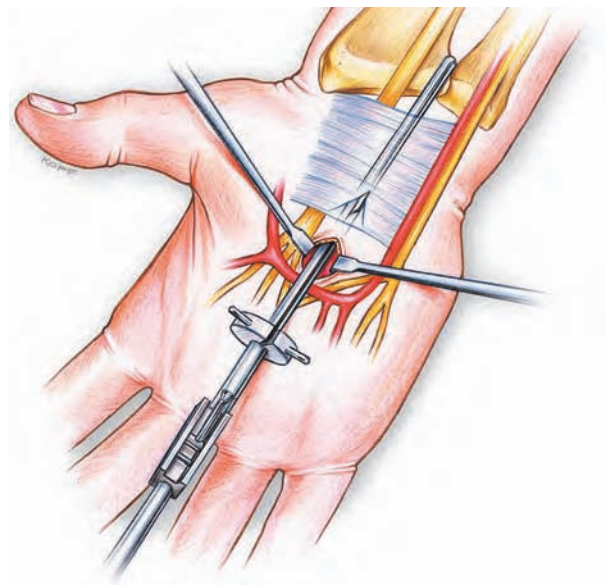


FIGURE 9 (**A,B**) The transverse carpal ligament L is divided by advancing the blade under direct endoscopic visualization through the cannula from distal to proximal.

FIGURE 10 The blade is removed and the endoscope reinserted to visualize the divided edges of the transverse carpal ligament.

To date, the following complications have been reported with endoscopic carpal tunnel release:

- Injury to the median nerve: Dheansa and Belcher 4reported two cases of median nerve injury using the original Agee technique in patients under general anesthesia (12).
- Injury to the ulnar nerve: cases of ulnar nerve transaction have been reported using the Chow two-portal technique. This type of injury is thought to be the result of entry into Guyon's canal instead of the carpal canal, or of looping under the neurovascular bundle (13,14). More common perhaps are cases of transient ulnar nerve neuropraxia.
- Injury to digital nerves: these range from transient digital nerve neuropraxia to complete nerve transaction (15).
- Injury to superficial palmar arch (16).
- Injury to the flexor tendons: this was originally described in a patient with arthritic contractures who was unable to fully extend the wrist and metacarpophalangeal joints. The flexor digitorum superficialis to the ring finger was found to be tethered around the arthroscopic sheath (17).
- Incomplete transection of the TCL leading to recurrence of symptoms and reoperation (7).

PEARLS AND PITFALLS

We have attempted over 40 Mirza single-portal endoscopic carpal tunnel releases in our practice thus far. To avoid complications, the insertion of the blunt hemostat, elevator, and dissecting cannula under the TCL is always performed gently and without significant force. If resistance is met at any point in the process, the procedure is converted to an open carpal tunnel release. We also actively identify the recurrent motor branch to ensure that it is not at risk along the radial side of the incision. In addition, when inserting the dissecting cannula proximally and ulnar into the distal forearm, care must be taken to avoid compressing the recurrent motor branch against the proximal aspect of the cannula.

At present, our conversion rate to open carpal tunnel release is approximately 20%. Following these careful guidelines, we have not had any complications to date.

CONCLUSIONS

Endoscopic carpal tunnel release continues to generate interest among hand surgeons and patients alike. Despite worrisome reports of complications in the initial stages, modifications to the surgical techniques and instrumentation have yielded improved clinical results. The Mirza technique allows direct visualization of the distal edge of the TCL, where most complications occur. Published series have revealed excellent patient satisfaction but randomized trials comparing the distal uniportal technique with open techniques as well as to other endoscopic techniques are needed to validate the outcomes of these studies.

SUMMATION POINTS

Indications

- Same as for open procedure
- Failure of conservative treatment
- Thenar weakness or wasting

Contraindications

- Space-occupying lesions
- Limited wrist or finger extension
- Congenital wrist anomalies
- Any factor affecting the anatomy of the carpal canal
- Pregnancy
- Inflammatory arthritis (relative)
- Prior carpal tunnel release (relative)
- Patients on anticoagulant therapy (relative)

Outcomes

- Similar outcome to other endoscopic or open carpal tunnel release
- Grip strength approached preoperative values by the fourth postoperative week
- Return to work at a mean of 14 days after surgery
- No pillar pain or scar tenderness

Complications

- Transient neuropraxia
- Reflex sympathetic dystrophy
- Blade failure

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Endoscopic Carpal Tunnel Release: Chow Technique

James C.Y. Chow
Orthopaedic Center of Southern Illinois, Mount Vernon, Illinois, U.S.A.

Athanasios A. Papachristos
Orthopaedic Research Foundation of Southern Illinois, Mount Vernon, Illinois, U.S.A.

INTRODUCTION

History

Carpal tunnel syndrome was recognized by Sir James Paget in 1854 as a median nerve compression following a fracture of the distal radius (1,2). Later in 1880, James Putman, a neurologist from Boston, reported the symptoms suffered by a group of his patients (3) which would be considered as a description of a classic carpal tunnel syndrome today. The first formal description of the surgical release of transverse carpal ligament for the treatment of this pathologic condition was reported in 1933 (4) followed by Phalen's classic article in 1950 (5). Since that time, open carpal tunnel release has been established as the gold standard for the surgical treatment of carpal tunnel syndrome.

Evolution of the Chow Technique

Dr. James C.Y. Chow began working on endoscopic release of the transverse carpal ligament in 1985, unaware that both Dr. Ichiro Okutsu in Japan and Dr. John Agee in California were working on similar aims at approximately the same time. The primary motivation of Dr. Chow's concept was to create a method for the surgical treatment of carpal tunnel syndrome that could be able to preserve normal anatomic structures of the wrist and hand by minimizing the surgical wound and thus, resulting in a better clinical outcome. Through persistent trials and different approaches, a slotted cannula was developed late in 1986. Following several months of repetitive practice on cadaveric hands, the procedure was completed in May 1987 and it was first performed in a patient in September of the same year. There have been some modifications of the original procedure since its conception.

The first two reports in the literature on the topic of endoscopic carpal tunnel release, written by Chow and Okutsu et al. separately, were published in the March issue of Arthroscopy Journal in 1989 (6,7). In the next year, Chow presented a conference paper based on his clinical results after endoscopic carpal tunnel release in 149 cases at the 1990 AANA Annual Meeting in Orlando, Florida (8). In the fall of the same year, another conference paper by Agee et al. (9) was presented at the 1990 American Society for Surgery of the Hand Annual Meeting in Toronto, Canada, regarding the clinical results of a multicenter study with the use of the Agee technique for the endoscopic release of the carpal ligament.

Therefore, three different surgical techniques were developed in distinct locations worldwide aiming at the same idea of minimal incision in the palm region for the surgical treatment of carpal tunnel syndrome. The common denominator of these three procedures is that they all utilize the current technology in order to bring visualization of the surgery to a video monitor with the use of a camera. Since the publishing of the three original endoscopic carpal ligament release techniques, there has been an increasingly continuous interest and also, a lot of debate among surgeons regarding the safety and efficacy of endoscopic procedure versus the open one. Several modifications and variations to the three original ideas have been made since their initial demonstration (10,11).

INDICATIONS

Whenever a surgeon deals with a pathologic situation that has to be managed surgically, specific criteria must be kept in mind in order to designate the most appropriate surgical technique. These criteria include indications–contraindications, exposure and visualization of the related anatomical structures, reproducibility, a reasonable learning curve, and an acceptable complication rate. Endoscopic carpal tunnel release does have the potential to become a dangerous procedure if performed by inexperienced surgeons (12–15). Considerable intraoperative complications have been reported throughout the United States by surgeons who have used this technique (16–19). This situation has raised a controversy among surgeons regarding the value of endoscopy for carpal tunnel surgery. However, it has also been shown that endoscopic carpal ligament release can be performed safely by experienced surgeons, although its learning curve is steep sometimes, and can give both the patient and the surgeon a great deal of satisfaction (20). The safety of this procedure seems to have improved not only due to the surgical experience that has been gained but also due to the instrumentation that has been developed and the better knowledge of the endoscopic anatomy.

The indications for the open surgical release of transverse carpal tunnel ligament have been well established and, in most cases, they apply to endoscopic carpal tunnel release. In most cases, previous conservative management by means of wrist splinting, alteration of daily activities, physical therapy, and nonsteroidal anti-inflammatory oral medication have failed. A previous performed open surgical release of the carpal ligament was not considered to be a contraindication for the endoscopic procedure. Contraindications to the endoscopic procedure include space-occupying lesions, limited wrist extension, congenital wrist anomalies, and any factor that affects the anatomy of the region. Rheumatoid patients with abundant tenosynovium should be managed with caution as well as patients who had previously sustained a fracture of the hook of hamate. These and other conditions that require direct visualization of the carpal canal are relative contraindications (21,22). Obesity, diabetes, and a previous performed open

carpal tunnel release are not considered to be contraindications for the endoscopic release of the carpal ligament. During the endoscopic procedure, if any pathology or anatomic variation is detected which either limits the view or obstructs the access into the carpal canal, the surgeon should convert to an open procedure. The patient should be well informed before surgery of a possible conversion because of the aforementioned reasons.

The advantages of endoscopic over open carpal tunnel release include no hypertrophic scar or scar tenderness, no pillar pain, less compromise to the pinch or grip strength, and an earlier return-to-work and daily activities. However, the surgeon can be in front of unexpected difficulties, e.g., ganglion, neurofibroma, and neurilemmoma, that limit visualization into the carpal canal. As in any surgical procedure, safety and success are dependent upon a thorough knowledge of the anatomy of the area, adequate training, and familiarity with the use and capabilities of the instrumentation. Surgeons who are not familiarized with endoscopes and arthroscopic techniques may give rise to major iatrogenic complications.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Carpal tunnel syndrome is a compression neuropathy of the median nerve at the wrist and due to its incidence it counts for approximately 463,673 carpal tunnel releases performed annually in the United States (23,24). Patients who have developed this syndrome usually present with a typical history of characteristic symptoms such as nocturnal pain and paresthesias, numbness to the distribution of the median nerve distal to the wrist, and weakness of the thenar muscles. Although history is very important in the diagnosis of carpal tunnel syndrome, the physician should also be aware about the patient's general health condition and family history. Congenital diseases or anomalies, diseases of the connective tissue, systemic and metabolic disorders, and a previous sustained injury to the distal forearm and wrist should be taken under consideration. A malunited fracture of the distal radius, previously performed surgery in the wrist area, and a hypoplastic or aplastic hook of the hamate (25) can produce difficulties while the surgeon is trying to access the carpal canal with the use of the custom designed surgical instrumentation.

Physical examination will assist in the patient evaluation. In an acute case, there is tenderness along the carpal canal area. Light percussion over the median nerve at the wrist area produces a "passing of electric current" sensation that radiates to the median nerve distribution known as Tinel's sign. Phalen's sign is evoked by holding the wrists at maximum flexion and the dorsal aspects of the hands in full contact like a "reverse praying" position. This position narrows the carpal canal and if reproduces the paresthesias in the fingers within 60 seconds, the sign is considered positive. As the pathological condition advances, less time is necessary to evoke a response. Other examinations include the monofilament test, two-point discrimination, reverse Phalen's test, and tourniquet test. In the late stages, with thenar muscle atrophy, one can observe the muscle waste in the thenar area (26–28). Muscle weakness is tested subjectively by resisted palmar abduction of the thumb against the examiner's index finger, and comparison of one hand to the other. A carefully performed physical examination as well as the previous taken history will both help the physician to distinguish between an isolated compression neuropathy at the wrist and a double crush syndrome (29). Clinical correlation of the double crush phenomenon has been demonstrated by the high incidence of concurrent carpal syndrome in patients with cervical radiculopathy (30,31). An equally high incidence of association of carpal tunnel syndrome and a more proximal entrapment of the median nerve has also been reported (32). Therefore, the physician must exclude the possibility of thoracic outlet syndrome, pronator compression syndrome in the forearm, and even a central nervous system disease (33–35).

Electromyography and nerve conduction velocity (NCV) tests will also assist for the detection of carpal tunnel syndrome. Indications for surgery should not be decided or altered according to the results of NCV tests, especially when the results are normal but the patient has the clinical signs and symptoms of the syndrome (36–40). A delay of the distal latency of the median nerve of 7.0 msec or longer represents significant compression of the median nerve; if present, surgery should be considered without further delay. The most important aspects in diagnosing carpal tunnel syndrome are the history and physical examination. Electrodiagnostic studies of the median nerve are adjunct used to confirm the diagnosis and perhaps suggest how the patient will respond to surgery.

Wrist radiography can rule out any possibility of congenital or acquired bone and joint deformity, abnormality, or pathology. Previous sustained fractures of the distal forearm and wrist should be taken under consideration. Standard anteroposterior and lateral views of the distal forearm–wrist and a tunnel view of the wrist are required, either to detect or put the examiner under skepticism for further investigation of the aforementioned conditions. If a more extensive study is indicated, magnetic resonance imaging, computed tomography scan ultrasound bone scan, and arthrogram of the wrist may be necessary (41–43).

SURGICAL TECHNIQUE

Initially, the original technique was described by Chow as a transbursal approach to the carpal tunnel requiring penetration of the ulnar bursa (6,44). Due to the results of a multicenter study (45,46), the original technique has been modified in an attempt to decrease the complications and the learning curve. The conversion to an extrabursal technique has made the surgical procedure much easier and safer offering a better visualization of the proximal transverse carpal ligament (47–49). The following is a description of the extrabursal, dual-portal technique.

Operating Room Setup

The patient is placed in a supine position and a hand table is used. Two video monitors are preferred, although some surgeons can manage the procedure with only one. One of the two monitors should face the surgeon and the other should face the assistant. The surgeon sits on the ulnar side of the patient and the assistant faces the surgeon (Fig. 1A). The arthroscopic equipment consists of a short 4.0 mm × 30° video-endoscope that prevents light guide from interfering with the patient's forearm by having the light post on the same side as the direction of view, a camera apparatus, a light cord, a camera input device, and a light source device (Fig. 1B). Optional equipment includes a DVD video recorder and a video printer for the printing of any captured images. Water pump and shaver equipment is not used.

A standard handset should be available. Specific instrumentation for the procedure, designed by Dr. Chow, comprises an ECTRA™ System Kit and an ECTRA™ Disposable Kit (Smith & Nephew Endoscopy, Andover, Massachusetts, U.S.A.).

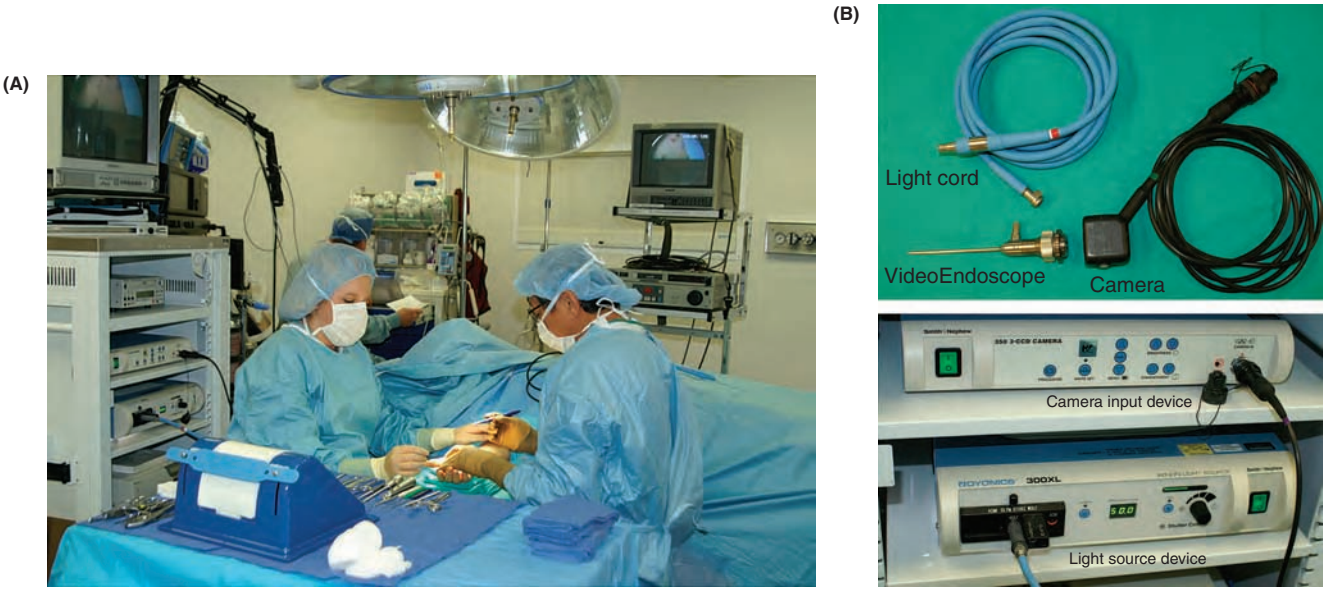

FIGURE 1 (**A**) Operating room setup for the endoscopic carpal tunnel release using the Chow dual-portal technique. (**B**) Arthroscopic equipment that is appropriate for the performance of this technique.

The ECTRA System Kit includes the video-endoscope, slotted cannula, dissecting obturator, curved blunt dissector, palmar arch suppressor, probe, retractors, and hand holder (Fig. 2). The dissecting obturator is attached with a detachable handle that can also take some other types of obturators included in the kit (conical, boat-nose obturator), the latter are not being used routinely. The ECTRA Disposable Kit includes a probe knife, a triangle knife, a retrograde knife, a hand pad, and swabs (Fig. 3). These knives allow the surgeon to determine both the direction and depth of cut. Standard preparations and draping are performed as usual without the application of a tourniquet. Before the introduction of local anesthesia, a skin marker is used to map landmarks for the entry and exit portals.

Anesthesia

Local anesthesia combined with intravenous medication is recommended for the procedure because it allows the patient and the surgeon to communicate. An alert patient can inform the surgeon, during the procedure, about any abnormal sensation in

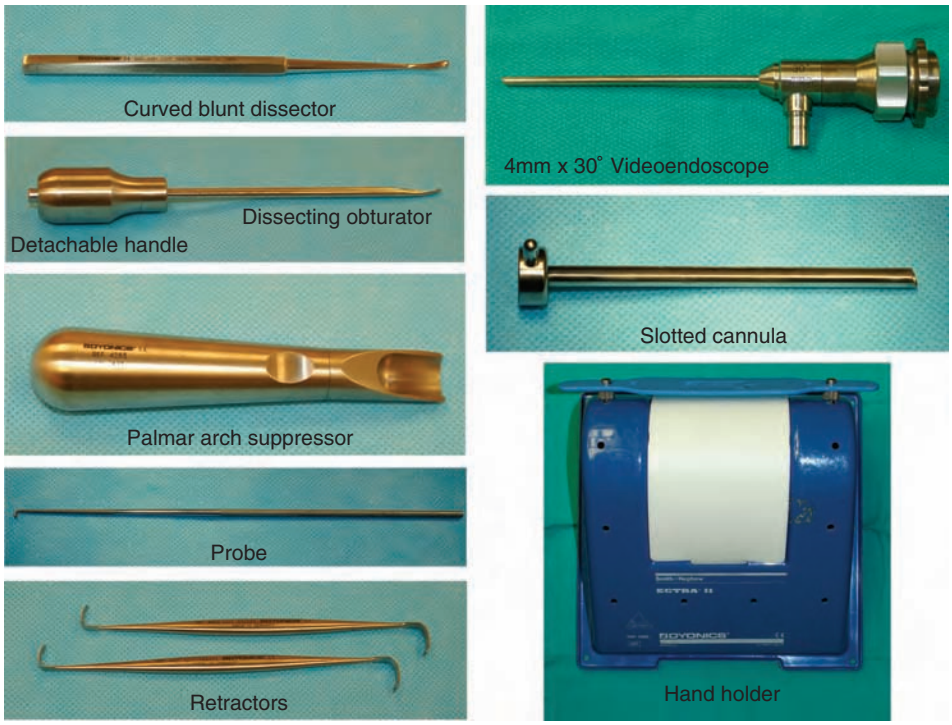

FIGURE 2 Instrumentation included in the ECTRA™ System Kit (Smith & Nephew Endoscopy, Andover, Massachusetts, U.S.A.).

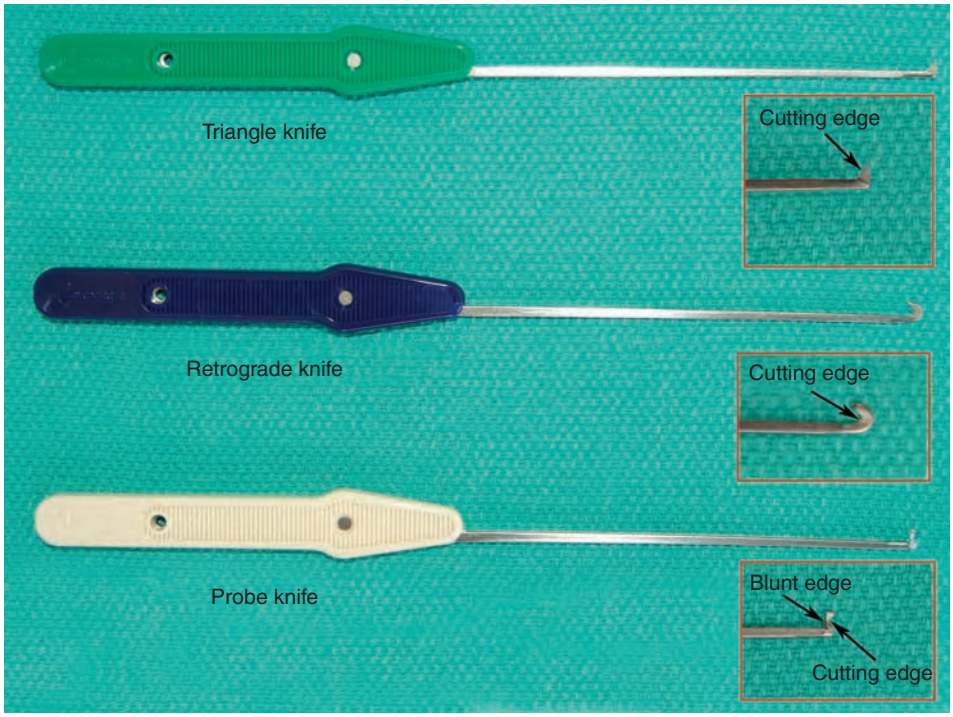

FIGURE 3 Specially designed knives for the release of the transverse carpal ligament. The tip of each knife is shown in detail (*red square*) on the right side. This instrumentation is included in the ECTRA™ Disposable Kit (Smith & Nephew Endoscopy, Andover, Massachusetts, U.S.A.).

the hand indicating a potential problem caused from any variance of nerve structure in the wrist and palm region (50–56). Usually, when the patient first comes into the operating room, fentanyl citrate (Sublimaze; Baxter Healthcare Corporation, Westlake Village, California, U.S.A.) 100 µg is given intravenously. This is a narcotic analgesic type of medication with an onset of seven to eight minutes and a peak action of approximately 30 minutes. Normally, the surgical time does not exceed 10 minutes. Xylocaine 1% (Astra, Westboro, Massachusetts, U.S.A.) without epinephrine is injected at the entry and exit portals, approximately 1 to 2 cc at the entry portal and 5 to 6 cc at the exit portal due to the higher degree of sensitivity of the skin on the palmar region. Special care is taken to place the injection only in the skin and to avoid affecting the nerve by penetrating deeply.

Positioning the Entry Portal

The proximal end of the pisiform bone is palpated on the volar surface of the wrist within the flexor carpi ulnaris tendon at the distal wrist flexor crease and is marked with a small circle. A line from the proximal pole of the pisiform is drawn radially, approximately 1.0 to 1.5 cm in length. From this point,

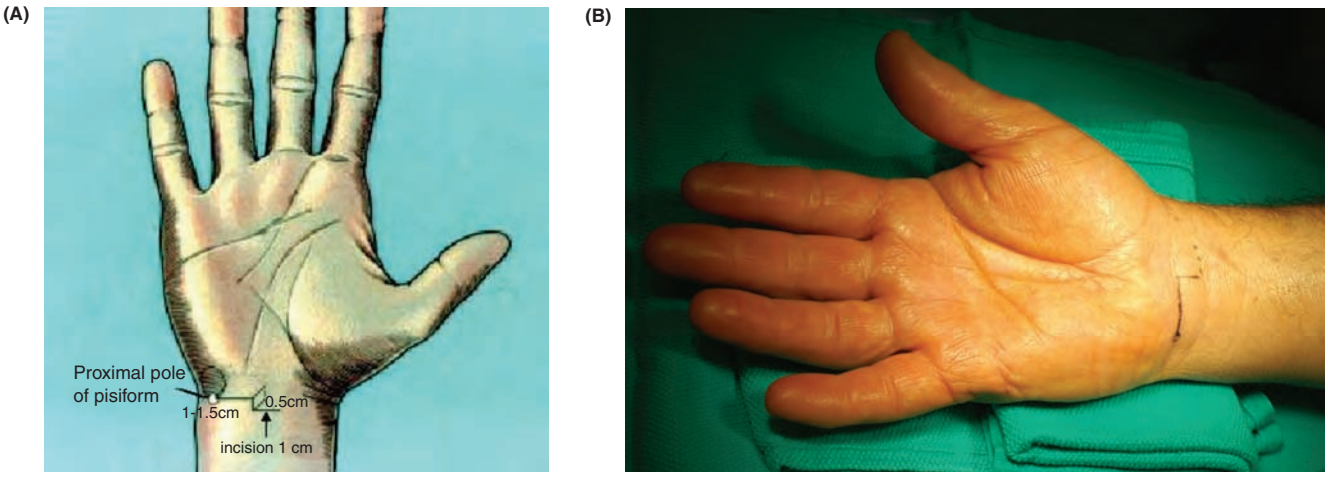

FIGURE 4 (**A, B**) The entry portal is located by drawing a line 1 to 1.5 cm radially from the proximal pole of the pisiform bone, then drawing an approximately 0.5-cm second line proximally from the end of the first one, and finally, an approximately 1-cm third line is drawn radially from the proximal end of the second line to create the entry portal.

a second 0.5-cm line is drawn proximally. A third dotted line, approximately 1.0 cm in length, is drawn radially from the proximal end of the second line to create the entry portal (Fig. 4). If the palmaris longus muscle is present, the center of the entry portal should be located at the ulnar border of its tendon almost at the level of the proximal wrist flexor crease. Average dimensions of these lines will vary slightly, depending on the overall size of the hand.

Positioning the Exit Portal

The patient's thumb is placed in full abduction. A line is drawn across the palm from the distal border of the thumb to the approximate center of the palm, perpendicular to the long axis of the forearm. A second line is drawn from the third web space, parallel to the long axis of the forearm, to meet the first line. These two lines should form a right angle. A third line is drawn, bisecting this angle and extending approximately 1.0 cm proximally from its vertex, which serves to establish the site of incision for the exit portal (Fig. 5). The surgeon should be able to palpate the hook of hamate. The exit portal should fall into the soft spot at the center of the palm and should line up with the ring finger, just slightly radial to the hook of hamate.

Creation of Portals and Placement of the Cannula

The procedure begins with the creation of the entry portal. An approximately 1.0 cm transverse incision (Fig. 6A) is made at the marked entry portal site extending just through the skin. Subcutaneous tissue is bluntly dissected off the volar forearm fascia with the use of a hemostat and is retracted with the retractors. Care must be taken to avoid damage to the small subcutaneous blood vessels. A knife is used to make a small longitudinal opening of the antebrachial fascia that is extended distally with the use of a Stephen's tenotomy scissors (Fig. 6B,C). If the palmaris longus muscle is present, the longitudinal cut should be along the ulnar border of palmaris longus tendon. Care should be taken, as sometimes there are two layers of fascia that both must be cut. Retractors are passed just beneath the fascia with one of them lifting the skin distally to create a vacuum that will separate the transverse carpal ligament from the ulnar bursa. A blunt curved dissector is gently slipped into the carpal tunnel just under the transverse carpal ligament. Maneuvering the dissector back and forth should result in a type of "washboard" feeling due to the rough undersurface of the carpal ligament. The curved dissector is then removed. A dissecting obturator/slotted cannula assembly unit can now be guided into the space vacated by the curved dissector. The slotted cannula assembly is advanced into the carpal tunnel on the underside of the transverse carpal ligament to the level of the hook of hamate, staying to the ulnar side of the carpal tunnel (Fig. 6D). With the tip of this unit touching the hook of the hamate, the surgeon gently picks up and hyperextends the hand. The hand and cannula assembly are now moved as a unit (Fig. 6E) and placed on the hand holder with the wrist and fingers in full hyperextension. The cannula assembly is advanced along the under surface of the carpal ligament, while the assistant keeps the hand onto the hand holder, until the tip of the cannula assembly can be easily palpated in the palm area where the mark for the exit portal was previously made. A small transverse or oblique incision is made just over the palpable cannula assembly tip cutting only the skin (Fig. 6F). The palmar skin and soft tissue is depressed using the palmar arch suppressor and the cannula assembly is then pushed into the receptacle of the palmar arch suppressor to exit through the distal portal (Fig. 6G). The obturator is then removed from the cannula which should lie just below the transverse carpal ligament and the hyperextended hand is strapped onto the hand holder (Fig. 6H). Hyperextension of the wrist brings the superficial palmar arch to a level lower than the exiting point of the slotted cannula assembly, thereby protecting it from injury. The creation of two portals is very essential, as they serve to stabilize the slotted cannula while it passes through both of them and thus, ensuring the reproducibility of the technique. The slotted portion of cannula allows a safe cutting zone, while delicate structures such as the median nerve and flexor tendons are being protected by the walls of the cannula.

Endoscopic Examination

The video-endoscope is inserted into the slotted cannula at the proximal portal. The camera and scope should rest comfortably in the first web space of the surgeon's hand. A cotton swab can

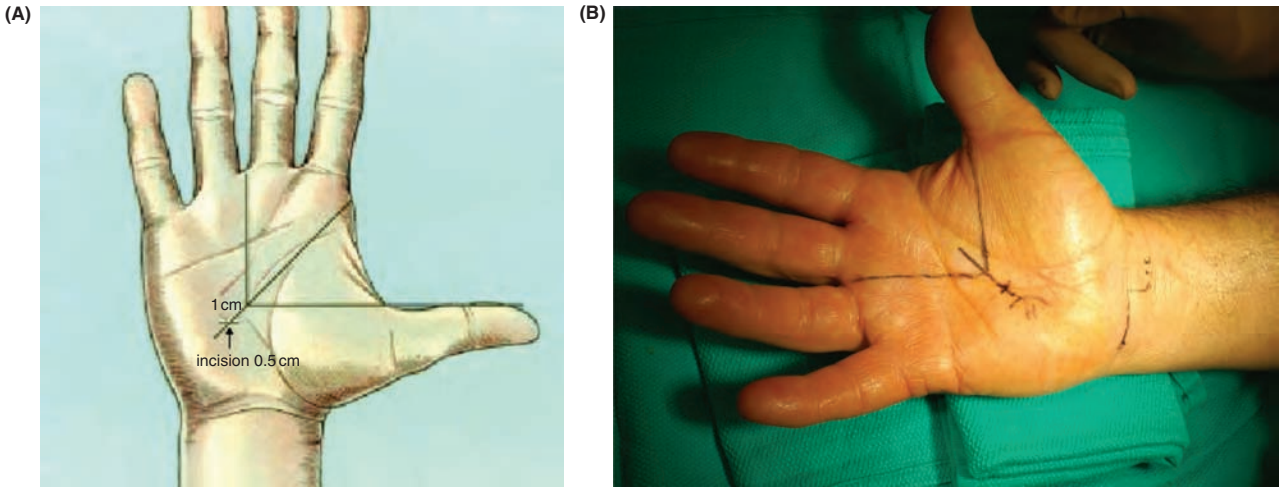

FIGURE 5 (**A, B**) The exit portal is located by drawing a line from the distal border of the fully abducted thumb perpendicular to the long axis of the forearm. A second line is drawn from the third web space parallel to the long axis of the forearm. These two lines form a right angle. A third line is drawn, bisecting this angle and extending approximately 1.0 cm from its vertex to determine the exit portal.

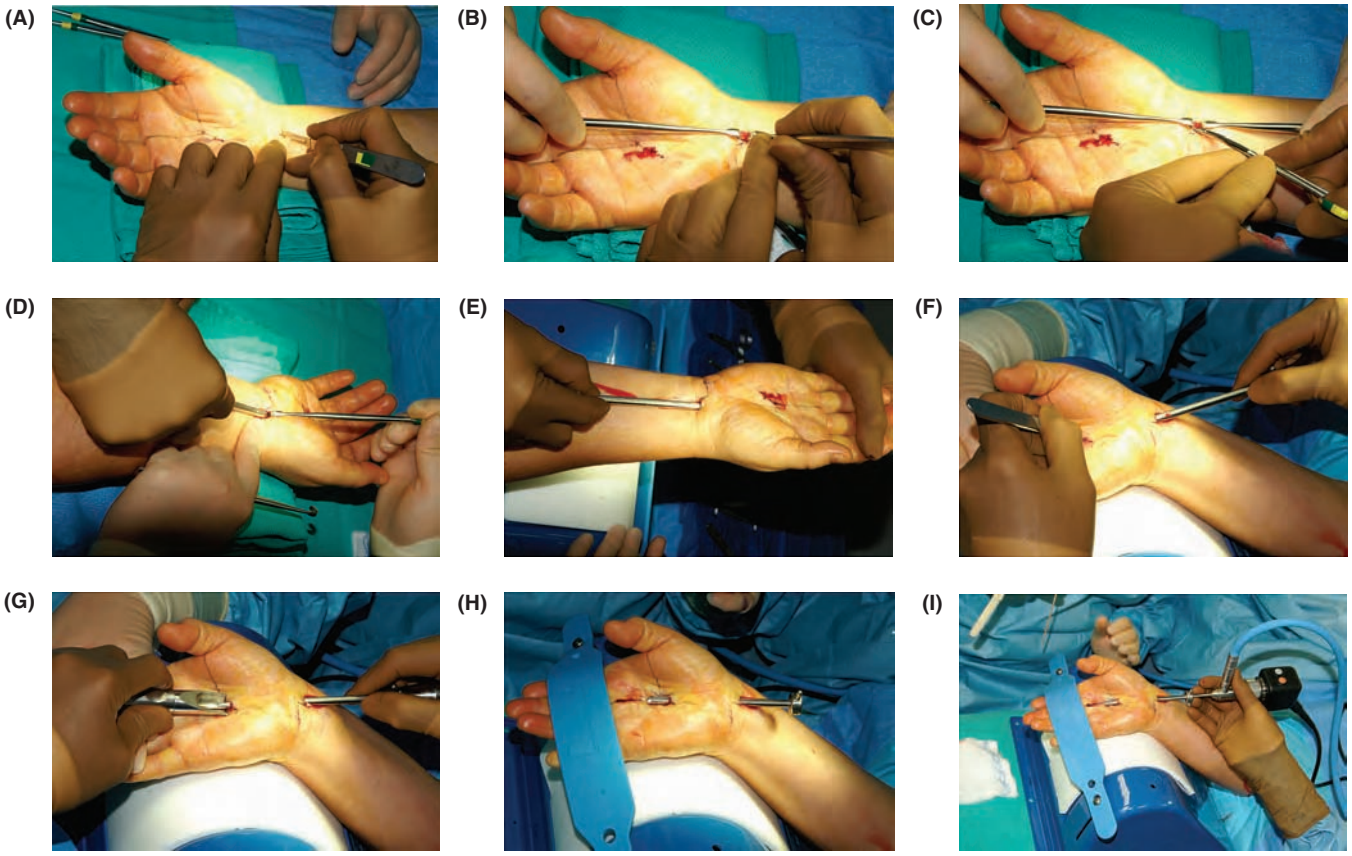

FIGURE 6 Step-by-step procedure for the creation of portals and placement of the slotted cannula. (**A**) Skin incision. (**B, C**) A small longitudinal opening of the antebrachial fascia is created and is extended distally using a tenotomy scissors. (**D**) Insertion of the dissecting obturator/slotted cannula assembly into the carpal canal. (**E**) Placement of the hand onto the hand holder. (**F, G**) Skin incision and use of the arch suppressor in order for the cannula assembly to exit through the distal portal. (**H**) The dissecting obturator has been removed leaving the slotted cannula into the carpal canal. (**I**) The scope is inserted into the carpal canal through the proximal portal.

be inserted into the tube from the distal portal to clean the lens while focus is adjusted to the best visualization. A blunt probe is inserted to palpate the undersurface of the transverse carpal ligament proximally to distally and in case a thin bursal membrane is seen above the cannula's slotted opening, this is carefully dissected with the probe to gain access to the ligament which has an "ivory type" white appearance with its fibers running transversely (Fig. 7). If the median nerve is present, the patient will feel sharp pain radiating to the fingers when the nerve is probed and this should alert the surgeon. If abundant soft tissue is noted in the opening of the cannula, the procedure should not be performed. The slotted cannula may need to be reinserted to ensure a better visualization; however, to avoid irreversible damage, surgery should not be carried out if tendons or other important structures are entrapped between the slotted cannula and the undersurface of the carpal ligament.

If there is only a minimal amount of synovium obstructing the view, the obturator is replaced into the slotted cannula.

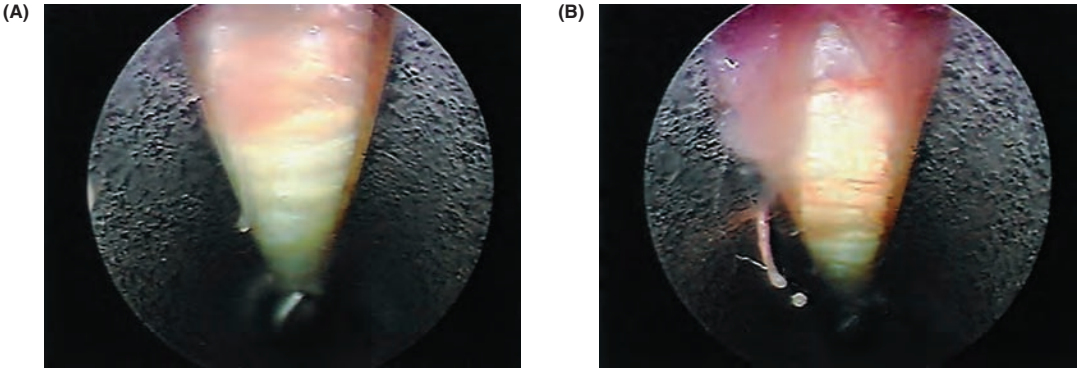

FIGURE 7 (**A**) Endoscopic normal appearance of the transverse carpal ligament with its fibers running transversely. (**B**) The thicker bursal membrane that sheaths the undersurface of the proximal portion of carpal ligament has been probed proximally depicting the fibers of ligament.

The slotted cannula assembly unit can then be rotated radially about 355° to 360° to provide the visualization and protection required. It has to be emphasized that surgeons should not hesitate to convert an endoscopic procedure to an open one, if they are not able to obtain adequate visualization.

Technique for the Release of the Transverse Carpal Ligament

With the scope in the proximal portal and the probe in the distal portal, the distal border of the transverse carpal ligament is identified. The probe knife, which permits forward cutting only, is inserted into the distal portal. The blunt edge of the knife can be used to probe proximally to distally along the ligament. The cutting edge is then used to release the distal border of the ligament by drawing the knife distally to proximally (Fig. 8A). Anything beyond the distal border of the carpal ligament should not be excised. The scope is withdrawn proximally about 1 cm and the triangle knife is used to make a small upward cut in the midsection of the ligament (Fig. 8B). The retrograde knife is now inserted through the distal portal and its blunt tip is gently positioned at the incision made by the triangle knife (Fig. 9B1,B2). The proximal cutting edge of the retrograde knife is drawn distally, making an incision that joins the previous two cuts, thereby completing the release of the distal portion of transverse carpal ligament (Fig. 9B3,B4).

The scope is removed from the proximal and inserted into the distal opening of the slotted cannula. The camera view on the screen now forms a mirror effect. The surgeon should realize that the previous ulnar side is now the radial side. By moving the scope proximally and distally, the previous distal cut is identified. The probe knife is inserted into the proximal portal and is drawn toward the level of the previous distal cut with its blunt tip touching the underside of the transverse carpal ligament, just before the beginning of the distal cut (Fig. 10B1). From this point, the blunt edge of the knife is used to retract the thick bursal membrane, which sheaths the proximal portion of the carpal ligament, distally to proximally along the ligament's undersurface (Fig. 10B2). When the cutting edge of the knife has engaged to the proximal border of the ligament, the knife is advanced distally to make an incision that joins the previous cut and thus to accomplish the release of the transverse carpal ligament (Fig. 10B3,B4). This is a slight modification of the technique that was described in previous textbooks (49,57) where the retrograde knife was used to complete the release of the ligament. The thick bursal membrane contains small vessels and it should be preserved to avoid bleeding into the carpal canal. Finally, the slotted cannula is gently rotated about a few degrees, clockwise and counterclockwise sequentially, enabling the surgeon to view the edges of the transected carpal ligament. If there are any additional fibers remaining, the triangle knife, or any other knife that feels appropriate, can be used to release these fibers until the surgeon is satisfied.

Due to the position of the patient's hand, the cut edges of the transverse carpal ligament should spring apart and disappear from the slotted opening of the cannula. If the edges can still be seen through the opening, the release is incomplete. While the assistant fully abducts the patient's thumb, the uncut portion of the ligament can be identified and the surgeon is able to complete the transection. There is a soft-tissue band that bridges the thenar and hypothenar musculature lying volar to the transverse carpal ligament that has to be preserved, as well as the palmaris brevis muscle, if present. This soft-tissue band prevents bowstringing of the flexor tendons after surgery, thereby maintaining their strength during contraction (58–60). Only one suture is required for the closure of each portal. Immediately after the procedure, the surgeon should clinically examine the patient while still in a sterilized environment. If there is any dysfunction indicating intraoperative damage to the median nerve or tendons, exposure and exploration of the carpal tunnel can be performed at the same time.

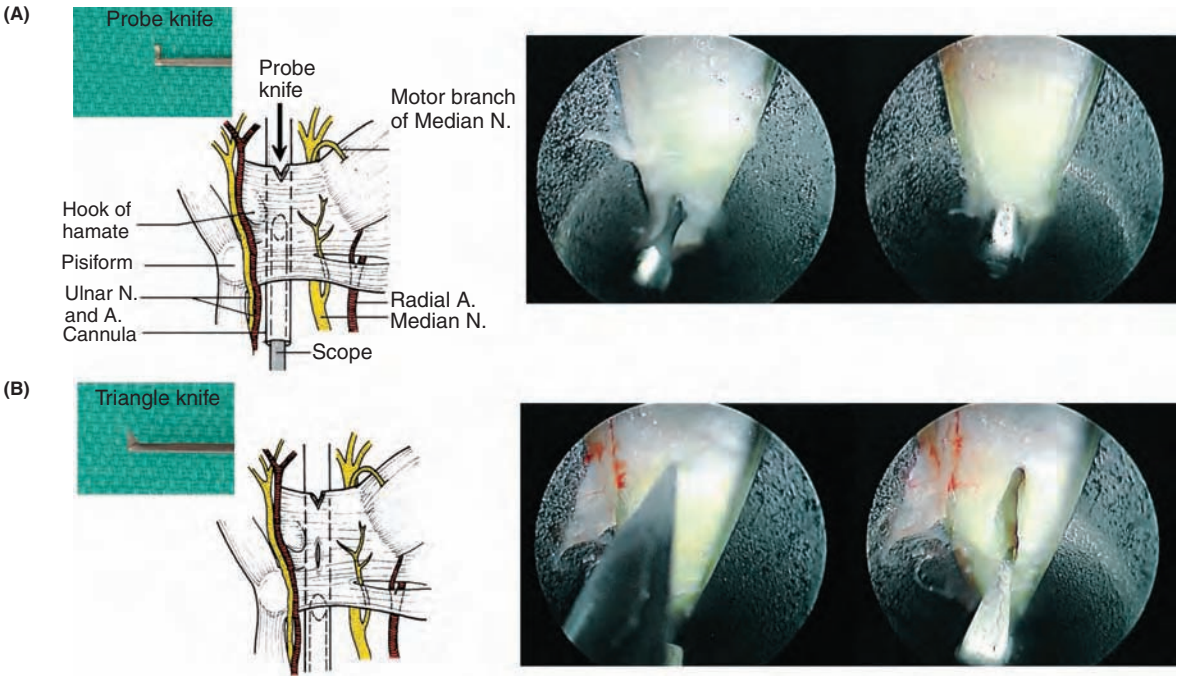

FIGURE 8 (**A**) After identifying the distal border of transverse carpal ligament, the probe knife is used to make the first cut distally to proximally. (**B**) The scope is withdrawn proximally about 1 cm and the triangle knife is used to make a small cut in the midsection of transverse carpal ligament.

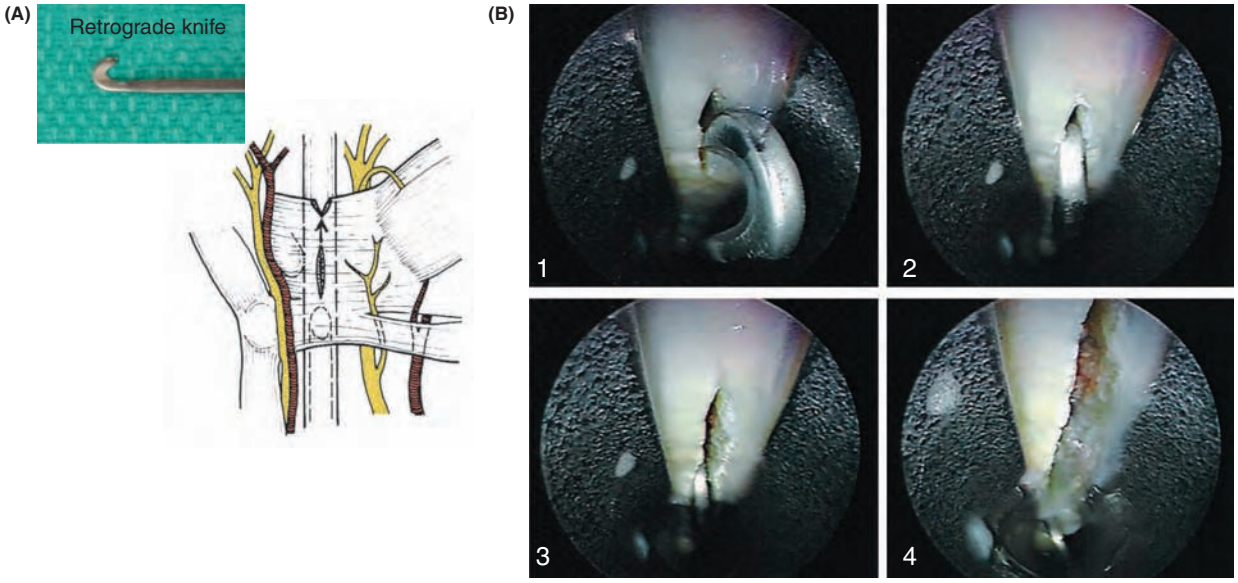

FIGURE 9 (**A, B**) The retrograde knife is placed in the incision made by the triangle knife (**B1, B2**) and it is drawn distally to make an incision that joins the previous two cuts (**B3, B4**).

Postoperatively, active range of motion is encouraged immediately after the effects of local anesthesia have subsided. The patient is advised to avoid heavy lifting or pressure on the palm region until the discomfort disappears, usually in two to three weeks. Active movement of the fingers decreases the formation of scar tissue in the wrist region and therefore prevents adhesions on the tendons or nerve at the surgical site. Sutures are usually removed in one week. If the patient engages in hard occupational activities, such as heavy lifting, too soon after surgery, there might be swelling and prolonged pain in the palm region. If these occur, fluidotherapy treatment 20 minutes daily helps to decrease the condition within one week.

■ COMPLICATIONS AND THEIR MANAGEMENT

Several complications after endoscopic carpal tunnel release with the use of the Chow technique have been reported in the literature (16). Nagle et al. (46) performed a multicenter prospective review study on a total of 640 cases. The initial transbursal technique was used in 110 cases and the modified extrabursal technique was used in the rest of 530 cases. An overall (perioperative and late) complication rate of 11% was found in the cases that were done with the transbursal technique compared with 2.2% in the cases that were done with the extrabursal technique. There were 21 out of the total 640 cases (3.3%) in which perioperative complications

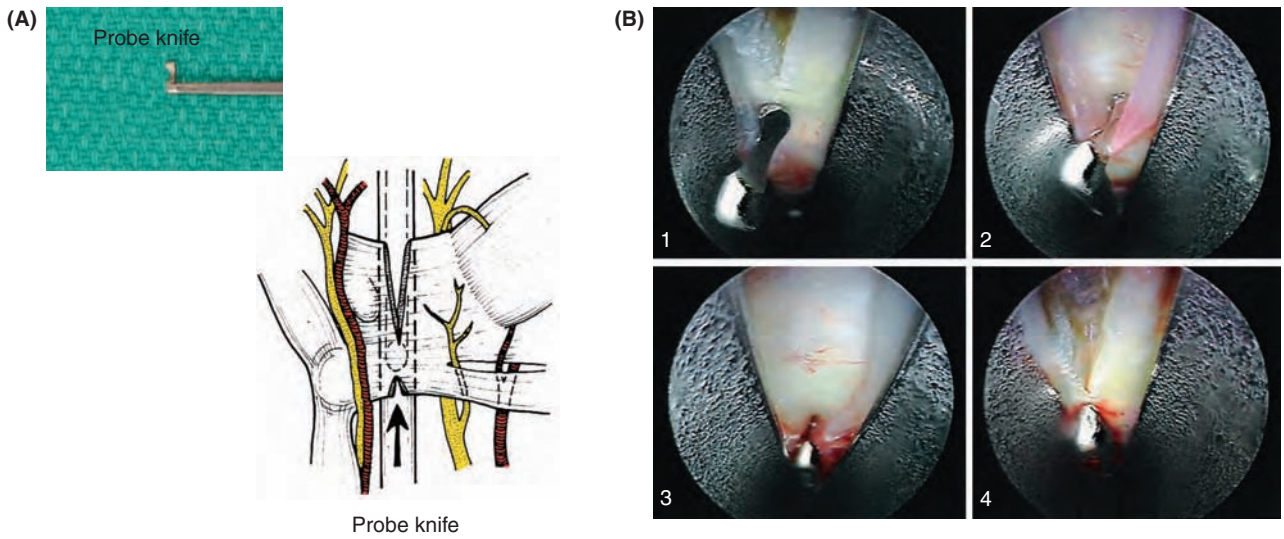

FIGURE 10 (**A, B**) Once the scope has been switched from the proximal to the distal opening of slotted cannula, the tip of the probe knife is placed just before the beginning of the distal cut (**B1**). From this point, the knife's blunt edge is used to retract the thick bursal membrane distally to proximally (**B2**). When the knife has engaged to the proximal border of transverse carpal ligament, it is advanced distally to complete the release of the ligament (**B3, B4**).

occurred. Fourteen of these 21 cases involved neurapraxia, all of which resolved without sequelae, and no nerves were lacerated or transected. There was one laceration of the superficial flexor tendon of the ring and small fingers, four incomplete releases, and two cases with hematoma and laceration of the superior palmar arch, respectively. Late complications included three cases of reflex sympathetic dystrophy (0.5%). This complication resolved in all cases without the use of sympathetic nerve blocks. The authors of this study concluded that endoscopic carpal tunnel release using the dual-portal extrabursal technique reliably decompresses the carpal tunnel and can be effectively performed with low perioperative and late complication rates.

Malek and Chow (19) in a national study of the complications of 10,246 cases in 9562 patients using the dual-portal Chow technique found a complication rate of 2.3% (240 cases with complications were reported). Of these, there were 154 nerve-related complications (median or ulnar nerve neurapraxias, lacerations, and transections), 38 complications related to blood vessels, 15 tendon injuries, 18 incomplete releases of the transverse carpal ligament, and 6 reflex sympathetic dystrophy complications. The remaining nine were listed as miscellaneous complications, including hematoma or superficial wound infection. The majority of intraoperative nerve injuries occurred in cases where general or regional anesthesia was used. The complication rates of endoscopic carpal tunnel release that have been reported compare favorably with published series of open carpal tunnel release. Complications of the latter include incomplete ligament release, nerve injuries, palmar hematomas, bowstringing of the flexor tendons, adhesions between nerve and tendons, reflex sympathetic dystrophy, deep wound infections, scar tenderness, pillar pain, tendon lacerations, and vascular injuries (61–70). Most of the damages to the surrounding anatomical structures that occur during carpal tunnel surgery, either open or endoscopic, usually require a second surgical procedure in order to be repaired.

Surgeons, who are interested in performing endoscopic carpal tunnel release, should be aware of the steep learning curve and should realize that many details must be followed to avoid serious iatrogenic complications. Normal wrist anatomy and its variances must be well-known. Visualization is also a critical portion of the procedure. Regardless the etiology, when the surgeon is unable to obtain a clear view of the undersurface of carpal ligament, the endoscopic procedure should be abandoned. A common pitfall is the ulnar placement of the entry portal. To avoid this situation, helpful guidelines have been established for the correct estimation of portal placement. These are based on years' experience and are as following:

1. Watch the entire width of the wrist to ensure the central location of the entry portal.
2. Make sure that the landmarks of both the entry and exit portals are aligned along the long axis of forearm.
3. Palpate and mark the hook of hamate. Both portals should be located radially to the hook of hamate.
4. Palpate the pulse of ulnar artery before making the skin incision for the entry portal to avoid damage of the ulnar neurovascular bundle. If a tourniquet is applied and inflated, this significant guideline is lost.
5. During the entire procedure, surgical instruments that are introduced in the wrist and hand should follow the long axis of the forearm.

OUTCOMES

From September 1987 through April 2005, in Mount Vernon, Illinois, 3536 hands in 2479 patients underwent endoscopic carpal tunnel release using the dual-portal Chow technique. The diagnosis of carpal tunnel syndrome was based on symptoms from the patient's history, clinical findings, and NCV tests. Previous conservative management by means of wrist splinting and oral nonsteroidal anti-inflammatory medication had failed or the NCV test had revealed a potentially permanent harm to the median nerve. A total of 232 of 2479 patients (9.3%)—or 330 of 3536 wrists (9.3%)—were lost to follow-up evaluation and were excluded from this report. All patients, including those who were lost to follow-up evaluation, visited the office at least one time for suture removal one week after surgery. Therefore, the immediate postoperative status of the hand was followed-up in all patients. The lost to follow-up group includes all those patients who could not be reached either because they were deceased or had moved without a forwarding address. Thus, the results of this report are based on 2247 patients (3206 wrists). The average age of these patients was 52.3 years (range 14–96 years) and they were 813 males (36.2%) and 1434 females (63.8%).

Patients with limited wrist extension associated Dupuytren's contracture or ulnar nerve entrapment into the Guyon's canal and also those who had carpal tunnel tumorous like lesions were treated with the open surgical procedure and their results are not included in this report. Patients with bilateral carpal tunnel syndrome were offered surgery at separate sessions. All procedures were done by James C.Y. Chow. The average follow-up period was seven years and eight months (range 4–209 months). The average duration of symptoms before the endoscopic carpal tunnel release was three years and one month (range 1 month to 45 years). Systemic diseases (rheumatoid arthritis, hypothyroidism, lupus, and diabetes) were noted in 210 (9.3%) patients. Previous trauma to the involved extremity was reported in 124 of 3206 (3.8%) cases. Eighty-six patients had recurrent carpal tunnel syndrome after having a previous open procedure.

Patients were told to return to work as soon as their symptoms had subsided and this date was used to calculate the return-to-work status in weeks. The return-to-work status was not followed-up to those who were unemployed or retired. Therefore, 1463 (65.1%) patients were followed-up regarding this status. Both preoperative and postoperative grip strength were measured but, due to the geographic distance that some patients would have had to travel, only 635 of the 2247 patients returned to the clinic for a complete evaluation. Grip-strength measurements begun at the first postoperative week and were repeated regularly once a week until four weeks after surgery. The numeric data that represent the results from the return-to-work and grip-strength analysis are expressed cumulatively, the latter demonstrating the percentage of patients who retrieved 80% of the mean preoperative grip-strength value.

The average operating time was eight minutes (range 5–27 minutes). The operating time was longer than 20 minutes in 23 cases. In these cases, an ulnar transligamental motor branch of the median nerve was noted. Endoscopically, this anatomic variation appeared like a dense longitudinal synovial structure on the dorsal aspect of the transverse carpal ligament containing small vessels that were running within its substance. Verification of the existence of a neural branch was performed by touching the synovial structure with the use of a probe and as a consequence, pain was induced radiating on the thenar area. The ratio of this anatomic variation in this series was 1 per 200 cases. Two cases were converted to an open procedure due

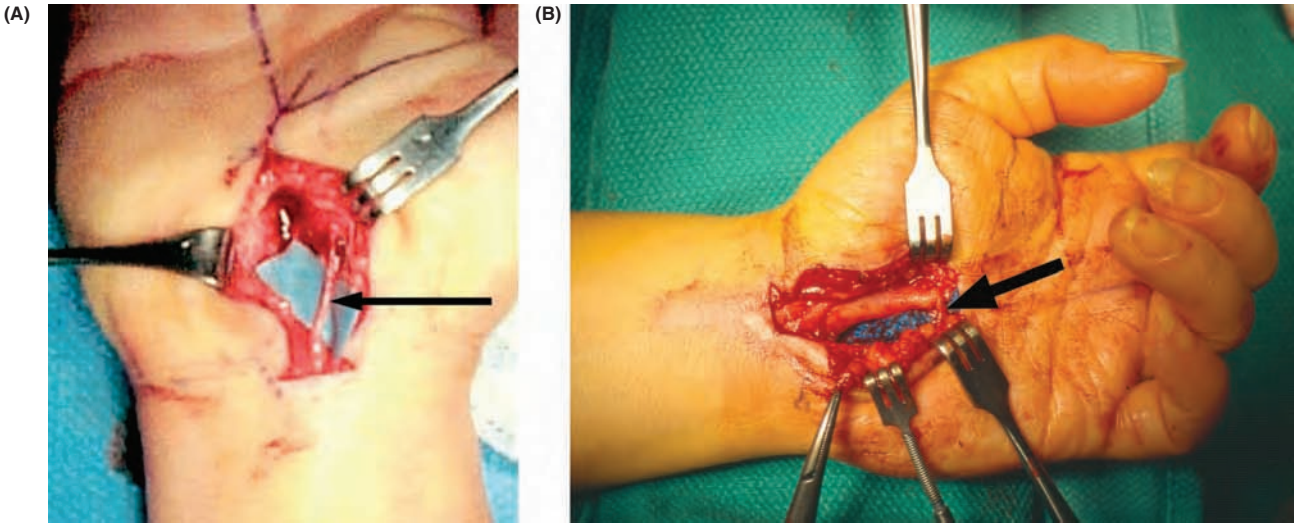

FIGURE 11 (**A**) The first of the two cases that were converted to an open procedure due to the close proximity of the motor branch of the median nerve (*long thin arrow*) to the entry portal. (**B**) In the second case, the communicative branch of the median nerve to the ulnar nerve (*short thick arrow*) was blocking the exit portal.

to rare anatomic variations in the course of median nerve. Exploration of the carpal canal revealed that the motor branch of the median nerve was extremely proximal in the first case (Fig. 11A) and the communicative branch of the median nerve to the ulnar nerve was blocking the exit portal in the second case (Fig. 11B). At the final follow-up evaluation, a total of 2990 (93.3%) hands were completely asymptomatic or had minor symptoms after endoscopic carpal tunnel release. None of the patients developed complex regional pain syndrome postoperatively.

Twenty-four cases (0.7%) were classified as failed. Of interest is the fact that four of these patients had a previous open procedure. When an open revision surgery was performed (19 cases), in four cases the carpal ligament was considered incompletely transected, and in the remaining 15 cases abundant scar tissue formation was found in the region of the previously transected carpal ligament. Eighteen cases (0.6%) were classified as recurrent. The mean time of recurrence was 20 months (range 6–70 months). Nine of these patients were engaged in heavy occupational activities that required constantly repetitive motion of their hands. Endoscopic revision surgery was performed in 11 cases.

Initially, when the transbursal approach was used and retractors were placed in a transverse manner (one at the ulnar and the other at the radial side of the surgical wound), two patients developed transient ulnar nerve palsy as a result of pressure to the ulnar neurovascular bundle. Spontaneous recovery took place within four weeks and after five months, respectively. Since that happened, retractors are placed in a longitudinal manner (one at the proximal and the other at the distal end of the wound). Neither laceration nor transection of any neural, vascular, and tendinous structure was occurred among the 3536 hands. Superficial infection in the proximal surgical wound (entry portal) was developed in three cases. Treatment consisted of oral antibiotics and local wound care.

The mean preoperative grip strength of the 635 patients who returned to the office for grip-strength testing was 243.68 N (range 19.62–588.60 N). Ninety-five patients (14.9%) regained 80% (194.95 N) of the mean preoperative grip strength within one week postoperatively, 238 (37.7%) within two weeks, 304 (47.9%) within three weeks, and 391 (61.6%) regained 80% of the mean preoperative strength in four weeks. Regarding the 1463 patients who were followed-up for their return-to-work status, seven patients (0.5%) returned to work within the first postoperative week, 381 (26%) within two weeks, 761 (52%) within three weeks, 1029 (70.3%) within four weeks, and the other 434 patients returned to work four or more weeks after endoscopic carpal tunnel release.

SUMMARY

The advantages of endoscopic over open carpal tunnel release include no hypertrophic scar or scar tenderness, no pillar pain, less compromise to the pinch or grip strength, and an earlier return-to-work and daily activities. However, the surgeon can be in front of unexpected difficulties, e.g., ganglion, neurofibroma, and neurilemmoma, that limit visualization into the carpal canal. As in any surgical procedure, safety and success are dependent upon a thorough knowledge of the anatomy of the area, adequate training, and familiarity with the use and capabilities of the instrumentation. Surgeons who are not familiarized with endoscopes and arthroscopic techniques may give rise to major iatrogenic complications.

Data gathered from the experience of past 17 years strongly indicate that, due to the preservation of normal anatomical structures of the hand, clinical results of endoscopic carpal tunnel release are better than those of the standard open procedure. Endoscopic carpal tunnel release with the Chow dual-portal technique is a reliable method of treating carpal tunnel syndrome and can be performed safely by a well-trained surgeon. Although a debate among surgeons still exists, the endoscopic release of the transverse carpal ligament has already established its position as a minimally invasive surgical technique.

SUMMATION POINTS

Indications

- Same as for open procedure
- Failure of conservative treatment
- Thenar weakness or wasting

Contraindications

- Space-occupying lesions
- Limited wrist extension
- Congenital wrist anomalies
- Any factor affecting the anatomy of the carpal canal

Advantages

- No hypertrophic scar or scar tenderness
- No pillar pain
- Less compromise to the pinch and grip strength
- Earlier return to work and daily activities

Outcomes

- 93% had complete relief or only minor post-operative symptoms
- 70% returned to work within four weeks

Complications

- Overall 2% to 3.3% complication rate
- Neuropraxia or nerve injury (1.5% to 2%)
- Flexor tendon laceration (0.2%)
- Incomplete release of transverse carpal ligament (0.2% to 0.6%)
- Hematoma (0.2%)
- Blood vessel laceration (0.2% to 0.4%)
- Reflex sympathetic dystrophy (<0.5%)

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Limited Incision Carpal Tunnel Release with the Indiana Tome

Kenneth R. Means, Jr., James P. Higgins, and Thomas J. Graham
The Curtis National Hand Center, Union Memorial Hospital, Baltimore, Maryland, U.S.A.

INTRODUCTION

Carpal tunnel syndrome (CTS) is a well-known compression neuropathy of the median nerve at the level of the wrist. Several surgical techniques have been described for the treatment of this disorder. These techniques began with the now traditional open incision procedure for release of the transverse carpal ligament (TCL) and have included varying degrees of flexor retinaculum and distal volar forearm fascia release. Recent years have seen an overall change in patient and surgeon perspective as to what defines an optimal surgical procedure. These changing expectations have led to the development of several "minimally invasive" methods in all surgical fields. The approach to carpal tunnel release has been no less affected by this shift in the general surgical paradigm.

The principles relevant to carpal tunnel release are, on the surface, quite simple. One must release all potential compression points involving the median nerve at the wrist in a safe and reliable manner. Yet, few surgical interventions for the treatment of a well-defined disorder have engendered more controversy with regard to treatment options and relative safety margins. The most recent carpal tunnel release options have endeavored to provide patients with a smaller scar, less pillar pain, and minimal postoperative functional deficit which allows rapid return to work. These goals must be combined with complete release of median nerve pressure points at the wrist while minimizing risks of permanent nerve or other structural damage. These minimally invasive procedures also attempt to achieve the low levels of recurrence that are available through conventional open release (1).

Limited incision carpal tunnel release (LICTR) with the Indiana Tome system was first described in the literature in 1996 by Lee, Plancher, and Strickland (2). The instruments needed for this method are currently available through the orthopedic products and technology company Biomet, Inc. (Warsaw, Indiana, U.S.A.). One distinct advantage of this method is that the release proceeds in a distal-to-proximal direction. This means that distal vulnerable transverse structures, such as the superficial palmar arterial arch and communicating digital nerve branches, remain distal, safely behind the field of dissection. Also, direct distal visualization allows determination of the presence or absence of a transligamentous variation of the motor branch of the median nerve.

INDICATIONS

LICTR with the Indiana Tome is indicated for patients with primary idiopathic CTS for whom nonoperative treatment options have failed to relieve symptoms to satisfaction. We do not recommend the use of this system for revision carpal tunnel release. We also emphasize caution for patients with significant anatomic alterations, such as those with major posttraumatic deformity. It is also our belief that a relative contraindication would include any patient with a suspected mass, dense median nerve motor and/or sensory deficit, or any other situation that would necessitate complete exploration of the median nerve and carpal tunnel contents. Essentially, indications and contraindications are not appreciably different from those for other minimally invasive carpal tunnel release methods.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Preoperative physical examination and work-up is no different from that obtained for standard open carpal tunnel release. Standard nonoperative treatment options should be explored prior to recommending surgical intervention, depending on the clinical severity of the median nerve compression. These may include, but are not limited to, activity modification, splinting (especially if night symptoms are prevalent), medications, and/or injections.

SURGICAL TECHNIQUE

Operating room setup is identical to routine hand procedures. We typically use local anesthesia and sedation as a minimum anesthesia requirement, though as with all cases we tailor this to the individual patient's needs. We often have our anesthesia colleagues perform intravenous regional Bier block anesthesia using a well-padded double forearm tourniquet. The surgeon should ensure that all of the necessary tools are available in the set (Figs. 1 and 2). The complete kit includes the blunt single pilot, the palmar stripper, the blunt double pilot, and the single-use Indiana Tome cutting instrument. There is also an optional tome guide.

The operative approach is based on anatomic landmarks. The first landmark is defined by visualizing a line extending proximally from the radial border of the ring finger. The second landmark is found by envisioning a line extending ulnarly from the distal edge of the thenar musculature (Kaplan's cardinal line). Where these two imaginary lines cross marks the center of the approximately 2.0 cm longitudinal palmar skin incision (Fig. 3). Dissection is carried through the skin elements to the level of the palmar fascia, with a gentle bias toward angling the dissection radially. The palmar fascia is incised slightly radial to the skin incision. This slight radial progression of dissection allows the healing skin and ligament wounds to be staggered. A small self-retaining retractor (e.g., Heiss retractor) is placed in the wound. A blunt right angle retractor (e.g., Ragnell retractor) placed in the proximal axilla of the skin incision can aid in obtaining a clear view for safe release

FIGURE 1 The single pilot, double pilot, and palmar stripper. *Source*: From Ref. 3.

of the distal TCL. Next, the distal edge of the TCL is identified. Using a scalpel, the distal edge of the TCL is incised for approximately 1.0 cm in a distal-to-proximal direction and along a line that is ulnar to the longitudinal midline of the wrist so as to avoid the underlying tendons and median nerve.

Before using the Indiana Tome preparatory instrumentation, it is possible to determine whether a transligamentous motor branch of the median nerve is present. If the origin of the thenar muscles is more ulnar than expected upon initial dissection and is in line with the path of release of the TCL, this should raise suspicion for a possible transligamentous motor branch. If this is the case, blunt scissors are used to decide whether such a branch exists and should be protected.

The blunt pilot (Fig. 4) is introduced beneath the TCL distally. The surgeon should drop the instrument handle toward the patient's hand during introduction such that the tip of the blunt pilot is angled in a volar direction, thus hugging the undersurface of the TCL. Passage of this blunt pilot should be smooth and not at all aggressive. All of the instruments should be passed longitudinally along the imaginary line extending proximally from the radial border of the ring finger. As the blunt pilot is passed, the tip will be felt as it exits the undersurface of the TCL proximally. A surgical pen is then used to mark the skin overlying the pilot tip, roughly two finger-breadths proximal to the proximal volar wrist crease (Fig. 5). This skin marking is used as a target for later instrument passes and ensures release of the TCL and the distal forearm fascia.

The palmar stripper is the next tool to be used (Fig. 6). It consists of a blunt skid, which is longer, and a sharp blade, which is shorter. The palmar stripper should be oriented such that the blunt skid will be inserted in a deeper position than the sharp blade. The blunt skid is passed under the TCL in the identical pathway as the previously passed blunt pilot, sliding along the undersurface of the TCL. This allows the sharp blade of the palmar stripper to pass superficial to the TCL and to free the dense connections to the overlying palmar fascia (Fig. 7). The palmar stripper is passed proximally until the blunt skid hits the skin target marked earlier on the volar forearm.

The double pilot is the final instrument to be passed in preparation for the cutting tome (Fig. 8). It has two blunt skids to straddle the TCL superficially and deep. The skids are slightly wider than the cutting tome, therefore preparing a pathway for smooth passage of the cutting tome (3). The double pilot is passed in the same distal-to-proximal direction, with the skids straddling the TCL, until the tip is again seen and felt at the volar forearm skin mark.

The single-use cutting tome may now be safely employed (Fig. 2). The longer blunt skid of the tome is inserted just deep to the TCL. The vertically oriented cutting blade is allowed to engage the axilla of the incision of the previously released distal edge of the TCL. Using a single, smooth, steady motion, the tome is passed proximally until the blunt skid reaches the skin mark, thus releasing the TCL and the distal volar forearm fascia. Any meeting of resistance should alert the surgeon to the

FIGURE 2 The single-use cutting tome. *Source*: From Ref. 3.

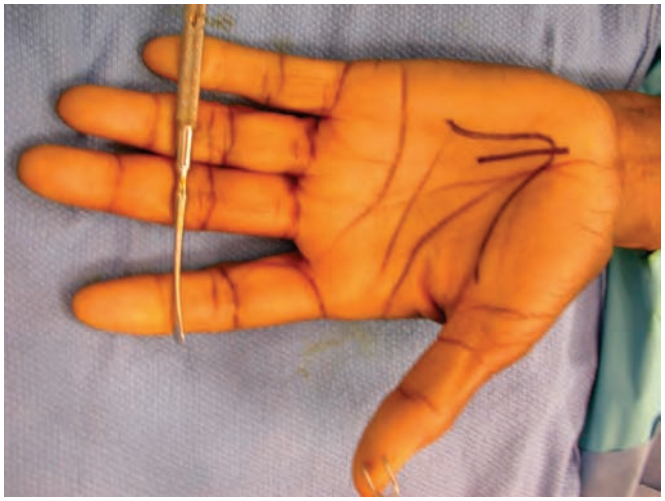

FIGURE 3 Operative markings of limited palmar incision and distal border of thenar/hypothenar arch. The curved line represents the distal margin of the pressure-bearing region of the carpal arch. The LICTR procedure maintains the integrity of this arch. *Abbreviation*: LICTR, limited incision carpal tunnel release. *Source*: From Ref. 3.

possibility that the cutting tome is drifting from the pathway defined by the preparatory instruments. Again, it is absolutely critical that the cutting tome, as with the preparatory tools, be passed along the same line visualized as extending proximally from the radial border of the ring finger.

Once the cutting tome is removed from the wound, the TCL may be inspected under direct visualization to ensure complete release. Also, the carpal tunnel can be explored to evaluate for tenosynovitis, masses, and median nerve condition (3).

For closure, tourniquet release is at the surgeon's discretion. We do not routinely let down our tourniquet prior to closure. Skin is closed with a suture of the surgeon's choice. No deep structures are repaired. A splint may be used if the surgeon desires, though we typically do not use one. Instead, we allow the patient to begin active range of motion in a postoperative soft dressing applied to the hand and wrist. Stitches are removed in one to two weeks and activities are gradually increased as tolerated. Patients may return to work when comfortable, some preferring to return even prior to the first postoperative visit if heavy labor is not part of their profession.

COMPLICATIONS

As with any procedure, complications may be divided into major and minor categories. Complications that would likely be considered minor would include superficial wound healing difficulties, superficial infections, scar sensitivity, incomplete

FIGURE 5 Marking the position of the blunt pilot tip to create a goal for orientation for subsequent instrumentation. *Source*: From Ref. 3.

symptom relief, and pillar pain. Major complications would include deep infection, wound dehiscence, and nerve, tendon, or arterial vessel injury. If these problems are encountered, standard treatments may be implemented as they are for open carpal tunnel release postoperative complications. The outcomes section below discusses published series that define complication rates with the LICTR system. As mentioned above, the most effective manner of eliminating iatrogenic damage to major structures is to follow the steps as outlined. If a technical impasse is encountered during the procedure, the surgeon must recognize the situation and either correct it so that the technique may proceed or transition into a complete open carpal tunnel release. As with any "minimally invasive" technique, we discuss with patients preoperatively the possibility of conversion to a larger exposure open procedure if obstacles arise.

OUTCOMES

Literature reports regarding outcomes and complications for the range of carpal tunnel release procedures vary widely. Resolution of preoperative symptoms with LICTR using the Indiana Tome has been comparable to those obtained with open or endoscopic carpal tunnel release. Several studies have presented preoperative symptom resolution rates over 90% with LICTR using the Indiana Tome (4–7). Recurrence rates with LICTR have likewise been similar to those obtained with other carpal tunnel release options. Yung et al. reported no recurrences requiring repeat operation in 58 LICTRs after one to two years (4). Botte et al. described a 1% to 11% recurrence rate for traditional open release procedures necessitating

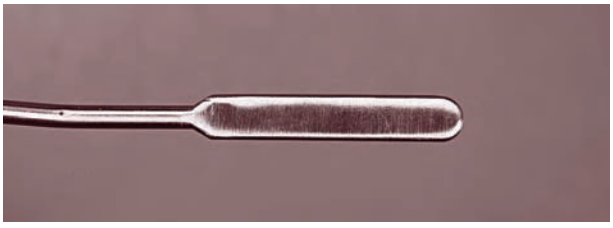

FIGURE 4 The blunt pilot. *Source*: From Ref. 3.

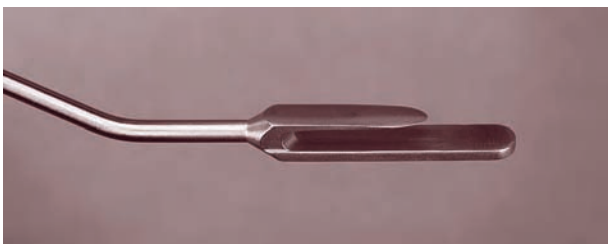

FIGURE 6 The palmar stripper. *Source*: From Ref. 3.

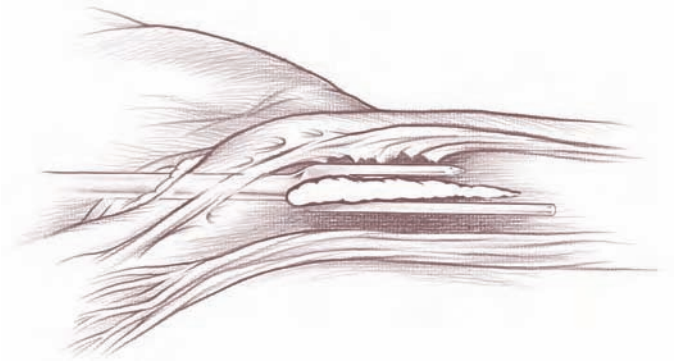

FIGURE 7 Using the palmar stripper, the TCL is dissected free of its dense connections with the overlying palmar fascia. *Abbreviation*: TCL, transverse carpal ligament. *Source*: From Ref. 3.

reexploration (8). Interestingly, they noted multiple studies in which the most common cause for recurrence was incomplete sectioning of the distal portion of the TCL. The LICTR with the Indiana Tome starts at the most distal aspect of the TCL, thus minimizing this potential cause for recurrence or incomplete symptom resolution while still allowing release of the distal antebrachial fascia (2).

The most recent study regarding LICTR found that pillar pain was present in 21% at three months, and 9% at one year (4). This is similar to a previous report which found that pillar pain and scar tenderness were present in 14% at three months following LICTR (5). These rates compare favorably with those described for endoscopic CTR and open CTR (9,10). Many of the difficulties in determining the incidence of pillar pain for different procedures come from the numerous definitions and criteria for its diagnosis that exist (9).

As with all surgical interventions, every possible route to carpal tunnel release has had reports of iatrogenic damage to structures. In Lee and Strickland's report of 694 LICTRs, there were two (0.29%) cases of median nerve laceration, one with partial injury and one with complete transection (2). These two events occurred early in their usage of the Indiana Tome and prompted a change in their release protocol in which more than one pass with the cutting tome is not allowed. There is also a case report of median nerve transection using the LICTR Indiana Tome (11) following a single pass with the cutting tome. In this case, it was felt that injury may have occurred by allowing the cutting tome to drift in a radial direction, based on the orientation of the transection at the time of exploration. The authors reference a biomechanical cadaver study by Gutow that showed 15° or more of radial deviation of the cutting tome led to median nerve injuries in 50% of their specimens. Conversely, keeping the tome in line with the long axis of the ring finger, as described in this chapter, led to no nerve or tendon lacerations (12). Atik et al. performed a cadaver investigation that confirmed a "safe zone" in line with the middle/ring finger axis for limited incision release procedures (7). They also established that working in a distal-to-proximal direction enhances the safety of these surgical interventions.

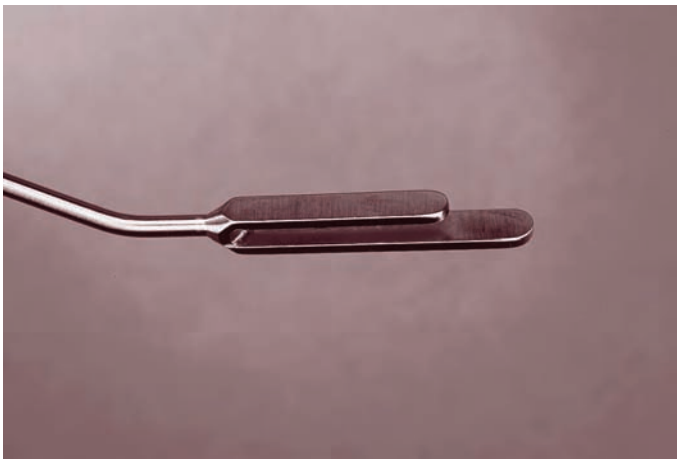

FIGURE 8 The double pilot. *Source*: From Ref. 3.

Palmer et al. found in a prospective, nonrandomized trial of 211 carpal tunnel releases that ulnar nerve parasthesias developed in 10% of Agee single portal endoscopic carpal tunnel release (ECTR) patients, 13% of Chow double portal ECTR patients, and 10% of open release patients (10). They had no instances of nerve, vessel, or tendon lacerations with any of the techniques used. In a prospective, randomized comparison of 192 hands using either the Agee single portal ECTR or standard open release, Trumble et al. showed better results for the first three months in the ECTR group (13). There was no significant difference in complication rates or cost between the two methods. Boeckstyns and Sorensen did an analysis of published series concerning endoscopic and open carpal tunnel release (14). They determined that ECTR had an increased risk of transient nerve disturbances (4.3%) over open releases (0.9%) in prospective randomized studies. However, their report also showed that the rate of permanent nerve damage following ECTR was equivalent to that for open release (0.3% vs. 0.2% respectively). They stressed, nevertheless, that the potential devastating complications of ECTR must be avoided by proper training and conversion to open release when there is poor visibility with the endoscope.

In a survey of members of the ASSH, Palmer and Toivonen noted a surprisingly high number of median, ulnar, and digital nerve lacerations as well as vessel and tendon lacerations which surgeons had reported following open and endoscopic carpal tunnel releases that either they had performed or they had explored following referral from institutions outside of their own (15). Out of 616 responses regarding open release, there were 230 nerve, 34 vessel, and 19 tendon lacerations. The authors concluded that carpal tunnel release regardless of technique may not be as safe as previously thought and that surgeons must be "ever mindful of structures that lie within the carpal tunnel."

We are aware of a single report comparing ECTR and LICTR with the Indiana Tome. Wong et al. investigated 30 patients with bilateral CTS in a prospective, randomized fashion (16). Patients were randomly assigned to have one side treated with the modified Chow two-portal ECTR technique and the opposite hand with the LICTR method, or limited open carpal tunnel release (LOCTR), as it is referred to in the article. The investigators found statistically significant less early postoperative pain and less pillar symptoms for those in the LOCTR group. At one year, these differences did not persist. At eight weeks postoperatively, there was a notable patient preference for the LOCTR procedure. This predilection for LOCTR showed only a trend at six months to one year postoperatively. There were no major complications in either group.

SUMMARY

Overall, LICTR with the Indiana Tome is as effective and as safe as other minimally invasive practices for carpal tunnel release. It is a relatively straightforward skill to learn and may be reliably reproduced. Future studies will no doubt help to elucidate the most successful, safest, and most cost-effective means of carpal tunnel release. However, as with most surgical endeavors, there likely will remain room for individual surgeons to decide what application works best in their hands. We feel the LICTR combines the reduced postoperative pain and rapid recovery of other minimally invasive systems with the safety and low cost of traditional open release.

SUMMATION POINTS

Indications

- Primary idiopathic CTS.

Outcomes

- Comparable to open and other minimally invasive procedures.

Complications

- Similar to open and other minimally invasive techniques.

However, significant nerve or other structural injuries are possible if the surgeon is not properly trained in the technique.

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Minimally Invasive Carpal Tunnel Release Using the Security Clip™

James W. Strickland and Lance A. Rettig
Department of Orthopedic Surgery, Indiana University School of Medicine, Indianapolis, Indiana, U.S.A.

INTRODUCTION

Carpal tunnel syndrome (CTS) results from irritation of the median nerve at the level of the wrist (1). Any process that increases the contents of the carpal canal can lead to higher interstitial pressure and compression of the median nerve (2,3). Treatments are designed to increase the space available for the nerve. First line treatment includes splinting the wrist in a neutral position. Kuo, utilizing ultrasound studies, demonstrated that positioning the wrist in neutral lowers compression of the median nerve (4). Additional non-surgical treatment options include steroid injection, activity modifications, tendon gliding exercises and the administration of anti-inflammatary medications (5).

When symptoms are recalcitrant to conservative management surgical intervention is indicated. The goal of surgery is to decompress the median nerve in the carpal tunnel by transecting the deep transverse carpal ligament (TCL). Surgical options include open or endoscopic division of the TCL. Open techniques are performed through a longitudinal incision in the proximal palm with or without extensions across the wrist. Dissection is carried out until all or part of the TCL has been exposed. The entire ligament is then carefully transected.

Limited or short palmar incisions have evolved because these methods are thought to result in reduced morbidity compared to more extensive approaches that violate all tissue planes over a greater distance. Decreased palmar sensitivity or pillar pain may be reduced in a carpal tunnel released with a limited incision (6). Instrumentation has been developed to allow for safe division of the TCL through a small incision (7). Design changes have taken place to decrease the chance of median nerve injury. The Security Clip™ (Biomet, Warsaw Indiana, U.S.A.) was designed as a method of enclosing the ligament before passing the transecting knife in order to prevent any adjacent structures from entering the cutting path.

INDICATIONS

Patients whose CTS symptoms are unresponsive to conservative treatment after two to three months may be considered for operative release using the Security Clip or a standard open incision. Contraindications for the Security Clip include patients with a known palmar carpal canal mass, previous displaced wrist fracture, or any other condition that may have altered wrist morphology. A relative contraindication is a patient requiring concomitant open palmar flexor tenosynovectomy.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Physical exam findings, symptoms, and neurodiagnostic tests are all helpful in the diagnosis of CTS. CTS must be differentiated from a more proximal median nerve compression such as cervical radiculopathy or pronator syndrome.

Phalen's maneuver and median nerve compression test can help localize embarrassment of the median nerve at the wrist level (8). Abnormally expanded two-point sensory exam and thenar muscle wasting suggests chronic and severe compression of the nerve. Nerve conduction and electromyographic studies are the principle objective tools used to evaluate CTS (9). These tests can also be helpful in clinical staging of CTS.

SURGICAL TECHNIQUE

Carpal tunnel release (CTR) with the Security Clip system is performed as an outpatient using local, regional, or general anesthesia. Instruments required for the procedure include a hand set, a small Holzheimer type self-retaining retractor, the soft tissue preparatory instruments, the Security Clip and the disposable blade that tracks in the Clip. The patient is placed supine on the operating table. A well- padded tourniquet is placed around the brachium. The operated arm is then placed on a hand table.

Ten to Fifteen cc's of 1% local anesthesia without epinephrine are placed into the midline of the proximal palm and across the wrist and distal forearm. Additional anesthetic is administered into the deeper tissues palmar to the TCL. Three to five cc's of local anesthetic should also be placed within the carpal canal staying ulnar to the midline to avoid injury to the median nerve.

The landmarks for the surgical incision are the distal border of the thenar muscles and the radial border of the ring finger. A line is drawn over the proximal extent of the TCL in line with the longitudinal axis of the radial border of the ring finger. A second line is drawn diagonally from the proximal thenar musculature. The point of intersection of the two lines approximates the most distal edge of the TCL (Fig. 1). The skin incision is approximately 1.5 cm in length. It is designed to be about two-thirds proximal and one-third distal to the extended thenar muscle line.

The arm is elevated briefly or an Esmarch wrap is utilized and the tourniquet usually inflated to 250 mmHg. The skin is incised down through the palmar fascia. A self retaining retractor (Holtzheimer or Biomet CTR retractor) is positioned in the wound. The Biomet (Biomet, Warsaw, Indiana, U.S.A.)

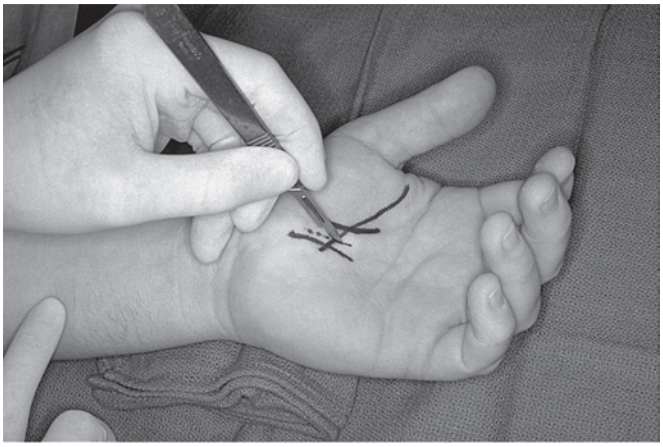

FIGURE 1 Landmarks for the surgical incision. The incision is about two-thirds proximal and one-third distal to the extended thenar muscle line and slightly ulnar to the midpoint between the two creases.

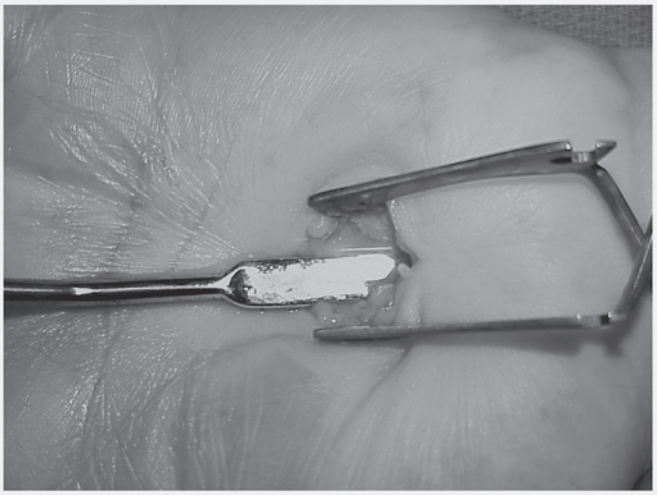

FIGURE 3 The blunt pilot is passed beneath the carpal ligament.

retractor has a slight palmar bend which is helpful for the slightly extended wrist. The retractor is gradually deepened by pushing the tissue walls away with an elevator and repositioning. The proximal component of the Biomet retractor or a Ragnell retractor is utilized to retract the soft tissue proximally exposing the leading edge of the TCL. With careful dissection within the distal portion of the carpal canal, anomalous or penetrating branches of the recurrent motor branch of the median nerve are identified. The superficial palmar arterial arch is usually visualized and easily protected throughout the procedure.

When the distal portion of the TCL has been identified a scalpel blade is then used to longitudinally divide the distal ulnar 1.5 cm of the ligament under direct vision (Fig. 2). Three instruments are utilized to clear any tissues adherent to the TCL. The first instrument the blunt single pilot, has a smooth edge and flat plane (Fig. 3). The purpose of the tool is to create a clear plane between the ligament and the underlying contents of the carpal tunnel. The pilot is placed just deep to the "V" shaped notch created by incising the distal 1.5 cm of the TCL. The instrument is passed from distal to proximal deep to the ligament. The pilot and all subsequent instruments must be directed slightly ulnarward to avoid injury to the radially vectored median nerve.

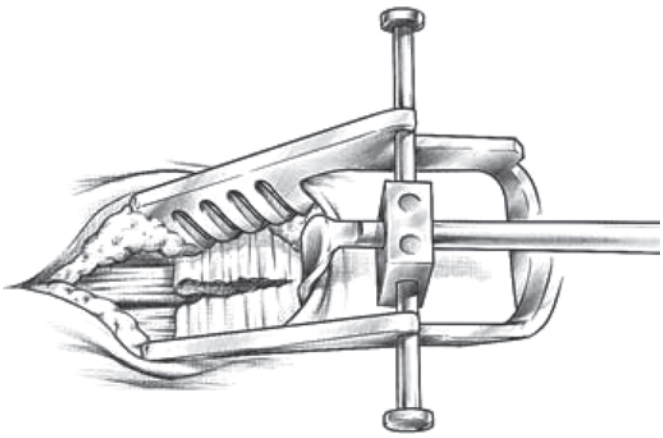

FIGURE 2 Incision of the distal 1.5 cm of the transverse carpal ligament under direct vision. The specially designed, three-sided Biomet retractor facilitates exposure.

After removal of the pilot, the palmar stripper is placed into the wound. It is a double sided instrument with a blunt lower skid and a sharpened upper edge 15 mm in length (Fig. 4A). The tool is designed to prepare a channel through the dense connective tissue immediately palmar to the ligament. The distance between the two skids is 3 mm approximating the thickness of the ligament at its distal third. This allows the instrument to straddle the ligament as it is passed from distal to proximal. Under direct visualization, the tool is inserted into the notch created by distal division of the ligament. The lower skid is placed deep to the ligament and passed proximally. The sharper shorter upper skid will pass palmar to the ligament. The stripper is passed until the blunt center post meets the edge of the "V" shaped defect of the ligament (Fig. 4B). After withdrawing the palmar stripper, the double pilot is introduced. The tool has long blunt upper and lower skids (Fig. 5A). There are no sharp edges on the skids which could injure surrounding anatomical structures. The double pilot enters the "V" notch created by the incision in the distal ligament. It straddles the ligament and is passed proximally to establish a pathway for the Security Clip. The tool is passed until the blunt center post is fully engaged against the distal edge of the ligament (Fig. 5B). It is critical that the instruments are passed sequentially using the same ulnar vector. All instruments are moistened prior to passage to provide better sliding characteristics. If some difficulty is encountered when passing the double pilot, it may be passed several times in a slightly different direction to be sure that there is an adequate channel for Security Clip passage.

The Security Clip is designed to protect the soft tissues on both the palmar and dorsal sides of the ligament. The lower skid has the same length as that of the double pilot. An upper skid is present which converges on the lower skid terminally (Fig. 6A). The distance between the proximal end of the clip and the terminal closure of the upper skid is 3.5 cm. With this configuration, the Security Clip straddles the ligament creating a closed system that is consistent with the usual morphology of the TCL; thin proximally and thicker distally. Prior to passing the Security Clip, a stylus is introduced into its central track creating a 3 mm separation between the lower and upper

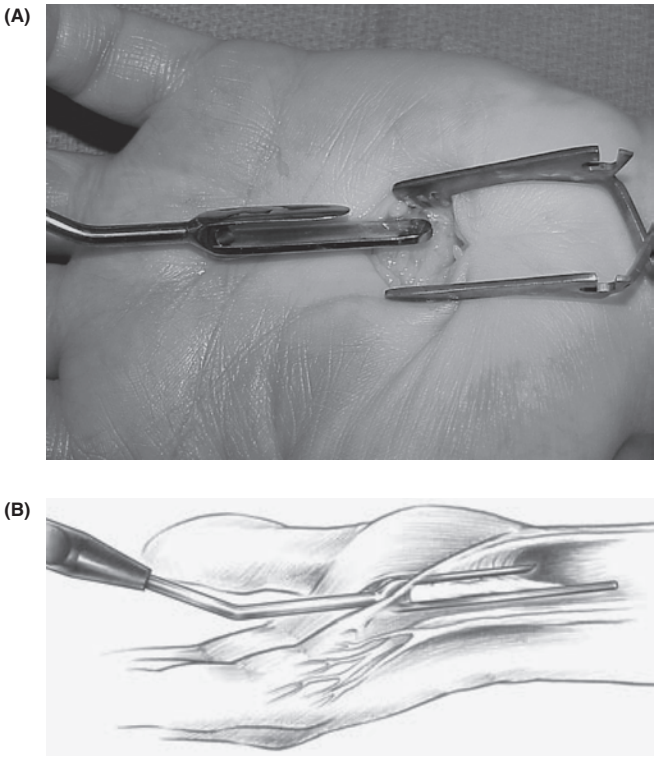

FIGURE 4 (**A**) The configuration of the palmar stripper with its short sharp upper component and long blunt lower skid. (**B**) Drawing of completed passage of the palmar stripper after it has prepared a channel through the dense palmar connective tissue.

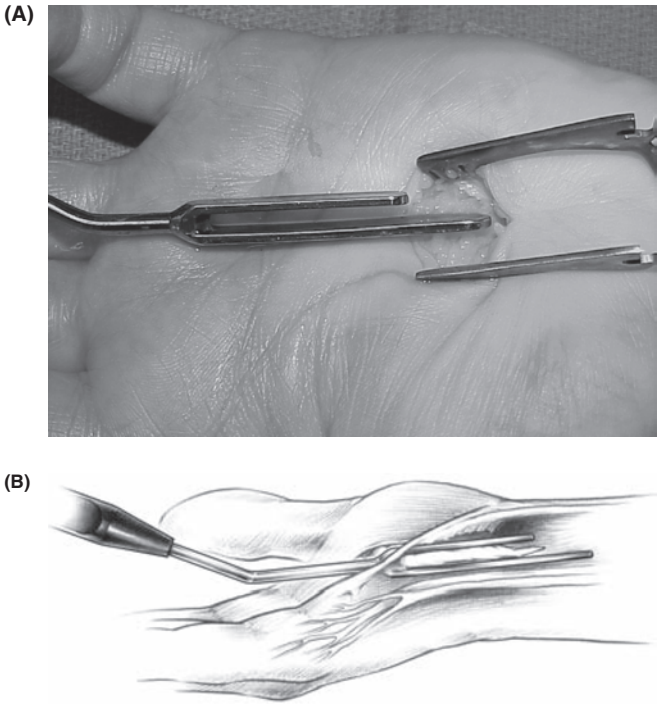

FIGURE 5 (**A**) Introduction of the double pilot with its blunt upper and lower skids. (**B**) Drawing of completed passage of the double pilot with the skids straddling the transverse carpal ligament.

skids (Fig. 6B). This facilitates positioning of the Security Clip into the prepared channel across the ligament. As the assembly is advanced from distal to proximal across the TCL the stylus will automatically be backed out by the edge of the ligament, and the distal tips of the instrument will close together on the ligament (Fig. 6C). When fully seated, the Security Clip will contain the entire TCL between its skids and all other adjacent tissues will be safely out of harm's way (Fig. 6D).

With the Security Clip straddling the ligament a disposable blade is inserted into the track of the device and passed from distal to proximal between the upper and lower skids (Fig. 7A). The blade is passed down the Security Clip completely dividing the TCL. The upper and lower skids serve to protect the tissues dorsal and palmar to the ligament. Advancement of the blade continues until the disposable device fits flush with the Security Clip (Fig. 7B,C). Once the blade is fully seated, it is withdrawn. The Security Clip is then removed from the wound.

The soft tissues are carefully retracted proximally to confirm complete decompression of the TCL. A Freer elevator may also be used to confirm the interval between the transected edges of the TCL. Hemostasis is achieved with bipolar cautery. The wound is irrigated and the skin closed with 5.0 non-absorbable horizontal mattress sutures. A well padded dressing is applied with the fingers left free for full motion and the tourniquet is deflated.

■ POSTOPERATIVE REHABILITATION

Early digital range of motion is encouraged within the confines of the dressing.

At 10 to 14 days following surgery, the sutures are removed and active range of motion of the wrist is initiated. Motion and strengthening exercises are begun at two to four weeks post-operation. At one month, patients are permitted to start wrist strengthening and return to moderate activities. In most cases, patients are able to return to work related activities including heavy labor vocations at six weeks.

■ COMPLICATIONS AND THEIR MANAGEMENT

The overall complication rate of open CTR is estimated to vary between 2% and 10% (10–12). Reported complications include: median, ulnar, and digital nerve lacerations, vessel and tendon injuries (13). Although the Security Clip is designed for protection of the surrounding anatomical structures, the possibility of median nerve injury still exists. There are two important technical tips to help minimize the risk of median nerve injury. No instrumentation should be passed until the distal portion of the TCL is well visualized and divided. The pilots and the Security Clip should always be angled slightly ulnar to the midline when passed from distal to proximal.

If at any time there is concern regarding the possibility of nerve injury then the limited palmar incision should be extended proximally for exploration. CTR utilizing a standard incision should be performed if an anomalous branch of the median nerve or an intracarpal ganglion cyst is discovered at the time of the operation.

Occasionally, some resistance may be noted while attempting to pass the Security Clip. In these cases, the steps of ligament preparation are repeated with passage of the palmar stripper and double pilot. Once again the Security Clip is passed making sure to maintain the same passageway and direction created by the pilots. If necessary, the skin incision may be lengthened proximally for a short distance and the incision into the distal TCL extended proximally.

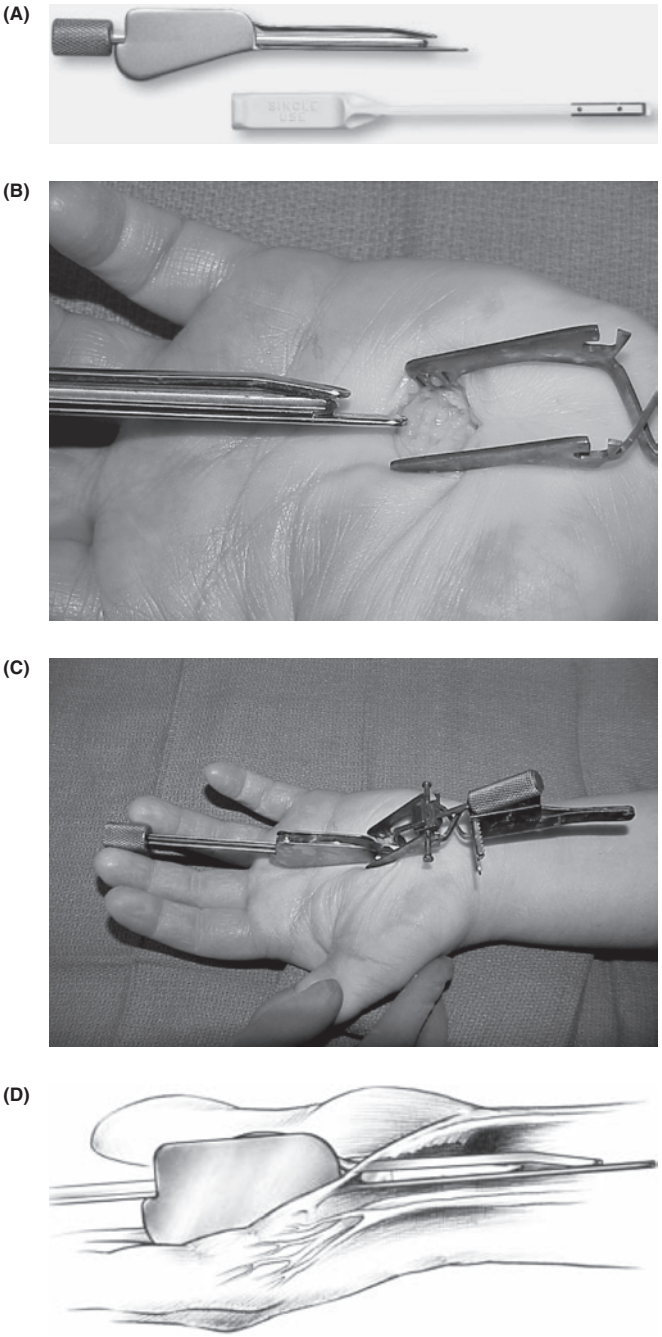

FIGURE 6 (**A**) The appearance of the Security Clip with the stylus in place (*upper*). The disposable blade fits into the midline of the Clip device. (**B**) The Security Clip with the stylus in place is passed from distal to proximal, positioning the lower skid deep into the transverse carpal ligament. (**C**) As the Security Clip is fully seated the stylus is automatically backed out of the device. (**D**) Drawing of the Security Clip fully engaged with the TCL contained between the upper and lower skids.

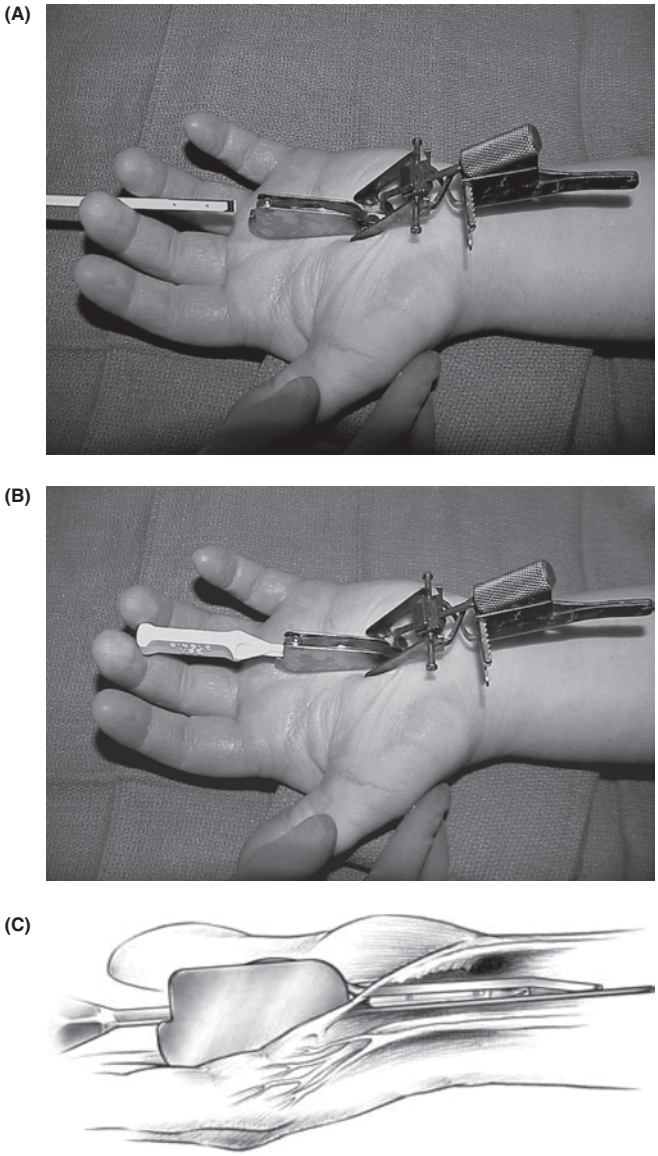

FIGURE 7 (**A**) The disposable blade is positioned into the clip and passed distal to proximal between the upper and lower skids. (**B**) Advancement of the blade continues until it is fully seated within the Security Clip. (**C**) Drawing of the Security Clip with the disposable blade fully seated within the device. The blade is positioned between the upper and lower skids protecting the surrounding tissue. The transverse carpal ligament has been transected at this point.

OUTCOMES

Previous published results of CTR utilizing a limited incision technique have demonstrated good relief of symptoms with minimal risk of nerve injury (6,7,14). Proposed advantages of using a limited incision are decreased pillar tenderness and earlier return to work or avocational activities (6,7). Hallock found similar results when comparing the mini-open technique to the endoscopic CTR (15). We have performed over 500 CTRs utilizing the Security Clip device. A single patient was thought to have sustained a digital nerve partial laceration. Postoperatively, the patient was found to have expanded two-point discrimination over the distribution of the ulnar digital nerve of the middle finger. The amount of pillar tenderness and time to return to activities has compared favorably with open CTR using a limited palmar incision (6,7,14).

SUMMARY

Open CTR through a limited open incision using the Security Clip is an effective device for complete division of the TCL. The

upper and lower skids protect the adjacent anatomic structures to allow for safe transection of the ligament.

SUMMATION POINTS

Indications

- CTS based upon physical exam and/or electrical studies with recalcitrant symptoms following conservative management.

Outcomes

- 92% achieve near complete relief of preoperative symptoms
- 6% improved but symptoms still present
- 2% unchanged
- Only slight pillar soreness noted at six to eight weeks
- Return to most activities at six weeks (7)

Complications

- Median, digital, ulnar nerve injury
- Tendon/arterial laceration

FUTURE DIRECTION OF TECHNIQUE

Instrumentation should continually be developed to increase the safety margin for release of the TCL. Refinements in the technique described here will include design changes to improve the ease of instrument passage and methods to better confirm the complete division of the TCL.

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Endoscopic Carpal Tunnel Release: Agee Technique

Emran Sheikh
Department of Orthopedics and Plastic Surgery, Rothman Institute, Thomas Jefferson University, Philadelphia, Pennsylvania, U.S.A.

Ednan Sheikh
Department of General Surgery, New York Presbyterian Hospital/Weill Cornell Medical Center, New York, New York, U.S.A.

Virak Tan
Department of Orthopedics, The New Jersey Medical School, University of Medicine and Dentistry of New Jersey, Newark, New Jersey, U.S.A.

INTRODUCTION

Carpal tunnel syndrome (CTS), or median nerve compression at the wrist, is the most common peripheral compressive neuropathy of the upper extremity with an overall prevalence of 1% to 5% in the United States (1–3). Prevalence estimates for the industrial population range as high as 15% (4–6), whereas the annual incidence of CTS is 1.0 to 3.46 per 1000 person years in the general population (6–9). CTS is most common in middle-age, occurring more often in women than men (10,11). Increased body mass index has also shown to be correlated with CTS risk (12).

At the wrist, the transverse carpal ligament (TCL) extends across the volar aspect of the carpus to create a space termed the carpal tunnel or carpal canal. Normal anatomical structures traveling through the carpal tunnel include nine digital flexor tendons and the median nerve. As pressure increases within the carpal tunnel, the median nerve is more prone to compression than the tendons (9,13). This pressure increase has a variety of etiologies, including positional variations (wrist extension or flexion) (3), hamate hook variations (14), and space-occupying lesions. Proximal nerve compression, general health issues, and comorbidities may make the median nerve more prone to increases in carpal tunnel pressure. Double crush phenomenon etiologies include, thoracic outlet compression, smoking, and diabetes mellitus (15). At a pressure threshold of 20 to 30 mmHg, epineurial blood flow to the median nerve is decreased (16). With prolonged and compromised blood flow, carpal tunnel symptoms and pathology advances.

Work-related risk factors for carpal tunnel are not clear, as there is literature supporting opposite conclusions. De Krom et al. concluded that although activities with a flexed or extended wrist carry a higher risk of CTS, typing was not associated with an increased risk of CTS (3). Repetitive tasks in the work industry are not clearly associated with the development CTS (12). Reports have shown that the meat-packing and poultry processing industries have the highest rates followed by the garment and automobile assembly industries, while clerical workers have a much lower rate (6). Although a myriad of conditions contribute to the nerve compression of CTS, the final symptomatology may be similar: paresthesias in the median nerve distribution, heaviness of the hand and/or wrist, nocturnal awakening, and even, pain and weakness. Sensory disturbances are often reversible and result from early compression. However, motor symptoms and signs may herald irreversible damage from advanced compression. Pain is due to direct physical damage to the nerve rather than early compression.

Advanced CTS with thenar wasting or intractable symptoms is addressed with surgical division of the TCL, thus reducing pressure on the median nerve (17,18). Learmonth is credited with the first open carpal tunnel release (CTR) in 1929 and was later popularized by Phalen in the 1950s (19). Classically, CTR is performed by an open technique. In attempts to reduce recovery time and risks such as pillar pain, modifications of the classic open CTR have centered on reducing incision size. However, despite the smaller incisions, recovery and risks were similar (20). A meta-analysis of the literature by Boeckstyn concluded that the risk of nerve injury to be 0.2% for open CTR (21).

With the advent of fiber optic technology, endoscopic carpal tunnel release (ECTR) techniques were developed as minimally invasive procedures for dividing the TCL. Initially, ECTR utilized a two-portal technique, which had a higher incidence of complications at the distal portal site (22,23). In 1992, Agee et al. (24) reported on endoscopic release using a single-portal approach where the endoscope, light source, and blade system are unified within the same instrument to allow visualization of the TCL, thereby increasing the safety. The focus of this chapter is to discuss the Agee technique for ECTR.

INDICATIONS

The general indications for surgical treatment (whether endoscopic or open) for CTS are failed conservative management and advanced stage with thenar atrophy or weakness. There are instances when ECTR should not be carried out, such as in cases where synovectomy or biopsy is needed. Although data has shown some success for ECTR for recurrent CTS after prior open release, this data is limited (25). Therefore, revision CTR, regardless the primary mode of release (open or endoscopic), may be best approached by an open release because neurolysis of the median nerve may also be necessary (26). Other relative contraindications for ECTR include calcified tendinosis, hamate hook fractures, and congenital anatomic anomalies.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

See discussion in Chapter 36.

SURGICAL TECHNIQUE

A standard surgical setup for wrist procedure is used with the patient supine and the arm abducted on a hand table. The instruments (MicroAire Surgical Instruments, Charlottesville, VA) are opened and assembled on a sterile field (Figs. 1 and 2). Surgery is usually performed with intravenous sedation and local anesthetic under tourniquet. Care is taken to use the local anesthetic for only cutaneous and subcutaneous injection at the site of proximal wrist crease incision. Injection within the carpal tunnel and deep into the antebrachial fascia is avoided because it can lead to fogging of the camera lens and poor endoscopic visualization.

After surgical markings and inflation of the tourniquet, a transverse skin incision is made within the long axis of the ring finger metacarpal (Fig. 3). The antebrachial fascia is divided in transverse fashion. The distal margin of the fascia incision is used for traction to allow initial blunt dissection between the synovium and undersurface of the antebrachial fascia, permitting entry into the carpal tunnel. A Hamate Finder is introduced through the incision into the carpal canal, deep into the TCL and radial to the hook of the hamate (Fig. 4). Gentle serial passes with the Hamate Finders can be done to prepare the path. The undersurface of the TCL is then cleared of synovial tissue with the Synovium Elevator. This step is performed blind but guided by knowledge of surgical anatomy and tactile feedback. Adequacy of dissection can be determined by feeling the "ridges" on the undersurface of the TCL. At this point, the endoscope is inserted (Fig. 5).

The majority of times, the endoscope can be inserted without resistance. If resistance is met, this may be addressed with further dissection with the Synovium Elevator and serial insertion of the Hamate Finders. Confirmation of adequate exposure of the undersurface of the TCL is made with direct endoscopic visualization. Light intensity is set to allow discrimination of the transverse ridges of the deep surface of the TCL. Inadequate or too much brightness will lead to suboptimal ability to discern any crossing structures, including anomalies of the motor branch of the median nerve. The endoscope can be used to bluntly push tissue away for better visualization.

FIGURE 2 Assembly of handpiece, endoscope, and disposable blade. *Source*: Courtesy of Virak Tan, MD.

Several options are available to create a clear path before incision of the TCL. Slight rotation of the endoscope in an ulnar direction can increase the distance from the median nerve or anomalous motor branch. Cautious blunt dissection with the endoscope by scraping away the synovium may increase visualization. Simple removal and reinsertion of the endoscope while providing traction on the distal antebrachial fascial edge at the site of incision may allow clearance of tissues (fat and synovium) from the endoscope line of sight. Finally, the subfascial path at the level of the antebrachial fascia should be well dissected to allow the Synovium Elevator to be inserted deep into the fascia at the level of the incision. Deliberate dissection at the undersurface of the fascia and TCL is necessary to allow optimal exposure.

Once the TCL undersurface is well-exposed (Fig. 6), the trigger on the Handpiece is pulled to deploy the blade at the end of the Disposable Blade Assembly. The distal margin of the ligament is divided first which allows the surgeon to assess the thickness of the TCL and to verify the distal extent of the true carpal ligament. The cross-section is often obvious in

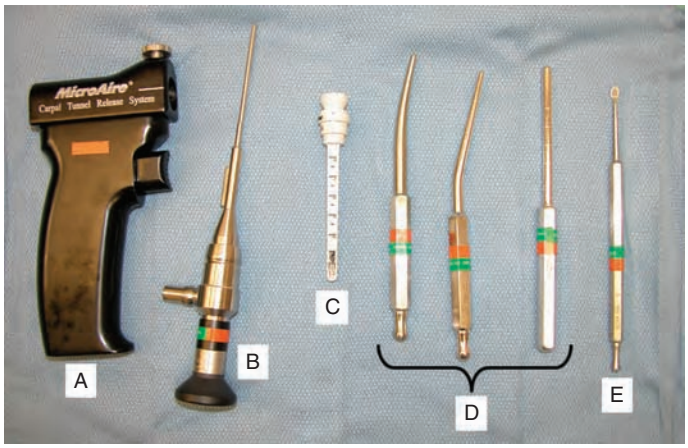

FIGURE 1 MicroAire instruments for Agee endoscopic carpal tunnel release technique. (A) Handpiece, (B) standard endoscope, (C) Disposable Blade Assembly, (D) Hamate Finders, and (E) Synovium Elevator. *Source*: Courtesy of Virak Tan, MD.

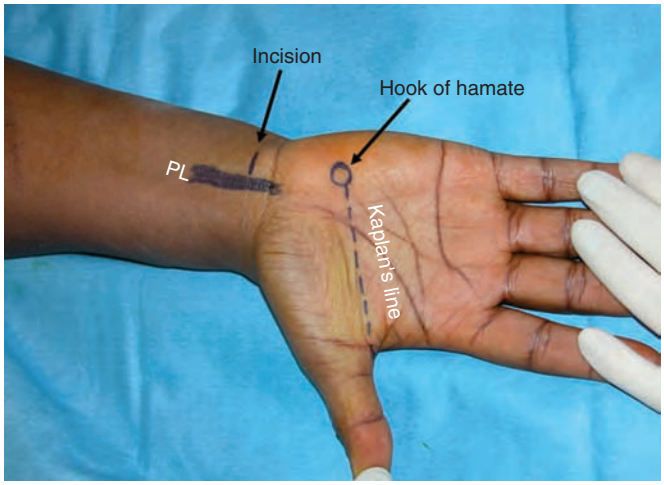

FIGURE 3 Surgical markings for Agee technique of endoscopic carpal tunnel release. *Source*: Courtesy of Virak Tan, MD.

FIGURE 4 Introduction of the Hamate Finder into the carpal canal, staying deep into the transverse carpal ligament and radial to the hamate. *Source*: Courtesy of Virak Tan, MD.

defining the distal TCL. Thereafter, serial, distal to proximal, division of the ligament is carried out. The surgeon's contralateral hand is used to position the wrist and provide external counter-pressure to juxtapose the endoscope blade with the undersurface of the TCL. The TCL is divided by engaging the blade on the undersurface of the ligament and slowly withdrawing it proximally. Complete division of the ligament is confirmed with protruding fat or visualization of the palmaris brevis muscle (Fig. 7). Division of the muscle is not needed as it adds to postoperative pain and prolongs recovery. Engaging the blade too deeply may result in injury to the palmaris brevis, intramuscular vessels, cutaneous nerves within the palm, or even the ulnar neurovascular bundle. After endoscope removal, another centimeter of antebrachial fascia can divided proximal to the incision under direct visualization with tenotomy scisscors, as warranted. Often this proximal antebrachial fascia can result in persistent carpal tunnel symptoms, especially after minimally invasive or short-incision open CTR.

At the end of the procedure, the tourniquet is deflated. Any bleeding can be controlled with manual pressure applied to the area of surgery for five minutes while elevating the hand above the level of the heart. Remaining cutaneous bleeding at the incision site may be controlled with bipolar electrocautery.

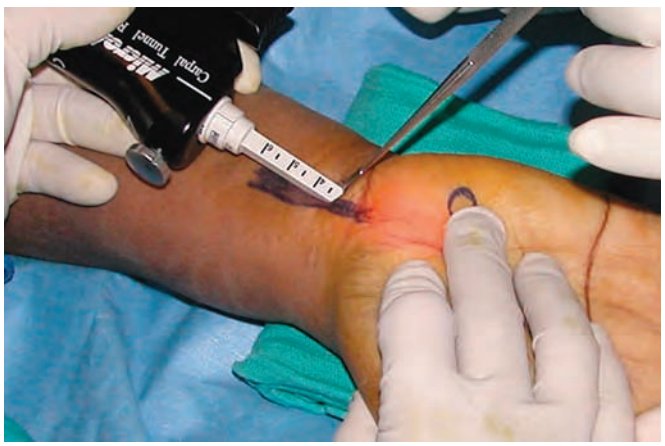

FIGURE 5 Insertion of the assembled endoscope into the carpal tunnel. *Source*: Courtesy of Virak Tan, MD.

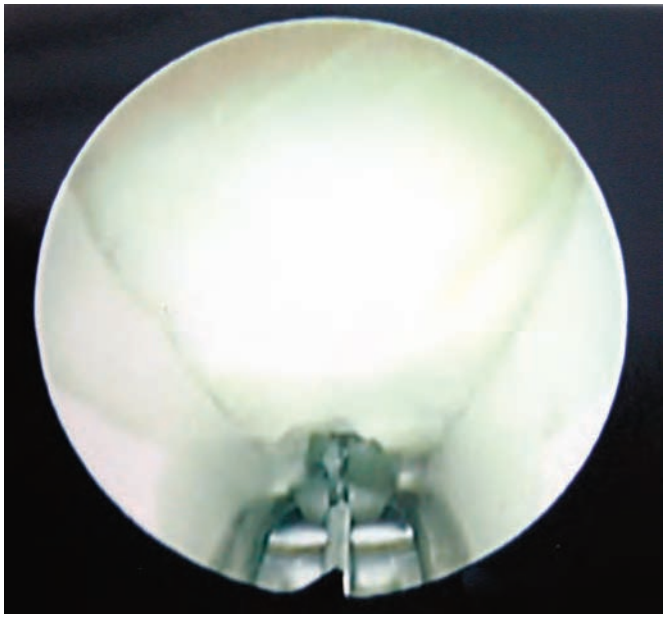

FIGURE 6 Endoscopic visualization of the undersurface of the transverse carpal ligament. *Source*: Courtesy of Virak Tan, MD.

The wound is irrigated and bupivicaine injected around the incision. Skin is closed in a simple, single-layered fashion. A soft dressing is applied.

Postoperatively, the patient is encouraged to use the hand immediately for light tasks such as handling paper or holding a cup. The surgical dressing is removed after twenty-four hours. At two weeks, the patient may carry up to ten pounds. The patient is allowed to return to work between 10 and 14 days with the above restrictions. Full, unrestricted activity is allowed at four weeks and the patient is also instructed on scar massage.

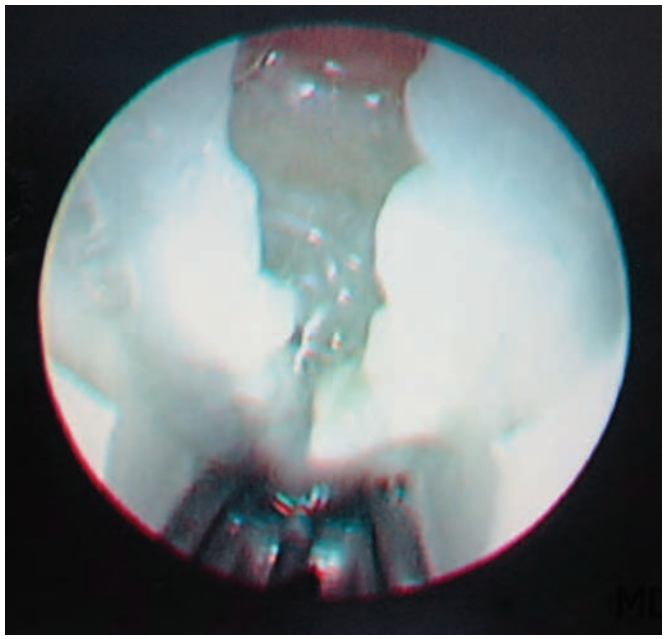

FIGURE 7 Endoscopic visualization after division of the TCL, showing a gap between the two ends. The subcutaneous fat and palmaris brevis muscle can be seen superficial to the divided TCL. *Abbreviation*: TCL, tranverse carpal ligament. *Source*: Courtesy of Virak Tan, MD.

COMPLICATIONS AND THEIR MANAGEMENT

As with any arthroscopic or endoscopic procedure, ECTR is vitally dependent on the surgeon's ability to visualize structures through the scope. Any impediment in visualization can render the procedure impossible to safely complete without conversion to an open technique. Various causes exist for inadequate endoscopic visualization: faulty camera hardware, inadequate light source, fogging of the lens, inadequate exsanguination of tissues, and anomalous anatomy. Progressing with the procedure with less than optimal visualization is unsafe and increases the risk of complications and incomplete division of the TCL. If the endoscopic procedure cannot be performed safely, it should be abandoned and converted to an open CTR.

When converting to an open procedure, the transverse skin incision should be incorporated into a zig-zag incision across the wrist flexion crease to decrease the risk of scar contracture postoperatively. Alternatively, a skin bridge can be left between the endoscopic and open carpal tunnel incisions. Other reasons for conversion to an open technique include uncontrollable bleeding after tourniquet deflation, intraoperative tendon or nerve laceration, inability to confirm complete division of the TCL, unclear or abnormal anatomy, or unexpected discovery of carpal tunnel pathology (mass, extensive synovitis, etc.). Any known intraoperative complication should be addressed during the open procedure.

OUTCOMES

Nocturnal awakening and provocation or exacerbation of parasthesias should resolve almost immediately. Subjective numbness of digits may take as along as several months to resolve depending on degree of nerve injury preoperatively. Similarly, thenar wasting or weakness may also take several months to reach final recovery levels. Although sensory recovery is usually near complete, muscle strength is dependent on degree and length of neuromuscular injury preoperatively.

In their multi-center trial, Agee et al. (24) reported on 122 patients (147 hands) who were randomized to the endoscopic ($n=82$ hands) versus open ($n=65$ hands) techniques. For patients in the ECTR group with one affected hand, the median time for return to work was 21.5 days less than that for the open carpal tunnel group. Two patients who had ECTR required reoperation; one had incomplete release of the TCL. Two patients in the device group also experienced transient ulnar neurapraxia.

In 2002, Trumble et al. (27) published a prospective, randomized, multicenter center study comparing open CTR to ECTR using the Agee technique. The open method was performed in 95 hands in 72 patients, and the Agee method was performed in 97 hands in 75 patients. The authors found that during the first three months after surgery, the patients treated with the Agee method had better Carpal Tunnel Syndrome Symptom Severity Scores, Carpal Tunnel Syndrome Functional Status Scores, and subjective satisfaction scores. These patients also had significantly greater grip strength, pinch strength, and hand dexterity. Patients who had open CTR had more scar tenderness and longer time off from work during the same time frame. In this series, the rate of complications and cost of surgery between the two groups were not significantly different.

Schonauer, Varma and Belcher (28) reported on 565 consecutive ECTR by a single surgeon using a modified Agee technique. There was 4.4% rate of conversion to the open technique because of inadequate visualization, tight carpal canal, tourniquet failure, and aberrant anatomy. Postoperatively, immediate symptomatic relief was reported in 99.5%. There were 25 complications including pillar pain (8 wrists), digital neuropraxia ($n=6$), median nerve contusion ($n=3$), incomplete division of the TCL ($n=3$), superficial infection ($n=3$), reflex sympathetic dystrophy ($n=1$), and scar tenderness ($n=1$). The authors concluded that their modified Agee technique can result in good outcome but also recommended caution in performing ECTR in patients who may have small wrists because of the risk of median nerve contusion.

SUMMARY

The Agee ECTR technique represents a single-portal, minimally invasive procedure to treat patients with median nerve compression at the wrist who meet the criteria for surgery. General advantages of this technique over open CTR include:

- less scar tenderness
- decreased pillar pain
- faster recovery of pinch and grip strength, and
- earlier return to work and daily activities.

Moreover, the Agee technique has the advantage of being a single incision technique that utilizes a blade system that readily attaches to the standard endoscopic equipment that is widely available in most medical centers. However, as in any surgical and especially endoscopic procedure, safety and success are dependent upon patient selection, thorough knowledge of the surface and surgical anatomy, adequate training, and familiarity with the use and capabilities of the instrumentation. Surgeons who are not familiarized with endoscopic equipment and technique may give rise to major iatrogenic complications.

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Percutaneous Trigger Finger Release

Min Jong Park
Department of Orthopedic Surgery, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea

INTRODUCTION

Trigger finger is one of the most common problems seen in the clinical practice of orthopedic surgery. It is caused by a disproportion between the flexor tendons and their sheath, and it presents with painful triggering or locking of the affected digit during finger motion. The most common form of trigger finger is the primary type, which is found most frequently among middle-aged women, two to six times more commonly than it is observed in men. The most commonly affected digit is the thumb, followed by the long, ring, index, and little fingers. The involvement of several fingers is not unusual. Secondary trigger finger can be found in patients with diabetes, gout, renal disease, and rheumatoid diseases, and it is associated with a worse prognosis after conservative management.

The main pathology of entrapment is mechanical impingement of the flexor tendons as they pass through the narrowed first annular (A1) pulley at the level of the metacarpal head. Thus, the goal of treatment is to provide a painless, smooth, and full range of finger motion. As a conservative method of treatment, steroid injection has been commonly recommended (1). Although this treatment is simple and has low morbidity, it may be associated with a high failure rate, and repeated injections are usually required because of a high recurrence rate. In reported series of injection therapy, the success rate varied from 37.5% to 84% (1–4). This therapy appears to be less useful in more advanced cases. Rhoades et al. observed that patients with symptoms of less than four months' duration achieved a success rate of 93% after steroid injection, while those with symptoms of greater than four months achieved a 41% success rate (5). Newport et al. reported that patients who had symptoms for more than six months were more likely to require surgery (4).

When conservative treatments fail to relieve the symptoms, surgical release of the A1 pulley by open technique is generally recommended (6,7). The most attractive aspect of operative management may be its ability to provide a permanent cure. Open trigger finger release is considered a simple and reliable procedure, but entails making a 1 to 2 cm incision in the palm directly the A1 pulley. The subcutaneous tissue is dissected bluntly off the pulley, which is then released under direct visualization. Successful results have been reported with this technique, but it is not without complications. These include infection, digital nerve injury, joint stiffness, hand weakness, scar tenderness, and bowstringing of the flexor tendons (8–10).

Since Lorthioir described a technique of percutaneous release of the A1 pulley using a fine tenotome in 1958 (11), several techniques for percutaneous release using a variety of cutting instruments have been described as simple office procedures (12–21). Percutaneous release, if it is equally effective and safe, would avoid the time and expense of an open surgical procedure. It also has the advantage of avoiding complications that are closely related with the open procedure, such as infection, incisional pain, hypertrophic scarring, and delayed use of the hand, which may be due to the development of reflex sympathetic dystrophy or stiffness.

INDICATIONS

The clinical course of trigger finger is generally divided into four stages as follows, depending on the degree of the tendon catching during the motion of the affected digit (15,19)

- Grade 1: No triggering, only uneven movements during finger motion
- Grade 2: Triggering, actively correctable
- Grade 3: Triggering, passively correctable by the other hand
- Grade 4: Locked and uncorrectable. Patients who have a locked trigger digit can present either with a fixed flexion contracture at the proximal interphalangeal (PIP) joint or with an inability to fully flex the affected digit from an extended position.

Percutaneous release of the A1 pulley is mainly indicated when the symptoms fail to be relieved by conservative treatment, including steroid injections. As the procedure can be simply performed in the office under local anesthesia without specific preparations, it is relatively indicated as a first-line treatment in patients with severe or longstanding symptoms, who are more likely to require surgery.

In this author's clinical practice, percutaneous technique is recommended in those patients who have had symptoms for more than four months, or have Grade 3 or 4 triggering at the time of their initial presentation. Others find locked trigger digits (i.e., Grade 4) as a contraindication to percutaneous techniques because of a higher failure rate (22). Although the percutaneous release of the locked digits seems to have a higher failure rate than that of other trigger digits, it is believed that locked trigger digits can be released safely and effectively by percutaneous method if several technical points are considered, which are discussed below.

Another issue with respect to indications of the percutaneous technique is whether it can be performed in children with a trigger digit. Although some authors have reported successful results (23), it should be performed cautiously for the following reasons: (*i*) due to anxiety pediatric patients may not be able to stay still and confirm complete release with just local anesthesia, which risks safety during the procedure, (*ii*) if general anesthesia is required, the patient will not be able to actively move the digit intraoperatively to determine that a complete release has been achieved, and (*iii*) almost all trigger

phenomena in children occur at the thumb, which has the increased risk of nerve injury due to the proximity of the digital nerves to the A1 pulley. The potential for nerve injury is significantly increased in children because of the small size of their thumbs.

In patients with secondary triggering, such as tenosynovitis, percutaneous release is generally not recommended because of unpredictable results.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Trigger digit can be diagnosed easily when "catching" is described by patients during active finger motion. Additionally, there is tenderness volarly over the A1 pulley at the metacarpal head. At a more advanced stage, locking of the flexor tendons in the A1 pulley develops, which results in an inability to fully flex or passively extend the affected digit. It should be noted that many patients, particularly with locked trigger digits, can have painful secondary contractures at the PIP joint or at the interphalangeal (IP) joint of the thumb. Although this is considered secondary to reluctance of the patients to perform a full range motion of the digits over time, it is frequently the main cause of pain and discomfort. Due to stiffness at the PIP joint and the absence of typical triggering, the patient or examining physician often localizes the pathology incorrectly at the PIP joint. In such a situation, the presence of a triggering history before the development of locking would contribute in making the correct diagnosis. When the triggering history is unclear, tenderness at the metacarpal head should be checked. Rarely, localized enlargement of the flexor digitorum profundus can trigger at a stenotic A3 pulley and lead to persistence of symptoms after release of the A1 pulley. Trigger digits in patients with rheumatoid arthritis may be due to synovitis along the flexor tendons and profundus entrapment at the superficialis decussation.

If the percutaneous release is determined to be indicated after the diagnosis is made, no imaging study is usually needed. However, when the PIP joint is unusually stiff and painful, plain X rays may be required to rule out articular problems. If fixed contracture of PIP is considered secondary to advanced stage of triggering, percutaneous release can still be tried as a first-line treatment. If the PIP contracture is resistant to manual stretching after percutaneous release, it may require surgical release. However, such case is very rare unless the PIP has intra-articular problems.

SURGICAL TECHNIQUE

Since Eastwood et al. described the percutaneous method using a hypodermic needle to section the A1 pulley (15), the hypodermic needle has been used most frequently among a variety of cutting instruments. Following is the brief description of this hypodermic needle procedure.

The A1 pulley is palpated directly over the metacarpal head in the palm, and the skin and flexor tendon sheath are infiltrated with 1 to 2 mL of 1% lidocaine using a 27-gauge needle. With the affected metacarpophalangeal joint held firmly in hyperextension, a 19- or 21-gauge needle is placed percutaneously through the A1 pulley. Placement of the needle tip within the flexor tendon is confirmed by asking the patient to slightly flex the digit and observing movement of the hub of the needle. The needle is then withdrawn slowly and rotated to align the beveled edge along the longitudinal axis of the tendon. A sawing motion is used to section the A1 pulley proximally and distally to the site (Fig. 1). Disappearance of a grating sensation indicates complete sectioning of the A1 pulley.

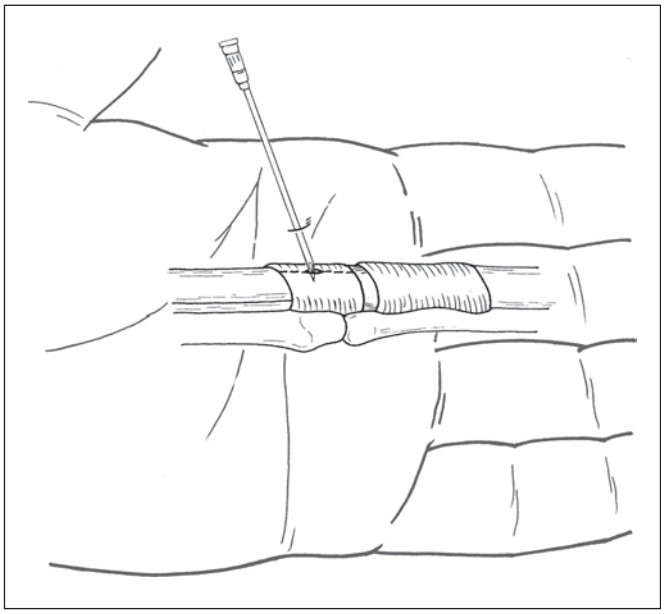

FIGURE 1 Percutaneous release of a long finger first annular (A1) pulley using a hypodermic needle. The bevel of the needle is oriented longitudinally with the tendon, and a sawing motion is used to section the A1 pulley.

My experience with the Eastwood technique demonstrated that it was not always successful because the needle bents easily and did not cut well when the A1 pulley was thickened and stenotic. It was also not easy to handle the needle because of the small hub and there was a steep learning curve. As a modified technique, a specially designed knife (HAKI knife; BK Meditech Inc., Seoul, Korea) has been developed (17), which has a hook-shaped end with a blade only on the inner side and a pointed end to facilitate its insertion into the skin without making an incision. The depth of the blade which is for section of the A1 pulley is less than 1 mm to prevent injury to the flexor tendons (Fig. 2). It is designed to cut the transverse fibers of the A1 pulley longitudinally from a proximal to distal direction after it is inserted distal to the A1 pulley (Fig. 3).

The procedure is generally performed in the outpatient setting under local anesthesia. The patient is placed in a supine position with the affected hand on the examination table. The surgeon sits on the distal side of the affected hand. The point of triggering at the A1 pulley is located by palpation (Fig. 4).

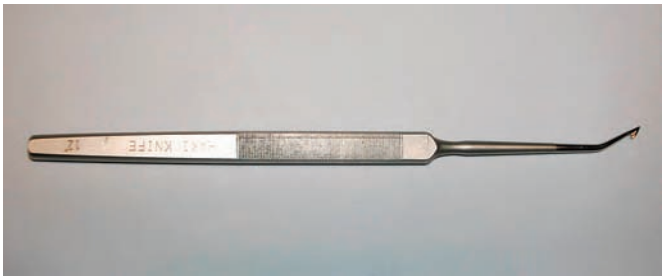

FIGURE 2 A specially designed knife (HAKI knife; BK Meditech Inc., Seoul, Korea) for percutaneous first annular pulley release. It has a hook-shaped end with a blade on the inner side and a pointed end to facilitate its insertion into the skin.

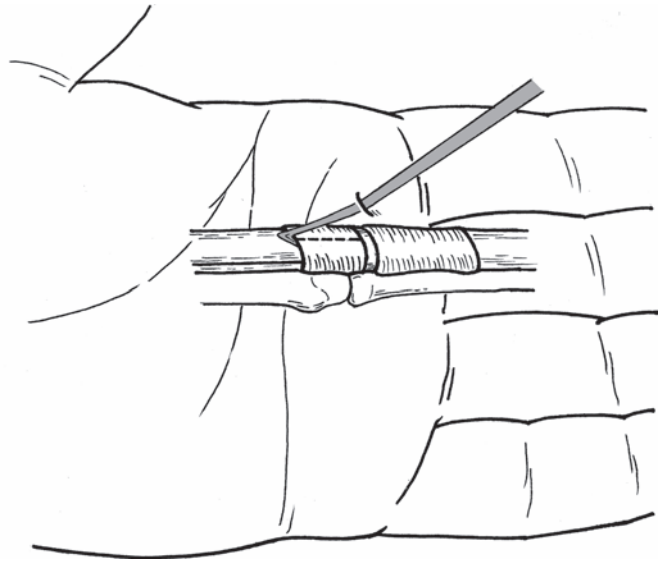

FIGURE 3 The technique of first annular (A1) pulley release using HAKI knife. After the knife is introduced distally to the pulley, the blade is advanced to its proximal margin and hooked over the border. The A1 pulley is divided by moving the knife from a proximal to distal direction.

FIGURE 5 One percent of lidocaine is infiltrated into the skin, subcutaneous tissue, and tendon sheath using a 27-gauge needle inserted over the point of knife entry.

The skin of the palm is thoroughly cleaned and 1 mL of 1% lidocaine without epinephrine is infiltrated into the skin and subcutaneous tissue by means of a needle inserted directly over the point of knife entry (Fig. 5).

The relationship of the surface anatomy of the palm to the A1 pulley needs to be reviewed in order to identify the exact point of knife entry. Several studies (11,24) have demonstrated that the proximal edge of the A1 pulley coincides almost exactly with the proximal palmar crease in the index finger, halfway between the proximal and distal palmar creases in the middle finger, the distal palmar crease in the ring and little fingers. In the thumb, metacarpophalangeal crease indicates the middle of the A1 pulley (Fig. 6). The knife is introduced a few millimeters distal to the A1 pulley, which coincides with the point approximately 1.5 cm distal to the landmarks that indicate the proximal edge of the A1 pulley. The precise locations of the knife entry are important for successful release. An incomplete

FIGURE 4 Percutaneous first annular (A1) pulley release of a ring finger in a patient with longstanding triggering. The point of triggering at the A1 pulley is palpated after skin preparation.

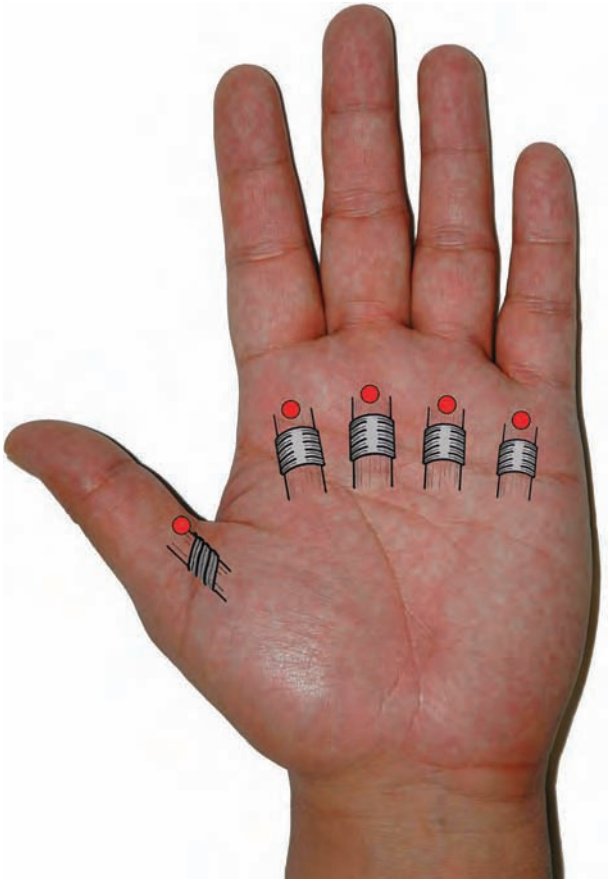

FIGURE 6 Surface anatomy of the palm to the first annular (A1) pulley. The proximal edge of the A1 pulley coincides with the proximal palmar crease in the index finger; halfway between the proximal and distal palmar creases in the middle finger; at the distal palmar crease in the ring and little fingers. In the thumb, metacarpophalangeal (palmodigital) crease indicates the middle of the A1 pulley. The knife is introduced 1.5 cm distal to the landmarks that indicate the proximal edge of the A1 pulley (*round dot*). The precise locations of the knife entry are important for successful release.

release might result from an inaccurate proximal insertion of the knife. If the knife is inserted too distally, excessive cutting extending to the A2 pulley would be a risk.

Once the hook-shaped point is inside the skin (Fig. 7), the knife is extended to the proximal edge of the A1 pulley, palpating the surface of the pulley with the tip of the knife. The tip of the knife is used to identify the step-off of the proximal margin of the fibrous pulley and the blade is placed at the proximal margin. The A1 pulley is sectioned longitudinally by moving the knife from proximal to distal (Figs. 3 and 8). It usually requires several repeated motions to complete the section. A grating sensation and sound indicate the cutting of the A1 pulley. When the grating sensation and sound stop, the knife is withdrawn and relief of clicking or locking is confirmed by the patient during active flexion and extension of the digit. The surgeon should confirm complete release by digital palpating over the metacarpal head and observing full active finger motion without any sense of triggering or uneven motion (Fig. 9). If the release is incomplete, the procedure might be repeated one or two times until the clicking or locking is relieved. Conversion to an open surgical procedure is recommended when it fails after three attempts. The procedure usually takes two to four minutes.

For percutaneous release of the trigger thumb, the location of the A1 pulley needs to be outlined carefully. By positioning the patient's thumb in abduction, slightly flexing the wrist, and hypersupinating the forearm, the volar surface of the thumb is positioned facing the surgeon. The knife is inserted 1 cm distal to the metacarpophalangeal crease, in the center of the thumb after local infiltration of the subcutaneous tissue and the flexor tendon sheath (Figs. 10 and 11). The proximal edge of the A1 pulley is identified with the tip of the knife blade proximal to the metacarpophalangeal crease level. It is important not to extend the tip of the knife too proximally because of the proximity of the radial digital nerve. The remaining procedure is the same as that for the fingers as described above.

After the procedure, an adhesive strip bandage is applied and the patient is advised to flex and extend the digit several times a day until full movement is restored. The patient is recommended to passively assist full flexion and extension of the affected digit with the opposite hand when the finger joint is stiff after the procedure. Some patients require hand therapy for residual stiffness of the joints.

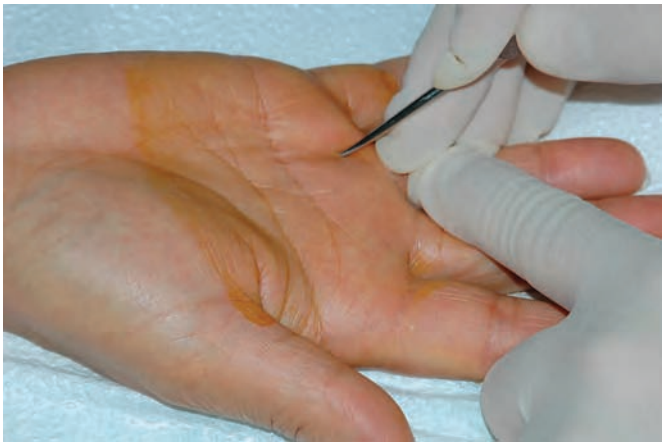

FIGURE 8 The first annular (A1) pulley is sectioned longitudinally by moving the knife from proximal to distal. A grating sensation indicates the cutting of the A1 pulley.

Several technical points need to be remembered for patients with locked digits. In contrast to an open release, complete sectioning of the A1 pulley cannot be confirmed by visualization during the percutaneous method. In the percutaneous release, adequate release of the A1 pulley is confirmed by complete disappearance of a triggering phenomenon. However, when the digit is locked instead of merely triggering, it is difficult to accurately evaluate the status of the A1 pulley after the percutaneous release. This may have caused some authors to believe that the percutaneous method is not indicated for locked trigger digits. During the initial trial period of the HAKI knife technique, locked cases accounted for the majority of failed cases among the percutaneous trigger releases performed by this author. For a successful release in the locked digits, it is essential to accurately locate the insertion point to prevent an inadequate release because it is difficult to confirm the site of triggering by palpation alone. Confirmation of a successful release must be made by both the surgeon and the patient while the affected fingers are anesthetized by intrathecal injection. As it can be difficult to differentiate incomplete release from a painful stiff interphalangeal joint, a local infiltration of anesthetic into the flexor sheath (intrathecal) is helpful. Even in

FIGURE 7 The knife can be easily inserted into the skin with its pointed end. After its insertion, the knife is advanced proximally to the proximal edge of the first annular pulley while palpating the surface of the pulley with the tip of the knife. The hook-shaped blade is placed at the proximal margin.

FIGURE 9 Complete release should be confirmed by the surgeon by palpating with the finger tip over the metacarpal head and observing full active finger motion without any sense of triggering or uneven motion.

FIGURE 10 Percutaneous release of the trigger thumb. Note the position of the patient's hand with the thumb in abduction and the forearm in hypersupination to make the volar surface of the thumb facing to the surgeon. The knife is inserted 1 cm distal to the metacarpophalangeal crease in the center of the thumb.

the setting of a secondary stiff finger joint, near active full range of motion can be achieved when the pain is eliminated with the intrathecal injection. If stiffness is severe but passively correctable, the surgeon can take the digit through a passive range of motion to assure that there is no "clicking" or "catching". Once the surgeon and the patient are assured about the complete release, the patient is advised to perform vigorous passive flexion and extension exercises of the released digit with the opposite hand until full painless motion is restored.

■ COMPLICATIONS AND THEIR MANAGEMENT

Several authors have pointed out the potential risk of nerve injury when the percutaneous technique is used in the thumb due to the proximity of the digital nerves to the A1 pulley (15,24,25). The radial digital nerve passes diagonally across the flexor pollicis longus tendon from the ulnar to the radial side. The site of the crossing is a few millimeters proximal to the metacarpophalangeal flexion crease of the thumb (Fig. 11). Digital nerve injuries have been reported as infrequent but serious complications of an open release (8,10), but there have been no reported instances of digital nerve injury after a percutaneous release. The author believes that HAKI knife is particularly effective in avoiding nerve injuries, since the knife is introduced through the skin at a point distal to the pulley where the nerve is located well on the lateral side of the thumb (Fig. 11). This is in contrast to the techniques of other authors, who inserted the needle or knife more proximally over the metacarpophalangeal crease. However, care must be taken to keep the tip of the knife in contact with the pulley surface during its proximal advancement, and not to extend the knife too proximally. The author does not recommend more than three repeated trials of the percutaneous release. Since the percutaneous technique was started in 1995, no nerve injuries were encountered after more than 1200 procedures.

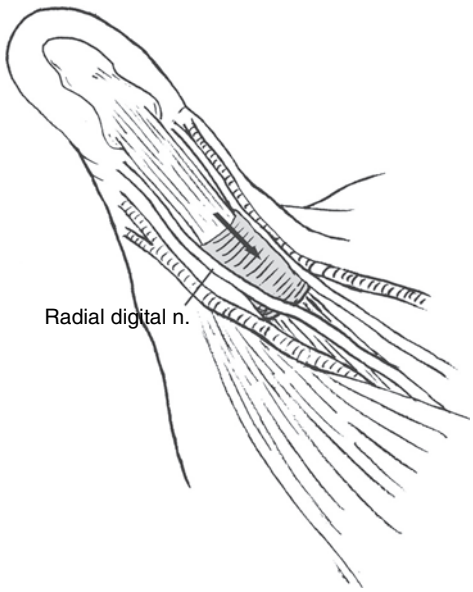

FIGURE 11 The radial digital nerve of the thumb has a potential risk of injury due to its proximity to the first annular pulley during percutaneous release. Distal insertion of the knife (*arrow*) is helpful in avoiding nerve injuries, but care must be taken to keep the knife tip in contact with the pulley surface during its proximal advancement, and not to advance the knife too proximally.

Injuries to the flexor tendon have been described in articles reporting the results of the percutaneous technique (15,19). Bain et al. observed some form of injury to the majority of tendons, ranging from simple lacerations to significant injuries on exploration after trials of percutaneous release on cadaveric hands using a 14-gauge angiocath needle (24). They recommended keeping the needle in a superficial position in order to minimize the flexor tendon injury. However, it is difficult to maintain the needle at a constant level in the soft tissue to minimize tendon injury and achieve the pulley release. The blade portion of HAKI knife has a constant depth of less than 1 mm, which would help prevent injury to the flexor tendon by a cutting blade.

Flexion contracture of the PIP joint with pain observed at the postoperative period is not uncommon, particularly in diabetic patients. These patients may not be fully satisfied with their results because they still have painful limited joint motion. The main reason is due to inadequate hand therapy after the procedure. If a complete release is confirmed after the procedure, it is also important to inform the patient that the triggering will not occur and that the stiffness of the interphalangeal joint should recover by repeated passive motion exercise. This postoperative care is essential, particularly for diabetic patients.

Care needs to be taken not to violate the proximal edge of the A2 pulley in order to prevent the potential for bowstringing and loss of digital flexion. Precise localization of the entry point of the knife is essential to avoid this. If the knife is inserted too distally, excessive cutting extending to the A2 pulley would be a risk. Discomfort or pain associated with the procedure can persist, but they usually disappear within several days or weeks after the procedure.

■ OUTCOMES

All authors who described the percutaneous technique of A1 pulley release invariably reported satisfactory results with a high success rate and few complications. To the best of author's knowledge, there have been no reported nerve or vascular complications associated with the percutaneous trigger finger release. Lorthioir was the first to describe a technique of subcutaneous release of the A1 pulley using a fine tenotome. He reported good results in 52 patients with no complications

(11). Eastwood et al. reported excellent results in 94% following release of 35 trigger digits using a hypodermic needle (15). Tanaka et al. reported excellent results in 64% following percutaneous release of 210 trigger digits with a fine scalpel (21). Lyu reported excellent results in 89% of 63 digits that underwent release with a curved scalpel blade (18).

Our early series demonstrated that 11 out of 185 digits (5.9%) failed to achieve relief of triggering with the first attempt (17). These included six thumb, three middle, and two ring fingers. The majority of the failed cases (nine of the 11 digits) were digits in a locked state at the time of their initial presentation. The main reason for failure in the locked digits might be a difficulty in confirming the complete relief of locking by the patients and surgeons. It should be remembered that the evaluation of the motion of the affected digit under the intrathecal block at the time of the percutaneous release is the most important step for confirming an adequate A1 pulley release and reducing the failure rate. A recent review of author's experience demonstrated that the success rate has increased to 98%, and locked digits are no longer considered as a majority of failed cases (unpublished data).

SUMMARY

A number of authors demonstrated that the percutaneous A1 pulley release for trigger digits is equally effective and safe as an open technique, and it avoids the time, expense, and complications related with surgical procedure. It can be performed easily, quickly, and safely in an outpatient or office setting. The procedure itself is well tolerated by most patients, and the discomfort associated with it compares favorably with that associated with steroid injection. Therefore, percutaneous trigger finger release is believed to be the indicated treatment of choice for:

- cases that failed conservative treatment,
- cases when the symptoms last for more than four months,
- Grade 3 (locking but passively correctable), and
- Grade 4 (a locked digit) triggering is present.

SUMMATION POINTS

Indications

- Failure of conservative treatment

Relative contraindications

- Trigger finger in children
- Locked digit

Outcomes

- 94% to 98% successful A1 pulley release on first attempt

Complications

- Inadequate release in 2% to 6%
- No reported injury to digital nerve or flexor tendon

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Endoscopic DeQuervain's Release

Joseph F. Slade III
Hand and Upper Extremity Service, Department of Orthopedics and Rehabilitation, Yale University School of Medicine, New Haven, Connecticut, U.S.A.

Greg Merrell
Department of Orthopedics, Brown University School of Medicine, Providence, Rhode Island, U.S.A.

INTRODUCTION

There are three reasons to consider an endoscopic approach to first dorsal compartment release rather than a traditional open release. First, the results of open release, when viewed critically, still have a number of complications. Second, the incisions for an endoscopic release are outside the area of maximal sensitivity. Third, we hypothesize that an endoscopic release may allow for a localized neurectomy.

On the first point, a study by Harvey et al. demonstrates scar adherence to the underlying tendon in two out of 20 surgical patients and temporary parathesias of the radial sensory nerve in three patients (1). Arons et al. describes 14 complications in 16 consecutive patients including three hypertrophic painful scars, one tendon subluxation, two neuroma's, and three adhesions (2). A study by Ta et al. shows 2% with severe scar tenderness, a 5% recurrence rate, and a 2% sensory nerve injury out of 43 patients (3). There have been other case reports of palmar subluxation of the tendon following operative release (4). Clearly, although surgical treatment of DeQuervain's is perceived as a simple and effective surgical procedure, when examined closely, there is a need for improvement.

On the second and third point, we believe that not only is there mechanical constriction from the restrictive tendon sheath, but also an element of peripheral nerve hypersensitivity. The endoscopic approach allows us to keep our incisions outside of the hypersensitized zone of injury. Additionally, we hypothesize that an arthroscopic approach allows for an extensive neurectomy of the tiny branches of the superficial radial nerve (SRN), which may innervate the first dorsal compartment. Therefore, the minimally invasive approach along with this neurectomy may result in faster and more complete pain relief, with less risk for painful scar development. Finally, with the proper training, we believe this to be a safe technique. We must be clear that at this point, the neurectomy component of the procedure is strictly a working hypothesis and not yet substantiated by substantial basic science and clinical research.

INDICATIONS AND CONTRADICTIONS

Any patient with a first dorsal compartment tenosynovitis who has failed conservative treatment of splinting and/or injections and has not previously undergone a release would be a candidate for endoscopic release. We have not yet performed an arthroscopic release on a patient with recurrent symptoms that failed previous open surgery. This would be a relative contraindication due to potential scarring and the displaced anatomy.

SURGICAL TECHNIQUE

The wrist is placed over a towel roll in a neutral position with a tourniquet inflated. A 5 mm superficial transverse incision just distal to the thumb carpometacarpal (CMC) joint establishes the distal portal. The incision is in line with the first dorsal compartment at the insertion of the abductor pollicis longus (APL) tendon, 2 to 3 cm distal to the end of the radial styloid. A small hemostat is used to clear the overlying subcutaneous tissue off the fascia enveloping the thumb CMC joint. A small right angle retractor elevates the subcutaneous tissue off the tendons of the first dorsal compartment. A long narrow hemostat is next used to bluntly create a working space between the skin and subcutaneous tissue down the length of the first dorsal compartment. A trocar and cannula are inserted above the fibrous fascial sheath of the first dorsal compartment, proximal to the radial styloid and the extensor tendon retinaculum. Next, a second 5 mm transverse incision is made over the trocar tip, approximately 4 to 6 cm proximal to the radial styloid (Fig. 1). A 2.7 mm 30° angled scope is inserted into the cannula through the proximal portal. The scope is inserted into the cannula until the tip of the scope is visible through the distal portal. The cannula is then removed. A small right-angled retractor elevates the proximal portal to maintain a working space and a dry endoscopic inspection of the first dorsal compartment is performed beginning distally over the CMC joint. The SRN is identified as it sweeps down crossing the fascia below (Fig. 2). Long thin Mueller scissors are introduced into the distal portal and used to bluntly dissect the overlying subcutaneous tissue off of the fascia. We hypothesize that this blunt dissection sweeps off small neurofibrils from the SRN which innervate the fascia of the first dorsal compartment. We believe this procedure serves as a neurectomy as well. Although there are some corroborating anatomical studies published, much of this needs further substantiation.

Next, incise the fascia of the first dorsal compartment starting proximal to the radial styloid and moving distally (Fig. 3). The tendon slips of the APL and extensor pollicis brevis (EPB) are identified under direct visualization. To ensure release of both the EPB and APL, stabilize the first metacarpal and manually flex and extend the metacarpal phalangeal joint. Through the endoscope, the EPB tendon can be visualized gliding proximally and distally while the APL tendons remain stationary. If all tendons are either stationary or

FIGURE 1 Incisions for endoscopic DeQuervain's release.

gliding, then search for a separate compartment. Postoperatively patients are placed in a volar splint.

The technique achieves two goals by addressing two possible sources of pain, mechanical and neuropathic. The first goal is to decrease the friction, which results in a restriction of tendon gliding. This is accomplished by release of the unyielding fascial compartment overlying the thumb extensor tendons. This release allows for a gradual reduction in tendon irritation. Over time, swelling decreases and the tissues recover.

The second goal is to perform a neurectomy of the small SRN branches to the first dorsal extensor compartment. Lin et al. demonstrated that the dorsal wrist capsule has an extensive array of sensory nerve endings (5). We hypothesize that a similar innervation may exist in the first extensor compartment and may help explain the severe pain that occurs in DeQuervain's. Berger and Weinstein have shown that ablation of the terminal portions of the anterior and posterior interosseous nerves, which supply proprioceptive fibers to the wrist capsule, can be an effective treatment for a variety of chronic unreconstructable pathologies (6,7). Our endoscopic technique for DeQuervain's release may provide pain relief through a similar denervation of the first extensor compartment. Additional support for the neurectomy hypothesis is found in the pattern of referred pain from the APL. It has been shown to resemble the C6, 7, and 8 dermatomes. This parallels the superficial radial sensory nerve distribution, and is very similar to the radiation of pain that is experienced in DeQuervain's tenosynovitis (8). We postulate that the sheath will likely eventually be reinnervated, but only after the tendon pathology has resolved, which breaks the cycle of local nerve irritation.

POSTOPERATIVE MANAGEMENT

After suture removal at seven days, the patient is allowed to resume activities without restrictions. No splints or braces are used.

RESULTS AND OUTCOMES

In our initial series of 43 patients, there have been no infections, neuromas, or significant scar tenderness. There have been no injuries to the SRN. No patient had to be converted to the open procedure for failure of visualization or inability to achieve appropriate release. There has been good subjective patient satisfaction and none were considered treatment failures. As with any arthroscopic surgery, it is imperative that the surgeon is comfortable with arthroscopic equipment and technique and that the relevant anatomy is fully understood.

SUMMARY

DeQuervain's tenosynovitis is a common problem that often requires surgical treatment. The classic open approach for release of the first dorsal compartment is not without complications and results are not uniformly excellent. Controversies that exist include location and orientation of the incision and the amount of retinaculum removed. Endoscopic treatment of this tendinopathy may be helpful in minimizing these problems.

SUMMATION POINTS

Indications

- DeQuervain's tenosynovitis recalcitrant to non-operative treatment
- No previous surgery and normal anatomy

Outcomes

- Excellent results in 43 patients
- Good relief of pain
- Less wound problems and scar tenderness

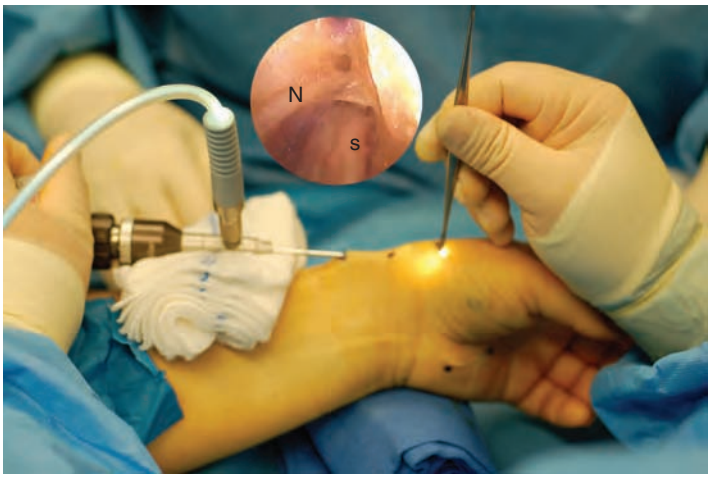

FIGURE 2 A small right angle retractor is used to elevate subcutaneous tissue off the fascial sheath of the first dorsal compartment. Endoscopic visualization of SRN and first dorsal compartment sheath below. Mueller scissors used to dissect soft tissue and microscopic innervations to the first dorsal compartment sheath from the SRN under direct vision. *Abbreviations*: N, nerve; S, sheath; SRN, superficial radial nerve.

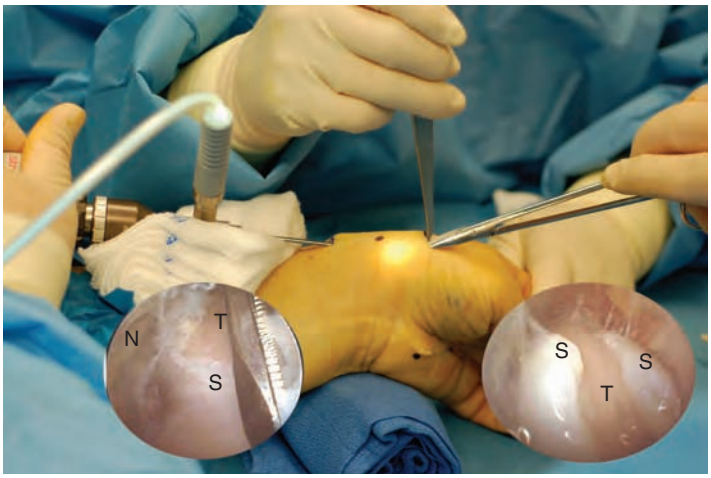

FIGURE 3 Endoscopic release of the sheath. Endoscopic image on the left shows beginning of the fascial sheath release of the first dorsal compartment, underlying tendons, and superficial radial nerve. Endoscopic image on the right showing complete release of first dorsal compartment sheath with underlying tendons. *Abbreviations*: N, nerve; S, sheath; T, tendons.

Complications

- Similar to open technique

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Treatment of Pyogenic Flexor Tenosynovitis Using Closed Catheter Irrigation

Karol A. Gutowski
Division of Plastic and Reconstructive Surgery, University of Wisconsin, Madison, Wisconsin, U.S.A.

INTRODUCTION

Pyogenic (or suppurative) flexor tenosynovitis (Fig. 1) is an infection of the flexor tendon sheath that is usually caused by a penetrating injury and less commonly by hematogenous spread. Lacerations, punctures, and bites account for most cases. Four classic findings have been described by Kanavel (1): (*i*) Flexed posture of the finger, (*ii*) Fusiform swelling of the digit ("sausage digit"), (*iii*) Exquisite tenderness along (and limited to) the course of the sheath, and (*iv*) Excruciating pain with passive extension of the finger (late finding).

Staphylococcus and *Streptococcus* species are common pathogens; however, Gram negative rods, anaerobes, and mixed cultures may also present. Gonorrhea (2) and *Candida albicans* (3) infection have been reported as causes of flexor tenosynovitis in immunocompromised patients.

Purulence within the sheath creates adhesions and disrupts tendon gliding, resulting in limitation of tendon function and loss of hand motion. Consequences of un- or under-treated tendon sheath infection are tendon necrosis, disruption of the tendon sheath, and digital contracture.

Early presentation of pyogenic tenosynovitis (within 48 hour of onset) can be treated with a combination of intravenous (IV) antibiotics, splinting for immobilization, and extremity elevation. If there is no clinical improvement after 24 hour, or if presentation is beyond 48 hour, and in cases where a defined abscess or infected fluid collection is present, surgical drainage is required to remove purulence from the closed space of the flexor sheath.

The established surgical treatment for pyogenic flexor tenosynovitis involves drainage of pus, followed by sheath irrigation. Traditionally, volar Bruner (Fig. 2) or lateral midaxial (see Fig. 6 in chap. 1) incision along the entire length of the finger allow access to the flexor sheath for open drainage (OD) and irrigation. In 1943, Dickson-Wright (4) conceived an alternative method for sheath drainage and irrigation by using a ureteric catheter. This technique thereby preserved peripheral structures and minimized loss of tendon function. Carter et al. (5) in 1966 were the first to recommend catheter irrigation of the sheath through a small incision proximal to the first annular (A1) pulley with a distal counter incision for egress of fluid. Subsequently, others reported successful treatment of suppurative tenosynovitis by minimally invasive closed catheter irrigation (CCI) techniques (6–10), where the entire flexor tendon sheath was not fully exposed.

A retrospective comparison of the OD versus CCI methods did not demonstrate a difference in early postoperative outcomes (11). The CCI treatment group appeared to have less postoperative complication than the open irrigation treatment group; however, this difference was not statistically significant. Nonetheless, there is support for the minimally invasive CCI technique being the preferred treatment for pyogenic flexor tenosynovitis. Advantages include thorough mechanical tendon sheath irrigation, less need to perform a repeat open irrigation and debridement, rapid return to function (12), and smaller wounds with less scarring.

INDICATIONS

The indication for CCI is based on history and physical examination consistent with acute stage I suppurative flexor tenosynovitis (Table 1) (13). Contraindications for CCI include stage III infections, chronic infections, or infections caused by atypical mycobacteria. In these cases of extensive infections, an open approach is more appropriate in order to assure that all pockets of purulence are adequately drained. In general, however, extensive tissue necrosis results in amputation.

CONSIDERATIONS FOR PREOPERATIVE PLANNING

Preoperative planning starts with making the correct diagnosis of pyogenic flexor tenosynovitis based on history and physical examination. Distinguishing a more superficial subcutaneous abscess from a tendon sheath infection can be difficult; however, a subcutaneous abscess should not have tenderness over the entire digit, and passive movement of the uninvolved segments should be painless.

The anatomy of the flexor tendon sheaths presents another point for consideration. The sheaths of the index, middle, and ring fingers extend from the distal phalanges to the distal palmar crease, ending at the A1 pulley. These sheaths generally do not communicate. The small finger and thumb sheaths are continuous with the ulnar and radial bursae in the wrist, respectively. Because the radial and ulnar bursae are frequently contiguous, infections in either the small finger or thumb are at risk of spreading to the other digit, causing a "horseshoe abscess." when such an infection does occur, the radial and ulnar bursae, along with both tendon sheaths require irrigation.

Another consideration is whether to start a trial of medical management with IV antibiotics. Empiric treatment with a synthetic penicillin combined with a beta-lactamase inhibitor or with a first generation cephalosporin and penicillin is appropriate (14), if initiated within 48 hour of the onset of symptoms.

Standard anteroposterior and lateral radiographs to rule out bony involvement or foreign body should be obtained as part of the preoperative workup. Complete blood count, erythrocyte sedimentation rate, and c-reactive protein are usually not necessary.

FIGURE 1 (**A** and **B**) A clinical photograph of a patient with pyogenic flexor tenosynovitis of the right middle finger. *Source*: Courtesy of Virak Tan, MD.

SURGICAL TECHNIQUE

A standard operating room (OR) setup (with the patient supine and the affected arm abducted over a hand table) is used. A basic set of instruments consisting of scalpels, skin hooks, ragnel retractors, tentomy scissors, small hemostats, freer elevator, and short IV extension tubing should be opened on the sterile field. The author's preferred technique for pyogenic tenosynovitis is a modification of Neviaser's CCI method (6,12):

1. Make a 1 to 2 cm skin incision in the palm in the region of the A1 pulley. Bluntly dissect down to the flexor tendon sheath and open it proximal to the A1 pulley of affected finger.
2. Send swab of sheath fluid/pus for Gram stain and culture.
3. Approximately 1 cm proximal to the skin incision, percutaneously insert an 18G angiocatheter 2.5 to 3.0 cm distally into the sheath. After securing the catheter to the skin with suture(s), attach the short IV extension tubing to the hub of the angiocatheter.
4. Make a distal midaxial counter incision (on the radial side for the small finger and thumb, and the ulnar side for the index, middle, and ring fingers), staying dorsal to neurovascular structures. Vent the sheath distal to the A4 pulley (Fig. 3).
5. Connect a syringe to the IV tubing and irrigate gently with 50 cc of normal saline through the catheter. Continue the irrigation until the output is clear. Failure to clear purulence indicates a need for OD.
6. Place small drain (1/4 in. Penrose) in distal counter incision to keep it open and secure the drain with a suture. Close the proximal incision at the A1 pulley (Fig. 4).
7. Place a short arm splint with the wrist and hand in the safe position at no more than 70° of metacarpalphalangeal joint flexion, to avoid kinking of the catheter and/or IV tubing.
8. Disconnect the syringe and cap the IV tubing outside of the dressing and splint. Make the tubing accessible for irrigation.
9. Irrigate with 50 cc of normal saline after splint applied but prior to leaving OR to assure the irrigation system is functioning.

If the thumb is involved, place the catheter in the flexor pollicis longus sheath as it leaves the carpal tunnel. If the ulnar bursa is involved, place a second catheter in the small

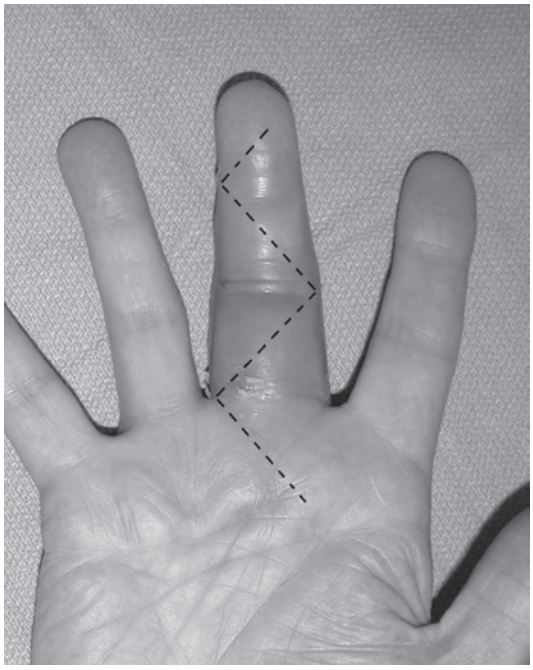

FIGURE 2 Skin marking for a Bruner incision over the entire length of the flexor tendon sheath. *Source*: Courtesy of Virak Tan, MD.

finger tendon sheath in a proximal direction with a counter incision and Penrose drain at the wrist.

Postoperatively, bedside irrigation should be performed manually with 10 to 60 cc of normal saline over two minutes, every two to six hours and continued for 48 hour. Extremity elevation and splinting in the safe or intrinsic-plus position is maintained in the early postoperative period. Appropriate empiric IV antibiotics should be utilized and changed if deemed necessary by intraoperative cultures. The catheter and penrose drain are removed at two to four days, depending on the patient's symptoms There should be reduction in pain, swelling, and erythema. Hand therapy beginning with range of motion exercises is started after the catheter is discontinued. Comparable oral antibiotic is continued on an outpatient basis to complete a 10 to 14 day course.

Variations in CCI Technique

Many variations in the CCI techniques have been developed through the years, but the basic concepts of: (*i*) Inflow/outflow, and (*ii*) Limited exposure of the tendon sheath, remain the same. Different catheters for inflow, including 16G angiocatheter, infant feeding tube (usually 4- or 5-Fr G) and uteretic catheter have been utilized. The used of a second catheter for outflow to minimize leakage of the irrigation fluid from the wound has been described (15). Another variation to help with drainage is to place the inflow catheter in the distal wound and have the irrigation fluid flow in a proximal direction to allow gravity assisted flow in the elevated extremity. These minor alterations in technique have proven successful and do not change the outcome of the procedure.

TABLE 1 Michon Classification of Tendon Sheath Infection

Stage I	Increased fluid in sheath, mainly a serous exudate
Stage II	Purulent fluid, granulomatous synovium
Stage III	Necrosis of the tendon, pulleys, or tendon sheath

In the past, authors have also investigated instillation of antibiotic solution through the catheter without routine irrigation (16), single antibiotic dose instillation with distal counter incision for drainage (16), and through-and-through intermittent antibiotic irrigation (5,17). However, it is doubtful if these variations are superior to CCI as described by Neviaser (6,12). Antibiotic instillation only, especially in low volumes, does not allow for adequate irrigation of infected and purulent matter. Single instillations with drainage do not allow for the dilutional effect of frequent irrigations to decrease bacterial counts. Also, instillation of a single antibiotic may not cover all possible pathogens, especially with the emergence of antibiotic resistance and frequent findings polymicrobial infections. Finally, instillation or irrigation of any non-physiologic solution such as concentrated antibiotics (5,10,16,17) or peroxide (5) may cause damage to otherwise healthy and viable cells, including leukocytes, synovium, tenocytes, and flexor tendon sheath endothelium. For these reasons, such irrigation protocols should be avoided.

Closed continuous high volume irrigation after wide exploration for drainage is a variation in the CCI technique that has been reported as a treatment for various hand infections (7). However, there is no evidence that volumes of 1500 to 2000 mL per day for one week are necessary.

COMPLICATIONS AND THEIR MANAGEMENT

Potential problems with CCI include dislodging or kinking of the catheter which prevents flushing of the sheath. Proper suturing of the catheter to the skin, splitting and immobilization of the extremity, and securing the catheter tubing to the splint helps prevent dislodging. Percutaneously inserting the catheter proximal to the incision at less than or equal to 30° angle to the plane of the palm helps prevent kinking of the catheter. Additionally, directly observing the catheter entering the sheath and testing the irrigation system prior to skin closure and after splinting, assure that the flow is unobstructed.

It is important to minimize high pressure or large volume irrigation, especially at the bedside, to avoid a "mini-compartment syndrome" of the digit. This complication is characterized by digital pallor which usually subsides within 15 to 30 minutes without any long-term sequella. This phenomenon can be avoided by adhering to the technique as described.

If the signs and symptoms of tenosynovitis fail to improve or worsen in the postoperative period, a second surgery with repeat irrigation and debridement should be done by open technique.

OUTCOMES

The outcome of pyogenic flexor tenosynovitis is related to the severity and duration of the infection, and the bacteriology (18). Several authors have reported on the outcome of treatment with CCI methods.

In 1978, Neviaser (6) reported on 20 patients treated by through-and-through saline irrigation using an indwelling catheter and small Penrose drain. The treatment lasted for 48 hour and all patients were discharged from the hospital within four days. Eighteen patients had regained complete active and passive motion by one week after operation. One patient had a slight residual flexor tendon adherence and one regained motion after a second operation. The author concluded that this technique provided rapid and complete return of function with minimal patient inconvenience.

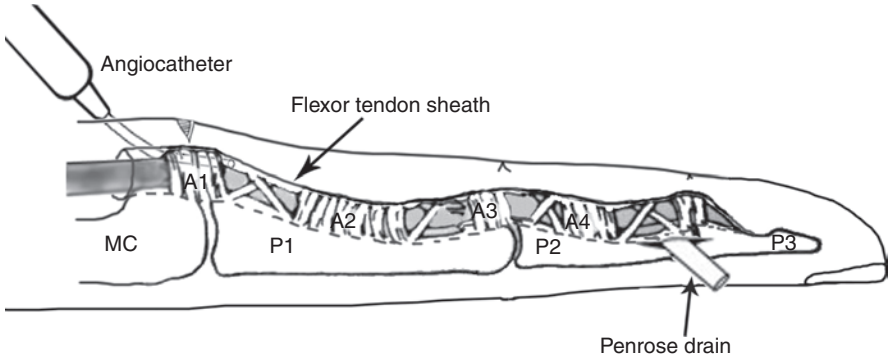

FIGURE 3 Diagram of the flexor tendon sheath and pulley system of a finger. One centimeter proximal to the skin incision over the A1 pulley, an 18G angiocatheter is percutaneously inserted for 2.5 to 3.0 cm into the flexor tendon sheath. A midaxial counter incision (on the radial side for the small finger and thumb, and the ulnar side for the index, middle, and ring fingers) is made to vent the sheath distal to the A4 pulley with a Penrose drain. *Abbreviations*: MC, metacarpal bone; P1, proximal phalanx; P2, middle phalanx; P3, distal phalanx. *Source*: Courtesy of Virak Tan, MD.

In 1999, Harris and Nanchahal (15) published their experience with CCI for the treatment of hand infections. There were six cases of pyogenic flexor tenosynovitis. The authors' technique consisted of two fenestrated tubes within the flexor sheath; one was for instillation of irrigation and the other for drainage. There were four excellent (normal total active motion-TAM), one good (≥75% of contralateral TAM), and one fair (≥50% of contralateral TAM) outcome.

This author and colleagues (11) retrospectively reviewed 47 cases of pyogenic flexor tenosynovitis to determine whether a difference in outcomes existed between OD versus CCI. OD was used in 32 patients and CCI was used in 15 patients. Complications appeared to be more common in the OD group ($N=9$) compared with the CCI group ($N=3$), but this difference was not significant. This study supported the use of CCI as the preferred treatment for pyogenic flexor tenosynovitis because it provides thorough mechanical tendon sheath irrigation and causes smaller wounds with less scarring.

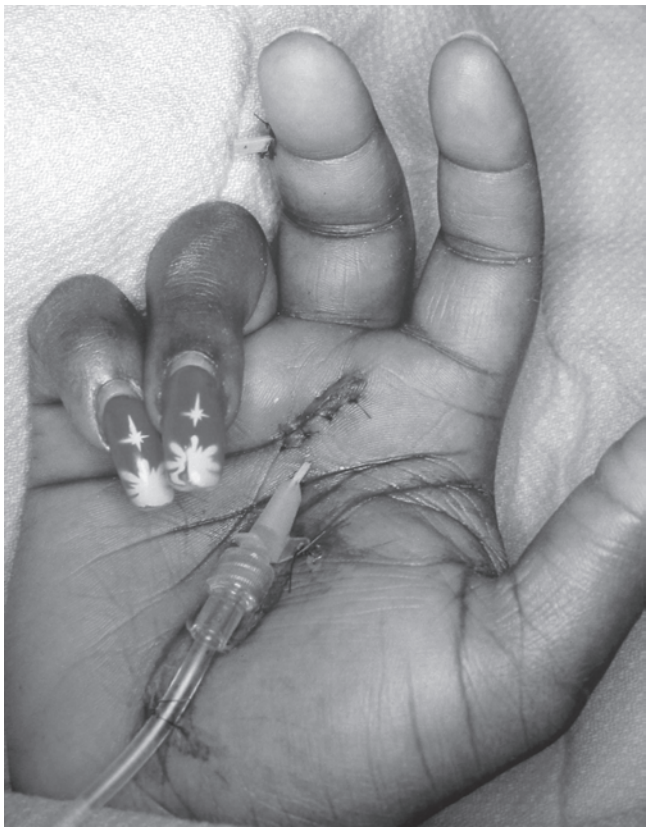

FIGURE 4 Clinical photograph of a closed catheter irrigation of pyogenic flexor tenosynovitis.

SUMMARY

Optimal management of pyogenic flexor tenosynovitis includes early diagnosis, elevation and splinting the affected wrist and hand in the safe position, appropriate antibiotics directed at the suspected pathogens, and frequent clinical re-examination. When the early stage of tenosynovitis has passed (duration of symptoms greater than 24 to 48 hour) or when medical treatment fails to show improvement, surgical drainage is indicated. Intermittent CCI of the flexor tendon sheath through small incisions is as effective as OD of the sheath through long volar or lateral midaxial incisions where the entire sheath is exposed. The limited incisions of CCI minimize trauma to the soft tissue of the finger, decrease the risk of surgical complications, and allow for faster soft tissue healing. As such, CCI decreases the time from surgery to therapist-directed range of motion exercises which optimizes long-term function of the hand.

In the future, there may be a role for minimally invasive CCI of pyogenic flexor tenosynovitis in the OR, followed by outpatient antibiotic treatment which has the potential benefit of limiting the socioeconomic burden associated with hospitalization (19).

SUMMATION POINTS

Indications

- Acute stage I suppurative flexor tenosynovitis

Contraindications

- Stage III infections
- Chronic infections
- Infections caused by atypical mycobacteria

Outcomes

- Successful eradication of infection
- 90% regain full digital motion

Complications

- Dislodging or kinking of the catheter
- "Mini-compartment syndrome" of the digit

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Dupuytren's Contracture

Lawrence C. Hurst and Marie A. Badalamente
Department of Orthopedics, State University of New York, Stony Brook, New York, U.S.A.

INTRODUCTION

Dupuytren's disease (DD) is a fixed flexion contracture deformity of the fingers that can cause progressive loss of hand function. It was first described by Felix Plater of Basel in 1614 (1). Henry Cline, from London, in 1777 was the first to recognize the role of the palmar fascia. However, in these early times confusion still existed as to whether the flexor tendons, their sheaths, or the palmar fascia were responsible for the finger contractures. Baron Guillaume Dupuytren, in France, in 1831 (2) correctly described the pathologic anatomy and performed surgery to correct the condition. Thus, the disorder now bears his name.

It was not until the 1940s and 1950s that investigators recognized the fibrosis of the palmar fascia and changes in cell density as time progressed (3,4). Luck divided the disease into stages based on microscopic cell density. The classification is still in use today. The first two stages, the proliferative and involutional, are characterized by increasing cell densities with collagen fibrosis. By the last residual stage, cell density markedly decreases with severe collagen fibrosis establishing the well known cords of the disease. By the early 1970s, Gabbiani and Majno's work (5) firmly established that the pathognomic cell in the palmar fascia was a type he termed as myofibroblast. This cell had characteristics of a fibroblast and smooth muscle cell, since it contained a dense array of intracellular contractile filaments. The question remained for a long period was how a supposedly contractile cell type might transmit contractile forces to the extracellular collagen, thus producing the contractures. In a landmark study, Tomasek and Haaksma (6) established that the intracellular generation of contractile forces by myofibroblasts was transmitted to the surrounding collagen through a structure they termed the fibronexus. This is a transmembrane adhesion complex from intracellular actin filaments via fibronectin to surrounding collagen fibrils.

Since then, much literature has reported on the nature of the collagenous and extracellular matrix (7–11), as well as substances which may influence the contractility of myofibroblasts. The rationale was that if the cell biology of the disease could be specifically detailed, then inhibitors of myofibroblast proliferation and/or the contractile properties could be developed. Among the cell substances studied were:

- Prostaglandins E_2 and $F_{2\alpha}$ (12)
- Platelet derived growth factor (13)
- Lysophosphatic acid (14)
- Interferon gamma 2β (15,16)
- Androgen receptors (17)
- Beta-catenin oncogene (18)
- Nerve growth factor (19)
- Interleukin 1α (20)
- Alpha 5-beta 1 integrin (21)
- Z9f transcription factor (22)

Among the substances studied for their ability to induce myofibroblast proliferation were transforming growth factor β_1 and β_2 (23–25) and fibroblast growth factor (23). It is still unknown what cellular signals induce apoptosis (cell death) of myofibroblasts in the last, residual stage of the disease.

The treatment goal for DD is restoration of hand function by correcting the flexion contracture. At the present time, there is no perfect operation or standard accepted approach to achieve this goal. Numerous surgical techniques are employed, ranging from simple fasciotomy (division of the contracted cords) to limited or radical fasciectomy. In addition, there are just as many different options for management of the skin. The rate of complications from surgical release of Dupuytren's contracture of the hand is relatively high and can be categorized into intraoperative, early and late postoperative. Intraoperative complications include nerve and arterial injuries. Early postoperative complications (before wound healing) include hematoma, wound infection, complex regional pain syndrome, and skin slough. Late postoperative complications include scar contraction and recurrence.

In an effort to minimize complications from Dupuytren's surgeries, many non- and minimally invasive techniques have been investigated. In recent years many nonoperative therapies targeting myofibroblasts have been studied. Hyperbaric oxygen for the treatment of early stage DD has been described in a case report on one patient (26). Triamcinolone injections of early disease nodules have been reported to have merit (27). Similarly, depomedrone, in vitro, was shown to down-regulate expression of transforming growth factor β (28). Also, in vitro, tamoxifen has been shown to decrease the ability of myofibroblasts to contract (29). The immunosuppressant 5-fluorouracil was shown in vitro to inhibit myofibroblast proliferation and differentiation (30). However, when used in patients as a topical treatment, there was no beneficial clinical effect (31,32).

French rheumatologists have recently popularized fasciotomy using a percutaneous needle technique. In this technique, the bevel of the needle is used as a cutting blade. The surgical approach of this percutaneous technique is blind, which is an obvious disadvantage. Foucher et al. (33) reviewed the charts of 211 patients in which 261 hands and 311 fingers were treated by percutaneous needle aponeurotomy. The first 100 patients were evaluated with a mean follow-up of 3.2 years. Only one digital nerve was found to be injured. However, the recurrence rate was unacceptably high at 59%. These 59 patients needed further hand surgery.

The use of the continuous elongation technique or technicadi extrensiona continua (TEC) device was developed first in the 1960s and then in the early 1990s by Messina et al. (34). This device provides continuous elongation of the Dupuytren's contracture before doing an open fasciectomy. The Messina TEC device provided skeletal traction of the

pathologic cord of DD (35,36). The traction (distraction) was applied at a rate of 2 mm per day over an average period of two weeks. Others have applied the skeletal traction using the TEC device for as long as four weeks. Significant reduction of the contracture is usually achieved, but stretching out of the finger must be quickly followed by limited fasciectomy or the contracture will recur rapidly. The complications following TEC can be significant, such as rapid recurrence, infection, stiffness in extension, pain, and reflex sympathetic dystrophy.

Another surgical method which was purported to be less invasive is segmental aponeurectomy. This procedure was first proposed by Vilain in 1982 in a presentation at a conference of the Belgian Hand Group. Moermans (37,38) performed prospective studies of this technique. He postulated that if a permanent discontinuity could be created without wide dissection of the diseased fascia, then the contracture might disappear. Small pieces of diseased fascia about 1 cm long were excised, beginning from proximal to distal through C-shaped incisions. While intraoperative correction of the joint contractures was achieved, the mean recurrence rate at 2.6 years in Moerman's series (37) of 213 patients was 35.7%. Andrew and Kay (39) also investigated the use of segmental aponeurectomy in 40 hands. They reported good results in correction of metacarpophalangeal (MP) joint contractures at 12 months follow-up, but only half the patients with proximal interphalangeal (PIP) joint contractures had a good result. In this study, the mean residual PIP joint contracture was 22° at both 1 and 12 months postoperatively. Segmental aponeurectomy is not a favored technique in use today.

In the mid 1990s, the authors of this chapter began to develop another nonoperative therapy using a well-known enzyme, collagenase, for the purpose of lysing the Dupuytren's cord and inducing cord rupture. The concept of enzymatic fasciotomy had been investigated before by Hueston (40), who combined both trypsin and hyaluronidase intraoperatively. This method provided clinical benefit initially, but reportedly had a high recurrence rate (41).

We developed purified collagenase (Auxillian Inc.) as a stand-alone injection therapy and not as an intraoperative adjunct (42,43). The results of Phase 2 clinical trials indicate that collagenase injection into Dupuytren's cords has merit as a minimally invasive treatment of this disorder (44,45). Our experience with this technique is presented below.

INDICATIONS

At the present time, collagenase injection into Dupuytren's cords can only be done as part of the U.S. Food and Drug Administration (FDA) investigational new drug. Indications are evolving as more experience is gained from the clinical trials. The authors have employed this technique on patients with the clinical diagnosis of DD who have 20° or greater flexion contractures of the metacarpophalangeal (MCP) and/or PIP joints. Patients with recurrence of contractures after a surgical release are also candidates for the injection. These criteria are similar to those for open release, where it is generally accepted that progressive MP contractures of 30° or greater or any progressive PIP contracture of greater than 15° is an indication for surgery.

There are relatively few contraindications for this procedure. Patients who are unable to tolerate a needle puncture in the palm and those who may be allergic to the collagenase should not undergo the procedure.

CONSIDERATIONS FOR PRE-PROCEDURE PLANNING

Pre-procedure examination should confirm that DD is the primary cause of the finger flexion deformity. Patients with secondary PIP capsular/volar plate contracture may require operative procedure at the PIP to restore extension. Imaging and other studies are not usually needed.

TECHNIQUE

The procedure is done in the office setting. The skin over the contracted cord is prepped and 10,000 units (0.58 mg AA4500) collagenase (in a sodium/calcium diluent) is delivered into the cord at the point of maximum bowstringing of the finger contracture using an insulin syringe and a 27-gauge needle (Fig. 1). A volume of 0.25 mL for the MCP joints and 0.20 mL for the PIP joints is used. In the case of patients with MCP contractures of adjacent fingers, with pretendinous and natatory Y-shaped cords (Fig. 2), placement of the injection should be at the point of the Y in attempt to affect both digits.

Patients are seen the following day for passive manipulation/extension of the affected digit(s) to manually rupture the cords. Local anesthetic can be used when attempting cord rupture but is not required. If cord rupture does not occur with the manipulation, the patients are instructed to apply extension forces at home under their own control. Home extension exercises are encouraged. Patients are also fitted with a night extension splint that is worn for four months. Daily vitamin E massage for four months is recommended to keep the treatment area soft and pliable.

For multiple joints or digits involvement that did not response adequately to the first injection, the collagenase injection technique is staged at four to six weeks later. The rationale for allowing time between injections was to allow potential adverse events to resolve. A total of three injections can be done directed at the cord of one finger joint contracture. The maximum number of injections per patient, involving several fingers and/or bilateral disease is still under investigation in clinical trials.

Illustrative Case Example

A 70-year-old right hand dominant male presented with bilateral DD of the hands. His contractures involved the right

FIGURE 1 The technique of collagenase injection involves direct cord injection, as shown in this photo of an metacarpophalangeal joint.

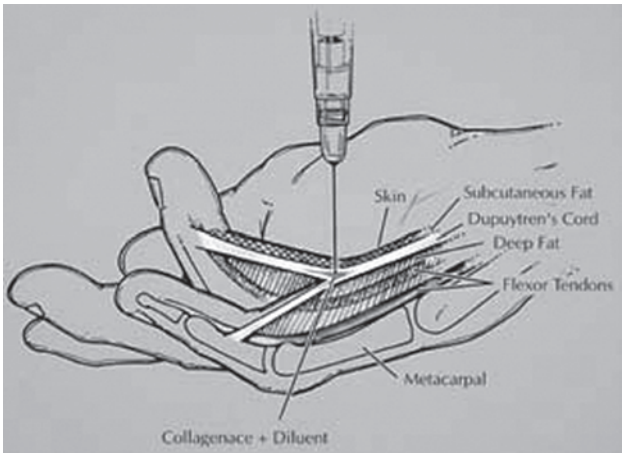

FIGURE 2 Cord injection. When a patient has a Y-shaped cord, created by a combination of the central and natatory cords, the point of the Y should be injected with collagenase. Injection of this site may result in simultaneous correction of adjacent finger metacarpophalangeal joint contractures.

little MP and PIP joints (20° and 50°, respectively) and the right ring MP and PIP joints (50° and 35°, respectively). Left hand disease consisted of 30° long and ring finger contractures. Figures 3 and 4 show this patient's pretreatment contractures. The first collagenase injection was directed at the right ring MP/PIP contractures. The MP joint is always injected first as this is the point of maximal bowstringing. It is not to be expected that both MP and PIP joint contractures will resolve with one injection. This is more likely if there is a central cord. At day one, the cord ruptured and the finger was fully straightened. As the right little MP contracture had a natatory cord, this contracture also fully corrected to 0° by one week post injection. The right little PIP joint contracture was injected with collagenase six weeks later. By one month after collagenase injection, the PIP joint contracture was fully corrected to 0°.

Attention was then turned to the left hand contractures. At five weeks post the second injection, the left ring MP contracture was injected and the cord ruptured the next day with full correction to 0°. Five weeks later, this patient received a final collagenase injection for the remaining left hand, long finger MP contracture. This contracture also responded with cord rupture and full correction to 0° at one day after the injection.

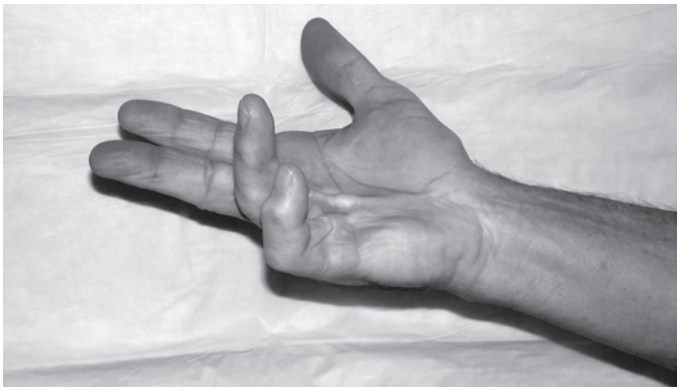

FIGURE 3 A 70-year-old male patient with right hand ring and little finger metacarpophalangeal and proximal interphalangeal joint contractures.

FIGURE 4 Same patient as in Figure 3, left hand long and ring finger metacarpophalangeal joint contractures.

This patient remains free of recurrence was no loss of flexion or grip strength at the last follow-up visit, 12 months post the last injection (Figs. 5 and 6).

COMPLICATIONS AND THEIR MANAGEMENT

Side effects of the collagenase injection include finger/hand edema, tenderness and ecchymosis of the injected finger. In patients whose PIP joint cords were injected, some experienced tenderness of the lymph nodes at the elbow and/or axilla. These adverse events resolved within 7 to 14 days of injection (44,45).

Skin tears can occur during manipulation and cord rupture in patients with long-standing, severe contractures. The tears can be treated with local wound care and will heal within several weeks.

OUTCOMES

The outcome of collagenase correction of Dupuytren's contracture is based on FDA regulated Phase 2 clinical trials (45). The first part of the study was a placebo-controlled, random, double-blind investigation. Thirty-six patients with MP contractures and 13 patients with PIP contractures only were enrolled. Eighteen MP patients were assigned to drug treatment and 18 to placebo.

FIGURE 5 Same patient as in Figures 3 and 4, after successful collagenase injection treatments.

FIGURE 6 Same patient as in Figures 3– 5 showing normal flexion after collagenase treatments.

Fourteen of the 18 MP patients (77%) fully corrected after one 0.58 mg unit collagenase injection. The remaining four patients fully corrected to 0° extension after a second open label, 0.58 mg unit collagenase injection. Two placebo patients with MP contracture also fully corrected, but it was subsequently determined that there was an error by the pharmacist. In fact, these two placebo patients had been given 0.58 mg collagenase. Five of seven patients (71%) with PIP joint contractures who were in the 0.58 mg collagenase group corrected fully after one injection and one patient corrected fully after a second collagenase injection. Six of six open label placebo patients did not respond. Upon re-treatment of placebo patients with 0.58 mg collagenase, four of the six patients (66%) corrected to normal extension. In this study, a total of six patients were injected who had prior surgical fasciectomy with recurrent contractures. All had PIP joint (only) contractures. Three PIP joints were corrected to normal extension and three were not. The recurrence rate, after collagenase injection(s), in this study was 8% for MP joints and 25% for PIP joints, at five years.

Because the results of the 0.58 mg versus placebo study indicated that collagenase injections had substantial merit, after FDA consultation, it was decided that a second random, double-blind, placebo-controlled, dose response study should be performed. This was to determine if 0.58 mg collagenase was indeed the minimum, safe and effective dose. This trial was multicenter with two test sites with 80 patients entered the study (45). Fifty-five patients had MP joint contractures and 25 patients had PIP joint contractures. Patients were randomized to placebo cord injections, ¼ dose, ½ dose, or 0.58 mg collagenase. The 0.58 mg treatment group clearly showed the best clinical benefit in inducing cord ruptures (Figs. 3 and 4). By one month after 0.58 mg collagenase injection, 14 of the 18 patients (77%) with MP contractures achieved full extension. The remaining four patients with MP contractures who did not respond to the first injection had a subsequent 0.58 mg injection. All four MP joints corrected to normal extension by one month.

PIP joint contractures also responded in a similar manner. Five of seven patients (71%) with PIP joint contractures who were treated with the 0.58 mg dose corrected to full extension after one month.

Statistical testing, using Fisher's exact test, indicated that the "clinical success rate" for return to normal extension at the 0.58 mg dose was 90% for MP joint contractures and 70% for PIP joint contractures. The authors speculate that the lower success rate in PIP joints may be due to resistant abductor digiti minimi cords and that division of the volar plate check veins is not possible with collagenase injections. The recurrence rate, after collagenase injection(s), in this study was 10% for MP joints and 20% for PIP joints at five years.

SUMMARY

Collagenase injection into the Dupuytren's cord is a safe and effective minimally invasive method to treat MCP and/or PIP flexion contractures. Patients regain finger extension and thus have improved range of finger motion. Flexion and grip strength were not adversely affected by collagenase injection. A random, placebo-controlled, dose-response study in clinical trial IIB showed that 0.58 mg of collagenase is the minimum safe and effective dose for cord injection. Adverse effects of collagenase injection are limited to local tissue reaction consisting of pain, edema, ecchymosis, and an occasional elbow and/or axillary lymphadenopathy. These side effects resolve in the short term and have no long-term sequela. To date, clinical trials show relatively low recurrence rates. We expect that recurrences of disease can be treated with repeat collagenase injections. Those that fail the maximum number of injections can still be treated with an open surgical procedure.

At the time of this writing, collagenase injection for DD of the hand is not yet commercially available. Multi-center, Phase 3 clinical trials are ongoing to provide data to the FDA for approval. In the future, this minimally-invasive technique of cord rupture may prove revolutionary as a stand-alone treatment of DD.

SUMMATION POINTS

Indications

- Can only be used as FDA investigational new drug
- Similar to those for open release
- Recurrence of Dupuytren's contractures after surgical release

Contraindications

- Allergy to collagenase

Outcomes

- 90% of MP joint contractures regain full extension
- 70% of PIP joint contractures regain full extension
- Recurrence rate of 10% for MP joints and 20% for PIP joints at five years

Complications/Adverse Effects

- Finger/hand edema
- Tenderness and ecchymosis of the injected finger
- Transient lymphadenopathy at elbow and/or axilla
- Skin tears

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Orthopaedics

about the book...

Hand and wrist surgery is evolving rapidly, and often advances are directed at developing procedures that are less invasive, with smaller incisions and shorter rehabilitation times. ***Minimally Invasive Hand and Wrist Surgery*** is the only book devoted exclusively to these exciting new percutaneous and minimal access techniques for the treatment of chronic and traumatic conditions of the hand and wrist. Nearly forty procedures are described, with step-by-step details and abundant illustrations, all contributed by the leading international experts who are pioneering these new approaches.

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about the editors...

JOHN T. CAPO, M.D. is Chief, Division of Hand and Microvascular Surgery in the Department of Orthopaedics at the New Jersey Medical School in Newark. He is also a staff surgeon and the director of the residency rotation at Christ Hospital in Jersey City, New Jersey. Dr. Capo received his Hand, Upper Extremity and Microvascular training at the Indiana Hand Center in Indianapolis and completed an AO Traveling Fellowship in Toronto, Canada and Bern, Switzerland. He has given over 75 international presentations on the upper extremity and has written over 20 peer reviewed articles.

VIRAK TAN is Co-Chief and Associate Professor, Division of Hand and Microvascular Surgery, Department of Orthopaedics, New Jersey Medical School, Newark, a staff surgeon at the Overlook Hospital, Summit, New Jersey, and is in a group practice at the North Jersey Orthopaedic Institute. Dr. Tan received his M.D. from the University of Pennsylvania School of Medicine, Philadelphia and has written over 30 peer reviewed articles.

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Telephone House
69-77 Paul Street
London EC2A 4LQ, UK