S. ROBERT ROZBRUCH
REGGIE C. HAMDY
EDITORS

Limb Lengthening and Reconstruction Surgery Case Atlas

Adult Deformity · Tumor
Upper Extremity

Limb Lengthening and Reconstruction Society · Association for the Study and Application of the Methods of Ilizarov
1989

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Adult Deformity – *S. Robert Rozbruch*

Tumor – *Levent Eralp*

Upper Extremity – *John E. Herzenberg*

With 934 Figures and 1 Table

Springer Reference

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To my wife Yonina and to my children Jason and Libby: thanks for your love and support. You have added immense joy and meaning to my life. In memory of my dear parents Max and Frieda, whose survival created purpose for me and from whom I learned that while ideas are great, follow-through and completion are awesome.

S. Robert Rozbruch, M.D.

I dedicate this Atlas to my wife Sylvie and to my son Sebastien, who have endured so much while I was working on the various chapters; to my mother, who – at the age of 97 – never fails to remind me every time I speak to her, "Don't work too much"; and to a very special person, the best teacher I have ever had, the best mentor I would have ever dreamed of having, my father. He will not see this atlas, but I am sure he would have been proud of it.

Reggie C. Hamdy, M.D.

In memory of our dear friends, colleagues, and past presidents of the Limb Lengthening and Reconstruction Society (LLRS), George Cierny, M.D., and Doreen Di Pasquale, M.D. You are sorely missed, and we know how pleased you would have been to see this society publication.

SRR and RCH

Foreword

There is a saying in Russian: it's better to see something once than hear about it a hundred times.

Dr. Robert Rozbruch and I have known each other for many years. We were first introduced by a colleague, and mutual friend, at a Christmas party in 2001; within a year, planning began to develop a new service at Hospital for Special Surgery focusing on specialized orthopedic treatment and research strategies. I was instantly impressed by his unsurpassed enthusiasm and goal-oriented personality and a certain indescribable quality, the combination of which resembled that of my father. The service rapidly took off, thanks to the leadership of Dr. Rozbruch and the team's approach, which mimicked my father's style in review of cases, detailed documentation (including pre- and postoperative photographs), X-rays, and an overall unbridled sense of quality. Pre-op conferences, publications, and presentations, all of which were a priority for the team, gradually became a routine (though not monotonous!) and finally a well-oiled machine. This was still just the beginning of the limb lengthening program at Hospital for Special Surgery!

Throughout my professional career, I placed a great deal of focus and effort into studying the cases presented in my father's book, *Transosseous Osteosynthesis*, also a Springer publication, which numbered in the hundreds and depicted fascinating transformations through before and after photographs and radiographs; I used this all-encompassing tool as my bible and would always refer to its omniscience in search of a similar case or as a source of inspiration to apply in our practice.

The idea for this atlas was conceived by Dr. Rozbruch while in the editing stage of our book *Limb Lengthening and Reconstruction Surgery* (Informa, 2007). Thanks to his tireless enthusiasm, unlimited energy, and perseverance, this book found life. I can truly say that I do not know anyone capable, in record time, to achieve knowledge, experience, and success with such complex cases and simultaneously bring together the now thriving LLRS community in an organized and constructive way to allow for sharing of this wealth of information with the world.

Dr. Rozbruch is currently the chief of the Limb Lengthening and Complex Reconstruction Service at Hospital for Special Surgery and served as President of the Limb Lengthening and Reconstruction Society (LLRS) in 2012–2013. He is also a Professor of Clinical Orthopedic Surgery at Weill Cornell Medical College, Cornell University.

Dr. Reggie Hamdy is well known for his achievements in orthopedics and research, and especially in limb lengthening and reconstruction. Dr. Hamdy is the Chief of Staff and Director of Clinical Research (Orthopedics) at Shriners Hospital for Children in Montreal and Professor of Surgery (Orthopedics) at McGill University. He is currently Vice President and will be President of LLRS in 2014–2015. He is the Program Chair of Limb Lengthening and Reconstruction Society annual meeting in Montreal, Canada, 2014. Dr. Hamdy was editor of *Management of Limb-Length Discrepancies*, an American Academy of Orthopaedic Surgeons monograph series published in 2011.

Drs. Rozbruch and Hamdy's goals in this atlas are to present a unique collection of cases in the already unique field of limb lengthening and reconstruction. This is the first and only atlas of a truly worldwide nature, depicting cases without national boundaries and, even more importantly, demonstrating a true sense of cooperation among physicians in sharing information for the betterment of mankind.

Despite the wonderful work that the contributors perform in the operating room, one must not forget the sometimes tedious task of documentation in office notes, taking into consideration the very particular state of current medicine. As such, I applaud each and every contributor that has made this atlas possible by making an extra effort, creating extra time (in an already overbooked schedule), and sharing their successes with the small, yet robust, limb lengthening and reconstruction community.

It is my hope that this atlas, with its invaluable information, will help not only the current but future physicians to find solutions in this challenging field and be a source of inspiration to both beginners and seasoned veterans when faced with complex cases and hopeless patients. With the wealth of knowledge etched into the pages of this work, every medical subspecialty may use this as a source to expand upon their knowledge and be able to provide patients with even more options in a rapidly expanding medical world.

I would encourage reviewing these cases and can fully assure that you will encounter patients in your practice who spark an urge to thumb through this book and locate a similar case that reminds you of your challenge. In times of doubt about the direction of a case, reach for this atlas. I promise the solution will come to you, and even if it doesn't, you will hold in your hands the names of people who possess and represent the world knowledge in limb lengthening and reconstruction. You will find your hand ultimately reaching for this atlas, I guarantee it.

My other hope in the release of this atlas is that it will serve as an example of good old medical practice, encouraging you to document challenging cases to not only learn from them but share them with the now global medical community.

March 2014 Svetlana Ilizarov

Introduction

During the second decade of the eighteenth century, Dutch physician Herman Boerhaave revolutionized medical education when he substituted clinical case teaching for the previous method of abstract pedantic instruction. His system soon catapulted Leiden's School of Medicine to the A list of the era.

Within a generation, Europe's other top medical schools – Stockholm, Paris, London, and Edinburgh – had adopted Boerhaave's methodology. The University of Edinburgh, epicenter of the Scottish Enlightenment, educated Colonial America's first physicians; their clinics and dispensaries became the nucleus of future medical schools in Boston, New York, and Philadelphia. It's no wonder, therefore, that clinical case pedagogy has always been a hallmark of North American medical education. *The New England Journal of Medicine's* Clinical-Pathological Conference exemplifies this principle.

In 1951, Soviet surgeon G. A. Ilizarov unlocked from within bone a previously hidden capacity to form limitless quantities of new osseous tissue under appropriate conditions of fracture, preliminary healing, and rhythmic distraction in a stable mechanical environment. As a result, surgeons could cure previously untreatable congenital, developmental, and acquired conditions in ways never before thought possible.

Ilizarov's monograph, *Transosseous Osteosynthesis*, contains introductory chapters summarizing research that validates the underlying biological principle of the Ilizarov method. For the most part, however, his textbook is a compendium of case examples, selected to illustrate the range of therapeutic options available to deal with conditions amenable to treatment with distraction osteogenesis.

Like Boerhaave, Ilizarov realized that case study is often the best way to convey clinical and technical information to those interested in learning the practical aspects of a body of knowledge.

As interest in Ilizarov's discoveries spread around the world, like-minded surgeons formed national ASAMIs (Association for the Study and Application of Methods of Ilizarov), starting in Italy in 1982. By the end of the 1980s, dozens of such organizations were holding annual meetings where reports of basic research and biomechanical studies were interspersed with clinical case and series reports. Likewise, new therapeutic strategies and ingenious devices debuted at such meetings.

ASAMI-North America, formed in 1989, evolved into the Limb Lengthening and Reconstruction Society, now a component of the American Academy of Orthopaedic Surgeons' Board of Specialty Societies. LLRS members attending the group's annual meetings were among the first clinicians to learn about modifications of Ilizarov's apparatus. These included half-pin mounting strategies, radiolucent components, internal-external fixation combinations, motorized lengthening rods, computer-associated hexapod frame configurations, and fully implantable distraction devices.

Additionally, attendees heard about new treatment-based disease classification systems, inventive osteotomies and soft-tissue releases, and, most significantly, protocols to reduce the incidence of pitfalls and complications.

In 2012, LLRS President Rob Rozbruch tasked himself the job of revising the moribund LLRS website, an occasionally accurate list of active members and meeting announcements. He envisioned the Society's website as a forum where surgeons would, in the tradition of Boerhaave and Ilizarov, upload instructive clinical cases as an educational tool for colleagues facing similar pathologies. Also, as a dynamic Internet location, the LLRS website would introduce members to the subtleties of new devices and procedures.

Another LLRS executive, current president Reggie Hamdy, joined Rob Rozbruch in begging, cajoling, wheedling, sweet-talking, and otherwise persuading LLRS members to submit illustrative cases that included information about the condition being treated, the therapeutic strategy and course of treatment, as well as the potential complications and pearls of wisdom. Rob and Reggie selected knowledgeable section editors to assure inclusion of a wide range of conditions and adherence to format.

The present volumes grew from that effort as surgeons from around the world responded with surprising enthusiasm and diligence to the requests for case examples. Congratulations to all those who have contributed to this project.

This year is the 300th anniversary of Boerhaave's 1714 appointment as Rector of the University of Leiden's School of Medicine, a position that allowed him to establish clinical case teaching as the essential focus of medical education.

Herman Boerhaave would no doubt say, upon reviewing the present volumes, "Het is goed." And Professor Ilizarov would heartily agree, "Да, очень хорошо."

Irvine, California Stuart A. Green

Preface

Limb lengthening and reconstruction surgery is a relatively new subspecialty of orthopedic surgery. The Limb Lengthening and Reconstruction Society (LLRS) became a member of the Board of Specialty Societies (BOS) of the American Academy of Orthopedic Surgeons (AAOS) in 1999, and we have been working over the last few years to create a Limb Deformity section in the educational program of AAOS. This is a work in progress, but I am confident that it will happen. We do find it difficult at times to define and differentiate ourselves since there is an apparent overlap with other subspecialties including adult reconstruction, trauma, foot and ankle, pediatrics, tumor, and upper extremity. But we are unique and distinct. We use the principles of deformity correction and stress the relationships among the hip, knee, and ankle. We use osteotomy to correct deformity and leg length discrepancy, adhering to the principles of the Ilizarov method. We use external fixation as well as internal fixation, and we perform limb salvage and joint preservation surgery. We address both simple deformity and complex cases with multiapical deformity, bone loss, and infection. We are distinct from the other subspecialties of orthopedic surgery, and our colleagues often call on us when they don't know what to do or when they think our approach will best suit their patient.

I have always found case-based learning to be especially enjoyable and educationally effective. This is not to say that traditional books and lectures with factual knowledge, principles, and data are not needed. Of course they are essential and compose the foundations of medical education found in lectures, textbooks, and peer-reviewed publications. However, I have always most enjoyed case presentations and the case examples as part of the lecture or abstract presentation. In fact, when I currently deliver a lecture, I predominantly use clinical cases to illustrate principles, strategies, and outcomes. I have also come to realize that I am not alone on this issue. In talking with colleagues, many people feel the same way and find it rather natural to review or present a case. As orthopedic deformity surgeons, we are visual, practical, and creative. It is more simple and natural for most of us to teach by assembling a case for presentation than to write a chapter or a manuscript. The same approach applies to learning as it does to teaching.

The chapter format used in this case atlas mimics my own personal approach to evaluating and treating a patient. When I was a fellow in Baltimore in 1999, I learned to perform a detailed physical examination, measure and analyze X-rays, and generate a problem list for every patient I evaluated. This exercise enabled me to analyze a very complicated case and break it down to its composite parts. The patient then became less complicated. My next step was to come up with a treatment strategy based on principles to address all component parts of the problem list. This often demanded creativity and some courage, but since the plan was based on sound principles, it was less intimidating. With increasing experience, I learned to utilize technical tricks, and these "pearls" were most helpful in surgery. I started to think a couple of steps ahead and have a backup plan or two in order to avoid and manage complications. Finally, I learned to diligently document cases in a photo database to be used for patient and colleague education as well as research. This has been my approach to limb deformity practice over the last 15 years. This was the approach that Ilizarov used and taught to the world. His major work *Transosseous Osteosynthesis* (Springer, 1991) was organized in large part like a case atlas, and with humility, I wanted to imitate his approach in this book.

Reggie Hamdy, my coeditor, and I have worked together on the board of the LLRS for several years and have become good friends. With education as a primary goal, we have collaborated on several projects and aspired to organize a case atlas for limb lengthening and deformity surgery. The goal was to feature all the components of this emerging field and to showcase the expertise of masters from around the globe. We wanted the format to be easily digestible and uniform.

With this background, we formatted our case atlas using the logical approach just discussed:

1. Abstract
2. Basic clinical history
3. Preoperative photos and X-rays
4. Problem list
5. Treatment strategy
6. Basic principles
7. Photos and X-rays during treatment
8. Technical pearls
9. Outcome photos and X-rays
10. Avoiding and managing complications
11. Cross references: list of other similar cases in the atlas
12. References and additional reading

The next goal was to include all the clinical areas that utilize the principles and techniques of limb reconstruction. This led to the development of six sections:

1. Pediatric Deformity
2. Trauma/Post-traumatic Reconstruction
3. Foot and Ankle
4. Adult Deformity
5. Tumor
6. Upper Extremity

Each of the sections has an introduction written by the section editor discussing its scope.

On a practical note, most of the text in this work is in outline format. Abbreviations are used liberally, and these include mechanical axis deviation (MAD), lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), lateral distal tibial angle (LDTA), anterior distal tibial angle (ADTA), leg length discrepancy (LLD), center of rotation and angulation (CORA), Taylor spatial frame (TSF), degrees (deg.), open reduction and internal fixation (ORIF), range of motion (ROM), and anteroposterior (AP).

I want to thank our brilliant contributors from around the world. With a large collection of cases, the reader will be exposed to an array of limb lengthening and reconstruction surgery. You will also notice similar cases presented by different authors who use differing approaches. Our field has less uniformity and more creativity than our brother subspecialties. Furthermore, I want to thank our colleagues who graciously agreed to be section editors: Mitch Bernstein, Levent Eralp, Austin Fragomen, John Herzenberg, Joe Hsu, and Chris Iobst, who have helped organize their sections and for their thoughtful and diligent review and editing of cases in their sections. Thanks to Seth Leopold, a fellow medical student at Cornell and now editor in chief of *Clinical Orthopaedics and Related Research*, who believed in this project and introduced me to Springer Publishing. Additional thanks go to the fantastic Springer team, including

Kristopher Spring, who helped initiate the project, and our wonderful, energetic, and organized German editorial team, Daniela Graf and Kerstin Beckert, without whom this project would not have been possible. I also want to thank my mentors Dror Paley and John Herzenberg, who generously taught me this craft, and Russ Warren and Tom Sculco at Hospital for Special Surgery (HSS), who had vision, believed in me, and gave me the opportunity of a lifetime to start a limb deformity service at HSS. This project would not have been possible without the friendship, encouragement, thoughtfulness, experience, and hard work of my coeditor, Reggie Hamdy. The beautiful cover art which portrays growth was graciously done by my talented wife and artist, Yonina Jacobs. Finally, a special thanks to my wife, Yonina, and to my children, Jason and Libby, whose love and encouragement make me smile and give me strength every day.

May 24, 2015 S. Robert Rozbruch

Preface

Limb reconstruction surgery is an emerging specialty, which has evolved over the last three decades as a result of innovations in the fields of bone regeneration and deformity correction as well as the development of various internal and external devices for stabilization of bony segments. However, this new specialty is much more than the simple acquisition of certain surgical skills and mastering the use of various fixators. It is a "philosophy" on how to approach a child or adult with a limb deformity. We start by identifying the problem and defining its impact on function, and this is followed by a detailed clinical and radiological assessment of the deformity. If there is an indication to surgically correct the deformity, then the next step is to proceed with careful preoperative planning and then finally execution of that plan. This is what this atlas is all about.

It is a monumental work, which was made possible only by the collaboration of many surgeons from numerous countries and members of the editorial office of Springer, Heidelberg, Germany. It includes a wealth of knowledge demonstrated with 306 cases compiled in three volumes, written by international experts in the field. All the cases follow the same format or "philosophy," which was designed by Rob Rozbruch (senior Editor). This unique format includes separate paragraphs on treatment strategy, basic principles, and technical pearls, as well as how to avoid and manage problems. The purpose of this atlas was developed to address multiple needs: as a teaching and educational tool for all medical and paramedical personnel involved in the management of limb deformities, as a guide for surgical approaches and techniques, as a manual on the use of various types of external and internal fixators, and, most importantly, as a philosophy on how to approach a patient with limb deformity. By putting together in one single reference work the experience, skills, and knowledge of all these authors, this atlas has fulfilled this purpose. This atlas is also unique in another way. Unlike other standard books and chapters, which are usually written by one single author, in this atlas the same problem may be addressed in several different cases by different authors with a different approach to the same problem. This content gives the readers a choice of options. This atlas is by no means comprehensive, and we welcome any suggestions that may lead to an improvement in the text and cases in the next edition.

This atlas is also intended to be a tribute to a giant in orthopedics, Gavriil Ilizarov, "The Magician of Kurgan," whose pioneering work in the field of distraction osteogenesis made possible all these new advances in technologies and techniques. His legacy has touched the lives of thousands of patients across the world. We, his disciples, are proud to be members of this great discipline, "Limb Lengthening and Reconstruction." This atlas is proof that there is almost no deformity that we cannot address. We learned the necessary skills from the giants who have preceded us, and now it is our role and responsibility to pass on these skills to the next generation. I sincerely hope the contents of this atlas will be of benefit to everyone who participates in the care of patients with limb deformities.

Finally, I would like to express my deep gratitude to Kerstin Beckert and Daniela Graf from Springer, who spared no time or effort in seeing this project to completion. Both have demonstrated unparalleled patience, specifically with me. Since the start of this project, we

have been exchanging hundreds (if not thousands) of e-mails. I would like to acknowledge the exceptional work of Denis Alvez, Mark Lepik, and Guylaine Bedard from the Illustration Department of the Shriners Hospital for Children – Canada in Montreal. They are truly dedicated and motivated artists working behind the scene. I would like to thank the section editors and all who contributed to this atlas. Last but not least, a very special thank you to my longtime friend Rob Rozbruch, with whom I have been working very closely on this project. It has been a privilege and pleasure working with him. When both of us embarked on this project 2 years ago, we could have never envisaged that it would be such an endeavor. Now that we see the final result, we are proud of what we have accomplished. A final word to say a very special Thank you to two very special persons for their continuous and unwavering love, understanding and support, my wife Sylvie and my son Sebastien.

Reggie C. Hamdy

Booknotes

This book is part of a set consisting of three volumes:

Volume 1: "Pediatric Deformity"
Section: Pediatric Deformity – *Reggie C. Hamdy and Christopher Iobst*
Contents: Pediatric Trauma
Growth Plate Injuries
Congenital Pseudarthrosis of Tibia and Fibula
Congenital Lower Limb Deficiencies
Pediatric Blount Disease
Pediatric Arthrogryposis
Pediatric Skeletal Dysplasias
Pediatric Metabolic and Vascular Disorders
Pediatric Hip Deformities
Pediatric Foot and Ankle Deformities
Pediatric Chronic Osteomyelitis
Pediatric Rotational Deformities (Miserable Malalignment Syndrome)

Volume 2: "Trauma • Foot and Ankle"
Section: Trauma – *Mitchell Bernstein and Joseph R. Hsu*
Contents: Femoral Reconstruction
Tibial Reconstruction
Intentional Deformation – Tibia
Distal Tibial Periarticular Reconstruction

Section: Foot and Ankle – *Austin T. Fragomen*
Contents: Ankle Arthrodesis
Ankle Distraction Arthroplasty
SMO (Supramalleolar Osteotomy)
Charcot Neuroarthropathy
Complex Foot Deformity
Metatarsal Reconstruction

Volume 3: "Adult Deformity • Tumor • Upper Extremity"
Section: Adult Deformity – *S. Robert Rozbruch*
Contents: Internal Lengthening Nail
Femoral Deformity
Tibial Deformity
Multiple Segment Deformity
Integrated Fixation

Hip
Knee
Knee Fusion
Bone Defects
Amputation Reconstruction

Section: Tumor – *Levent Eralp*
Contents: Reconstruction Following Resection of Benign Bone Tumor
Reconstruction Following Resection of Malignant Bone Tumor
Reconstruction of Failed Initial Treatment
Reconstruction Following the Sequela of Resection

Section: Upper Extremity – *John E. Herzenberg*
Contents: Humerus
Elbow and Forearm
Hand
Upper Extremity Trauma

Contents

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Principles of Deformity Correction

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Patients with lower limb deformities constitute a large proportion of referrals to both pediatric and adult orthopedic clinics. A practical approach to assessing and treating lower limb deformities should include four distinct steps. **First,** know what is normal: determine if there a deformity or if it is part of the normal development of the child. **Second**, define the characteristics of this deformity (type, site, plane, and magnitude). **Third**, decide if the deformity needs to be treated (depending on the clinical picture). **Fourth**, generate a treatment plan. In this atlas, more than 300 cases of lower and upper limb deformities of various etiologies are presented. A detailed analysis of these deformities is a prerequisite for appropriate planning of surgical correction. This chapter presents a practical approach to the assessment of lower limb deformities.

When a skeletally immature patient presents with a lower limb deformity, the first priority is to rule out **physiological** "deformity." Almost all newborn babies have a symmetrical angular genu varum deformity of the legs that changes to a genu valgum deformity around 18–24 months of age. This partially corrects, gradually, until the age of 7–8 years old, when the adult anatomic valgum value of 7° is reached (Fig. 1). Similarly, the vast majority of rotational deformities in children (in-toeing and out-toeing) is physiological and usually corrects with age. However, in some patients, these deformities are not physiological but secondary to **pathological conditions** (congenital or acquired) and should be fully investigated.

History taking. The presenting symptoms should be clearly identified: what is the reason for the consultation? Is this a cosmetic or functional problem? What are the functional limitations this deformity inflicts on the patient? Is pain present? What are the characteristics of this pain (when did it start, is it acute or chronic, any associated symptoms, any systemic manifestations, what are the relieving and precipitating factors, localization, radiation of the pain, character of the pain)? Are daily activities affected? In certain conditions, such as skeletal dysplasias and metabolic disorders, other nonskeletal systems may be affected, and it is important to recognize these. The patient may have more than one deformity. It is imperative to identify which deformity (or deformities) is the cause of the symptoms. It is also imperative to determine the cause of the deformity as this may have an impact on the surgical planning. In skeletally immature patients, the deformity may be progressive. This is especially true for partial growth arrest deformities. In addition, the possibility of recurrence of the deformity after a successful correction has to be explained to the patient and family.

Physical examination is very important for the assessment of not only bony deformities but also other musculoskeletal pathologies such as joint contractures and soft tissue problems, including the condition of the skin and soft tissues surrounding the deformity. These factors will have an impact in the decision-making process regarding acute versus gradual correction and bony stabilization. A complete neurovascular assessment should be performed. More than one type of deformity may be present, including angular (in frontal, sagittal, or oblique planes), rotational, translational, axial (limb length discrepancy), or multiplanar deformity. The deformities could be unilateral or bilateral and may be associated with other

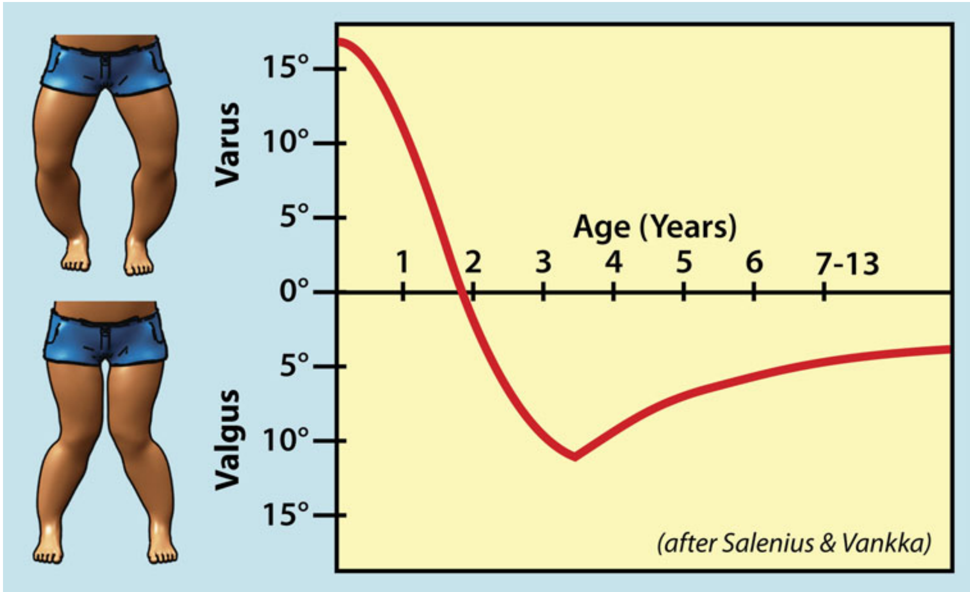

Fig. 1 Normal age limits for physiological genu varum and genu valgum

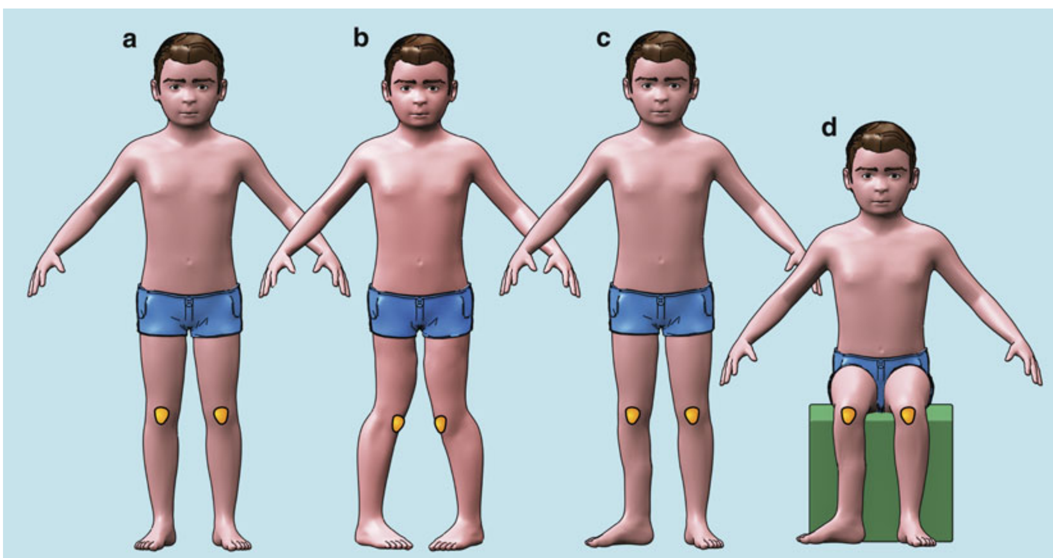

Fig. 2 (**a**–**d**) (**a**) Normal rotational alignment of the lower limbs. (**b**) Bilateral Internal rotation deformity of the lower limbs (in-toeing), partly due to exaggerated femoral anteversion, as the patella are "kissing" each other. (**c**) Right-side external rotation deformity due to external tibial torsion (patella is pointing forwards). (**d**) Sitting position showing external rotation deformity of the right tibia

musculoskeletal problems, as well as non- musculoskeletal problems. Physical examination is of specific importance in the identification and assessment of rotational deformities and limb length discrepancies. For rotational deformities, clinical examination is usually sufficient to quantify, plan, and correct the rotational deformity (Figs. 2 and 3). For a more precise measurement of rotational deformities, a CT scan can be performed (Fig. 4). Plain X-rays may suggest a rotational malalignment, but cannot quantify the magnitude of the deformity. For limb length discrepancies, a wooden block placed under the shorter leg to level the pelvis usually gives a good clinical measure of the magnitude of shortening (Fig. 5). When there are angular deformities in the limbs, it is important to differentiate true from apparent LLD (Fig. 6). Each deformity should be identified and characterized separately in order to decide which one (or ones) needs to be addressed and which need not be corrected.

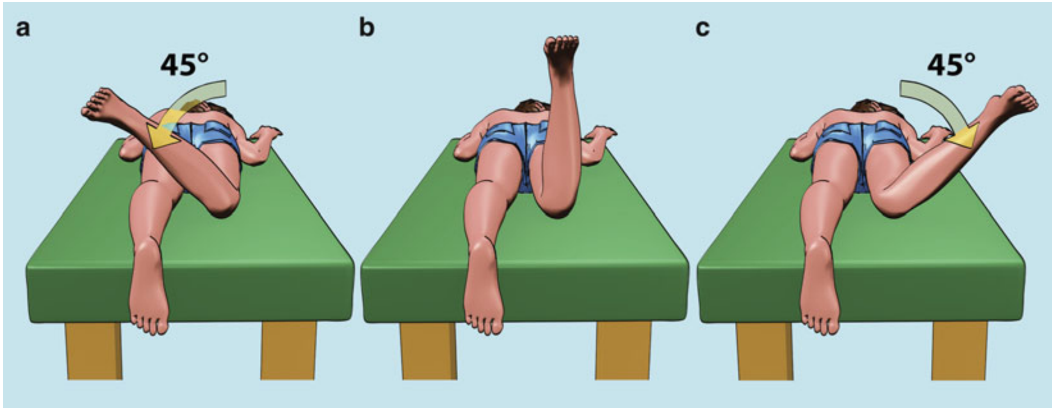

Fig. 3 Rotational alignment in the prone position. (**a**) Hip external rotation. (**b**) Hip in neutral position. (**c**) Hip internal rotation

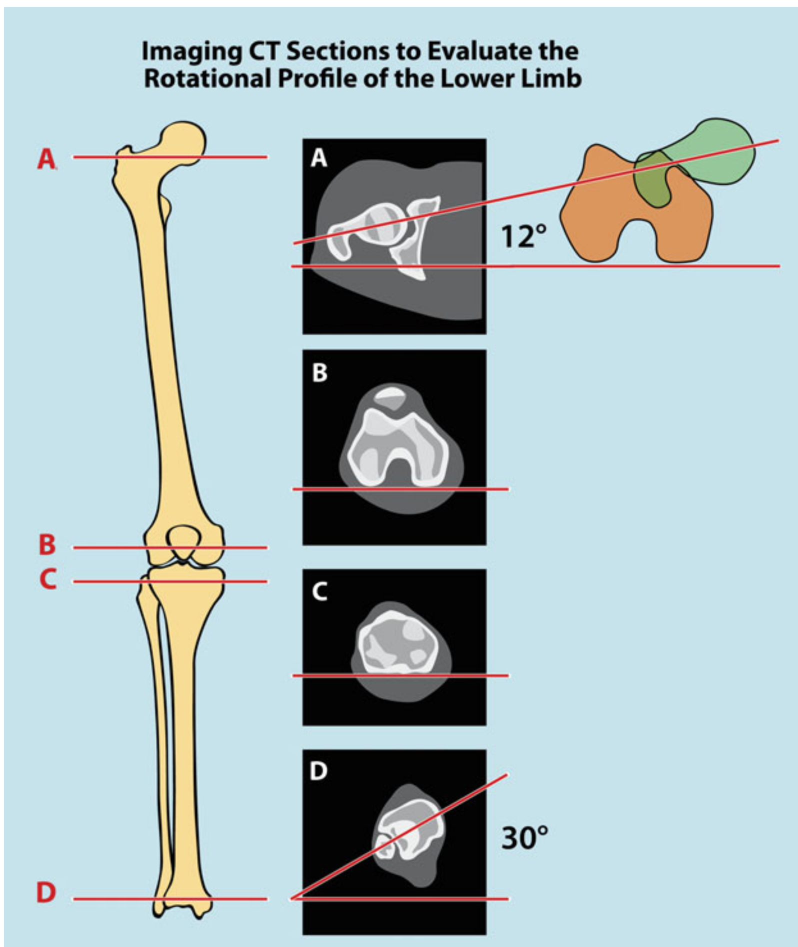

Fig. 4 CT scan measurement of rotational profile, using transverse cuts through. (**a**) Proximal femur (femoral anteversion) – normal 12°. (**b**) Distal femur (femoral condyle alignment). (**c**) Proximal tibia. (**d**) Distal tibia

Radiological assessment of bony deformities should address **six key questions**:

– What is the plane of the deformity (frontal, sagittal, or oblique)?
– What is the direction of the deformity (varus/valgus, anterior/posterior)?

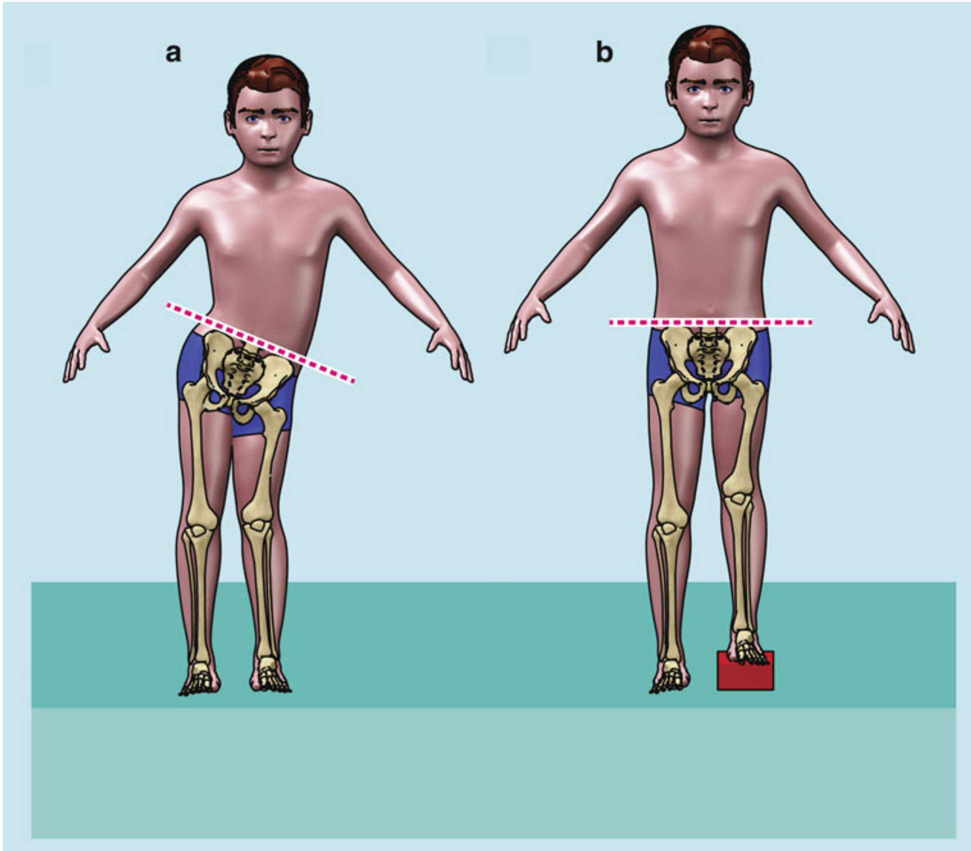

Fig. 5 Measurement of LLD with wooden blocks. (**a**) Without block, the pelvis is oblique. (**b**) With wooden block elevation equal to the LLD, the pelvis is level. This method takes into consideration the heel height, but cannot be used in the presence of knee or hip contractures

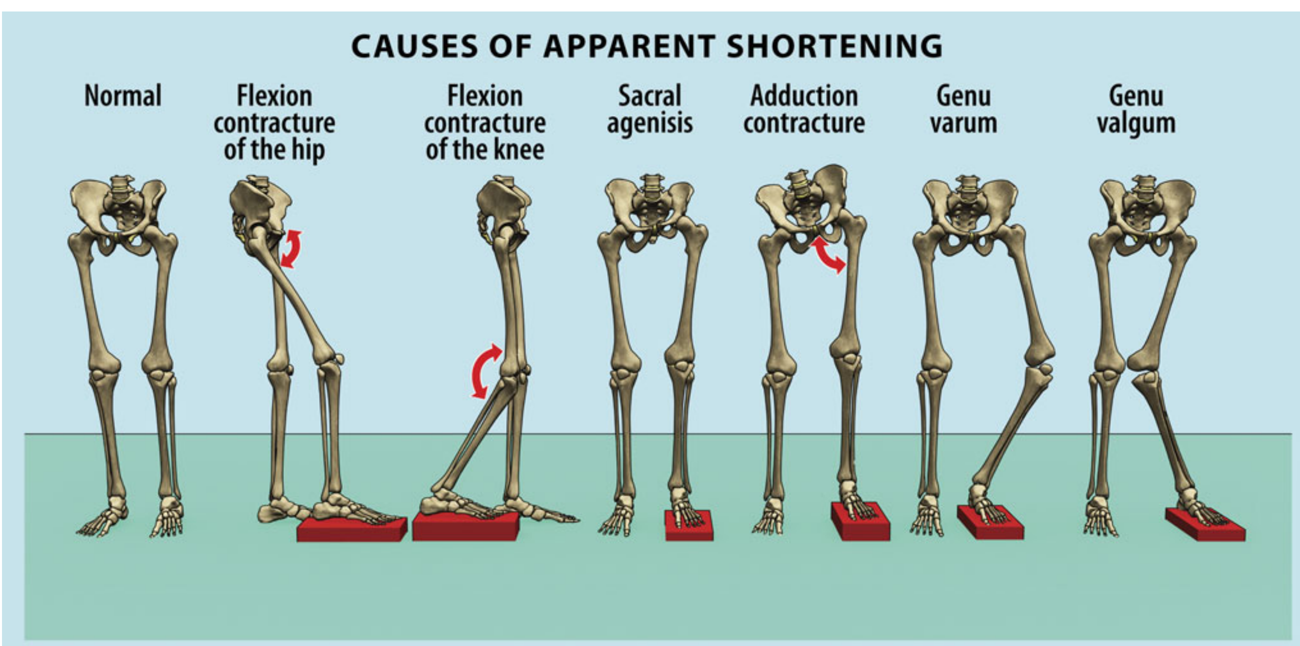

Fig. 6 Causes of apparent limb length discrepancy

– Which bone and/or joint is affected (femur, tibia, knee, or ankle joint)?
– Which segment of the bone is affected (epiphysis, metaphysis, or diaphysis)?
– Where is the apex of the deformity?
– What is the magnitude of the deformity?

The next step is to decide **whether or not the deformity needs to be corrected**. In other words, what are the indications for surgery? The decision to surgically address a deformity should take into consideration symptomatology, radiological assessment, the functional limitations of that deformity, the potential psychosocial impact of surgery, and the ability of surgery to improve these problems. In general, if function is affected, then surgery is indicated. The **goal of correcting any deformity** is to improve function and restore normal mechanical alignment of the lower limbs and thus prevent degenerative changes in the articular cartilage.

Having decided to proceed with surgical correction of the deformity, the next question is **how to correct the deformity:** is it by acute or gradual correction? If it is decided to proceed with an **acute correction**, then what type of osteotomy should be performed: closing, opening, neutral wedge, dome, or oblique osteotomy. One must consider how to stabilize the osteotomy: by internal or external fixation. To increase the accuracy and ease of acute correction, **fixator-assisted plating or nailing** techniques could be enlisted. The second option is **gradual correction** of the deformities by either **growth modulation** (in skeletally immature patients) or with external fixators or internal devices. The third option is **combined acute and gradual correction**, where one or more deformities are acutely corrected and then gradual correction is used for the remaining deformities, usually limb length discrepancy.

Radiological Assessment of Lower Limb Deformities

The first step is to obtain appropriate X-rays of the entire lower limbs standing with patellae pointing forward (usually the patella can be seen on the X-rays), as well as AP and lateral views of affected bones.

The following parameters are analyzed:

(I) Mechanical and anatomical alignment of the whole lower limb as well as that of individual bones
(II) Joint orientation lines
(III) Joint orientation angles
(IV) Apex of the deformity as determined by the CORA (center of rotation of angulation)

Mechanical Alignment of the Lower Limbs (Weight-Bearing)

Frontal Plane Alignment

Each long bone has two axes: mechanical and anatomical (Fig. 7).

The ***mechanical axis*** of a long bone is represented by a line joining the centers of the joints proximal and distal to that bone. The ***anatomical axis*** passes through the center of the diaphysis and is represented by a line joining the center of the transverse diameter of the diaphysis through several points along the bone:

- **Mechanical Axis** of the whole lower limb (Fig. 7a).
  – Is a straight line from the center of the femoral head to the center of the ankle or middle of tibial plafond.

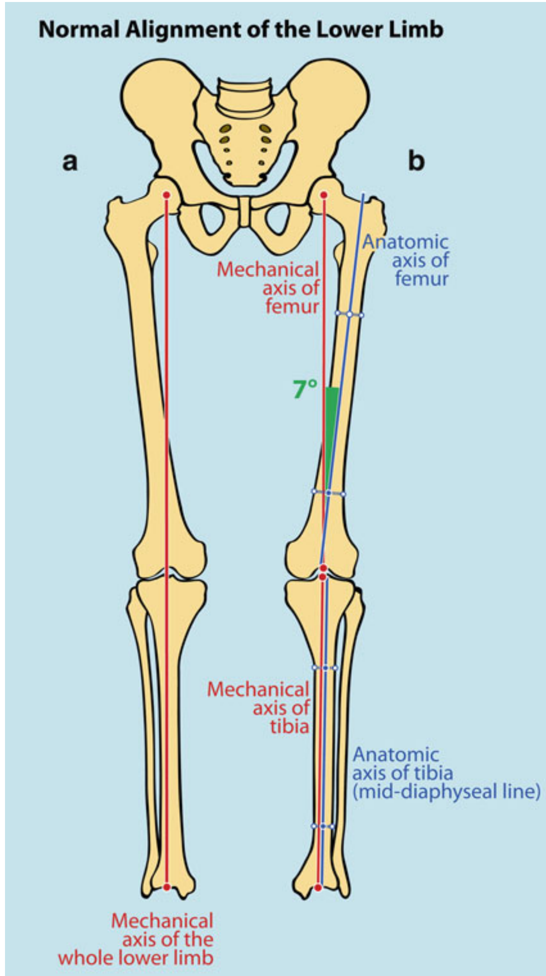

Fig. 7 (**a**) Mechanical axis of the whole lower limb. (**b**) Mechanical and anatomical axes of the femur and tibia

  - This is always a straight line.
  - Falls just medial to the center of the knee (up until 8 mm).
  - Measures varus/valgus angulation.
- **Mechanical and anatomical axes of individual bones (Fig. 7b):**
  (a) **Femur mechanical axis**
  From center of the femoral head to center of the knee (different from the anatomical axis)
  (b) **Femur anatomical axis**
  Is a mid-diaphyseal line: straight in the frontal plane
  Curved in the sagittal plane
  (c) **Tibia mechanical axis**
  Line from the center of the knee to the center of the ankle
  (d) **Tibia anatomical axis**
  Mid-diaphyseal line
  In the tibia, anatomical and mechanical axes are parallel and for practical purposes are the same
- **Mechanical axis deviation** (**MAD**) or **malalignment** (**Fig. 8**).
  - Represents loss of colinearity of the hip, knee, and ankle in the frontal plane.
  - Is the distance between the mechanical axis of the whole lower limb and the center of the knee. Could also be expressed in percentage.

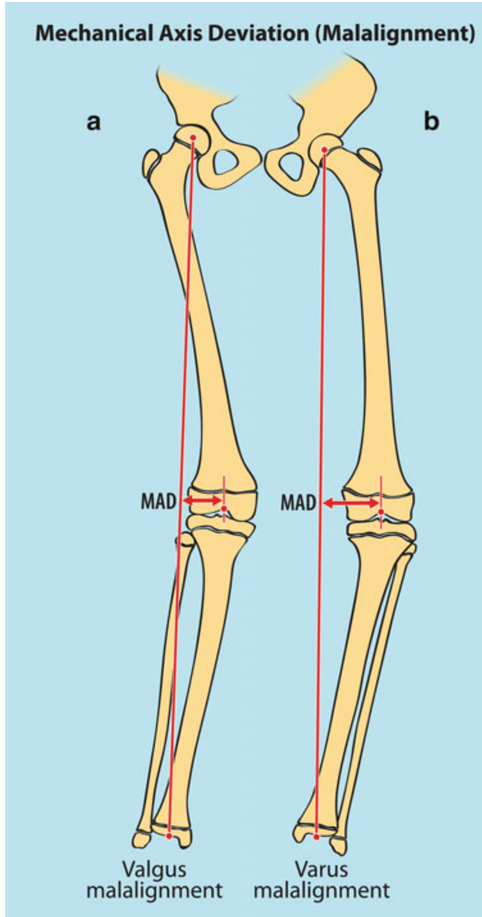

Fig. 8 *A* Valgus mechanical axis deviation (valgus malalignment). *B* Varus mechanical axis deviation (varus malalignment)

- As mechanical axis falls medial to the center of the knee, MAD up to 8 mm is considered normal.
- Any MAD greater than 8 mm (some authors consider 15 mm) medial to the knee center is considered varus malalignment.
- Any MAD lateral to the center of the knee is considered valgus malalignment.
- In general, malalignment in the frontal plane is much more serious than in the sagittal plane. The consequences of frontal plane malalignment on the knee (varus/valgus) are well described and documented and may lead to degenerative osteoarthritis, while the consequences of malalignment in the sagittal plane are less well defined. The knee joint is a uniaxial joint allowing no motion in the frontal plane, and any degree of malalignment in the frontal may be detrimental. That is not the case in the sagittal plane, where motion in the sagittal plane occurs all the time during walking, sitting, and other activities.
- MAD can occur secondary to bony deformities in the femur or tibia and joint deformities in the knee or ankle (due to ligamentous laxity or joint incongruity such as medial plateau depression in Blount's disease).

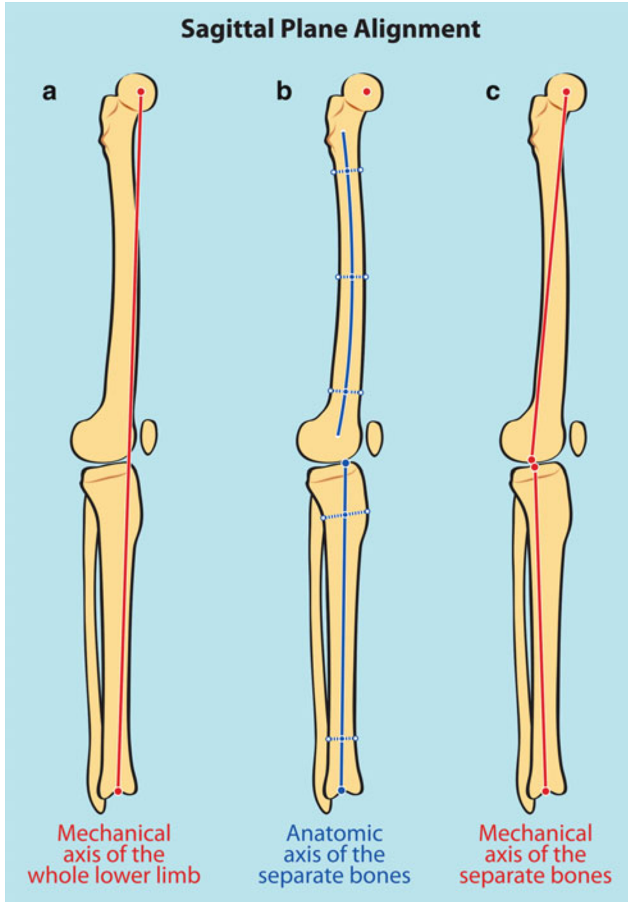

Fig. 9 Sagittal plane alignment. (**a**) Entire lower limb (falling through anterior part of the knee). (**b**) Anatomical axis of the femur (not a *straight line*) and tibia (*straight line*). (**c**) Mechanical axis of femur and tibia

Sagittal Plane Alignment

Whole lower limb falls just in front of the center of the knee joint line (Fig. 9):

(a) **Femur mechanical axis**
From center of the femoral head to center of knee
(b) **Femur anatomical axis**
Is a mid-diaphyseal line: curved in the sagittal plane
(c) **Tibia mechanical axis**
Line from the center of the knee to the center of the ankle
(d) **Tibia anatomical axis**
Line from the anterior one fifth of the proximal tibia to the center of the ankle joint

Joint Orientation Lines Assessment

This represents the relation of the joint axis to the anatomic and mechanical axis of a bone. Joint orientation lines are drawn on both frontal and sagittal planes.

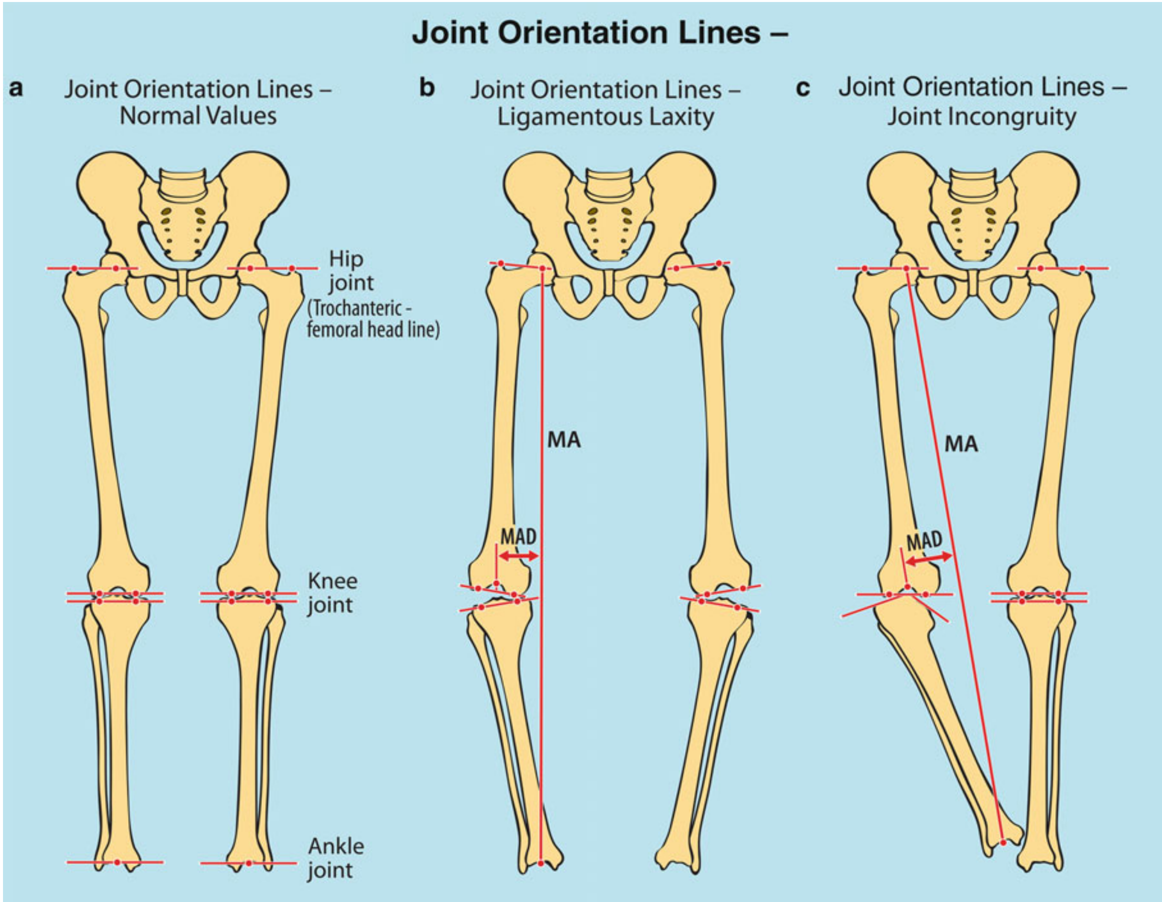

Fig. 10 Joint Orientation lines in coronal (frontal plane) (**a**) Normal lines and alignement (**b**) Varus malalignement due to ligamentous laxity (**c**) Varus malalignement due to joint incongruity

Frontal Plane

(a) **Hip joint orientation** (**Fig. 10a**):

1. Trochanteric – femoral head line: line from the tip of greater trochanter to center of the femoral head
2. Femoral neck line: line drawn from the hip joint center to several points that bisect the diameter of the femoral neck

(b) **Knee joint orientation:**

Represents the relation of the knee joint line to the distal femur and proximal tibia

– Normally is in valgus 3°.
– This is the most important measurement.
– Represented by lines joining the two femoral condyles and a line joining the two tibial plateaus. These 2 lines should be parallel (more than 2° considered abnormal and a source of MAD).
– Joint line congruence angle (JLCA) is the angle between these two lines.

If not parallel, this is caused either by joint laxity (such as in children with achondroplasia) (Fig. 10b) or by articular surface incongruity (such in Blount's disease with depressed medial tibial plateau) (Fig. 10c).

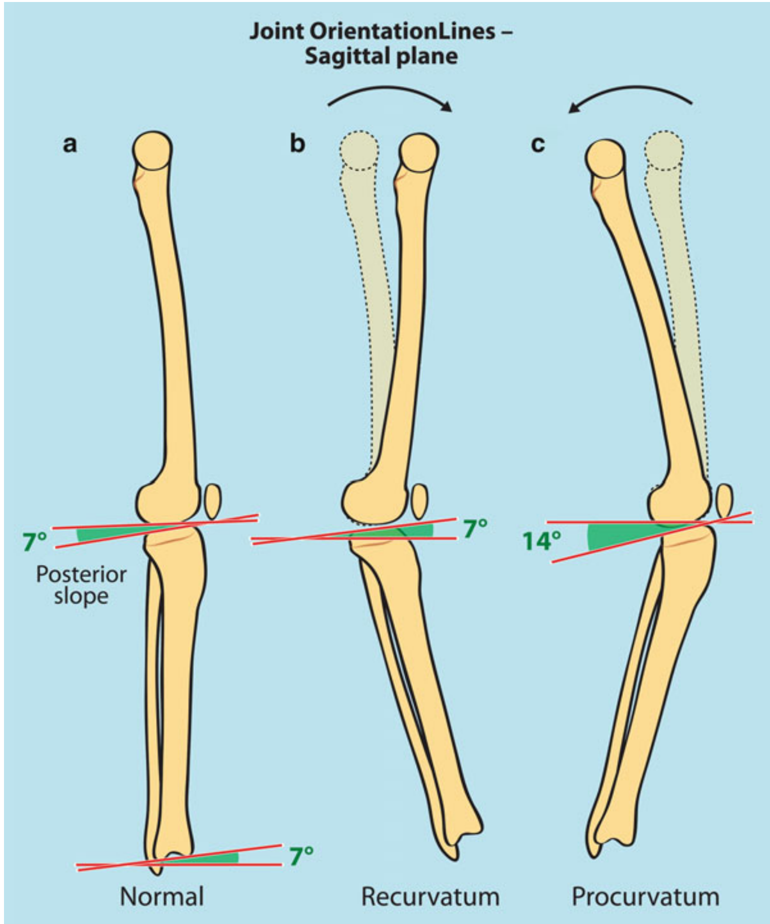

Fig. 11 Joint orientation lines in sagittal plane. (**a**) posterior slope of the tibial plateau (normal 7–9°) and anterior slope of the tibial plafond (normal 7–10°) (**b**) Tibia recurvatum with anterior slope of 7° (**c**) Tibia procurvatum with exaggerated posterior slope of 14°

(c) **Ankle joint orientation:**
  – Line drawn along the tibial plafond
  – Parallel to the floor or slight valgus (up to 8°)

Sagittal Plane

(a) **Knee joint orientation** (**Fig. 11**):
  – A line drawn along the tibial plateau
  – Normally 7–9° posterior slope

(b) **Ankle joint orientation line:**
  – A line drawn through the most distal points of the anterior and posterior distal tibia
  – Normally, about 7–10° anterior slope

Joint Orientation Angles

These are angles formed between the joint lines and either the mechanical or anatomic axis of separate bones.

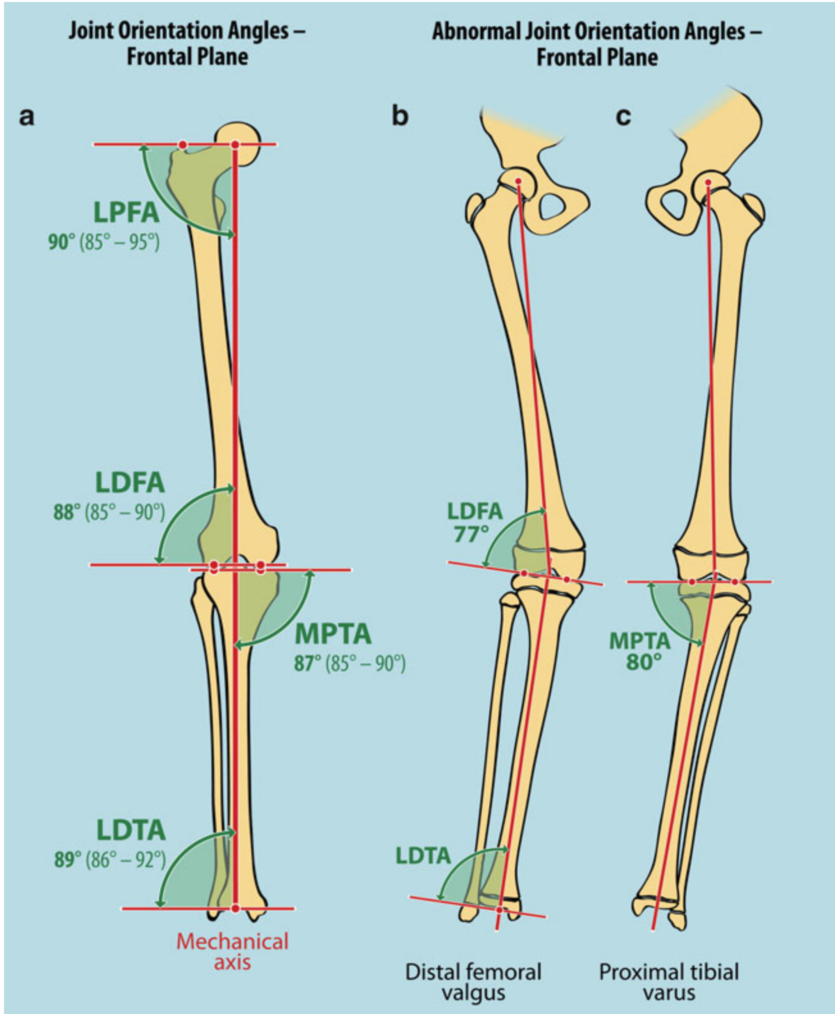

Fig. 12 Joint orientation angles in frontal plane. (**a**) Normal values. (**b**) mLDFA of 77° causing distal femoral valgus. (**c**) mMPTA of 80° causing proximal tibia varus

Frontal Plane (Fig. 12)

- **LDFA (Lateral Distal Femoral Angle).** This measures the angle between the distal articular femoral surface and either the mechanical or anatomical axis of the femur. The distal femoral articular surface is in slight valgus of one or two degrees when mechanical LDFA is measured and in about 7° of valgus when the anatomical LDFA is measured (Fig. 12a).
- **MPTA (Medial Proximal Tibial Angle).** This measures the angle between the proximal tibial articular surface and the mechanical or anatomical axis of the tibia. The proximal tibial articular surface is in about 1 – 3° varus with both mechanical and anatomical axis.
- **LDTA (Lateral Distal Tibial Angle**). This measures the angle between the distal tibial articular surface and the anatomical or mechanical axis of the tibia (both are the same). It measures about 90°.

Abnormal joint orientation angles are demonstrated in Fig. 12, showing distal femoral valgus (Fig. 12b) and proximal tibia vara (Fig. 12c).

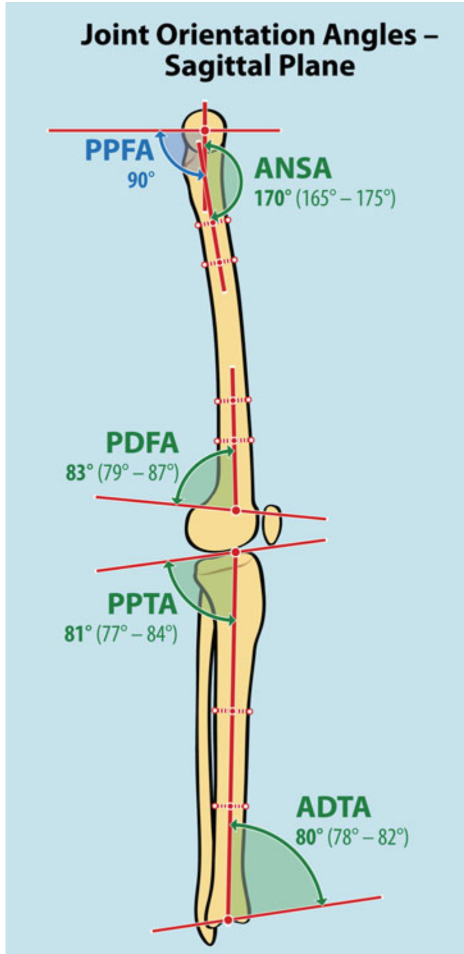

Fig. 13 Joint orientation angles in sagittal plane: normal values

Sagittal Plane (Fig. 13)

- **PPFA (Posterior Proximal Femoral Angle)**. This is measured between the mid-diaphyseal line of the neck of the femur and the line across the physis or physeal scar of the femoral head. Normally 90°.
- **ANSA (Anterior Neck Shaft Angle)**. It is measured between the sagittal plane mid-diaphyseal line of the proximal femur and the mid-diaphyseal line of the neck of the femur. About 170°.
- **PDFA (Posterior Distal Femoral Angle)**. This is measured between the sagittal distal femoral joint line and the mid-diaphyseal line of the distal femur. Usually about 83° (Fig. 13).
- **PPTA (Posterior Proximal Tibial Angle)**. This represents the angle between the proximal tibial surface and the mechanical axis of the tibia. It is usually about 81°.
- **ADTA (Anterior Distal Tibial Angle)**. This represents the angle between the distal articular surface and mechanical axis of the tibia. It is usually about 81°.

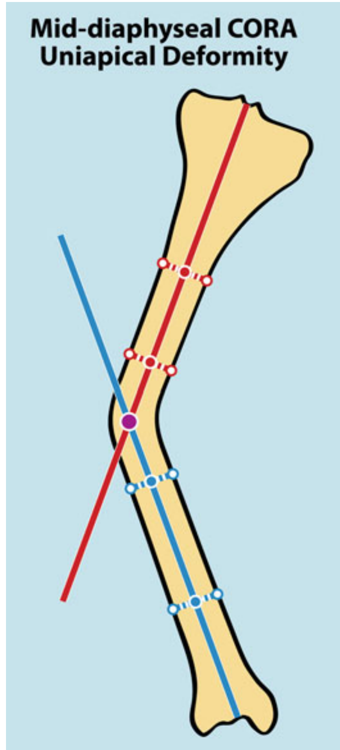

Fig. 14 Uni-apical deformity at the mid-diaphyseal region of tibia. CORA is located at the intersection of the anatomical axis of the proximal and distal segments of the tibia

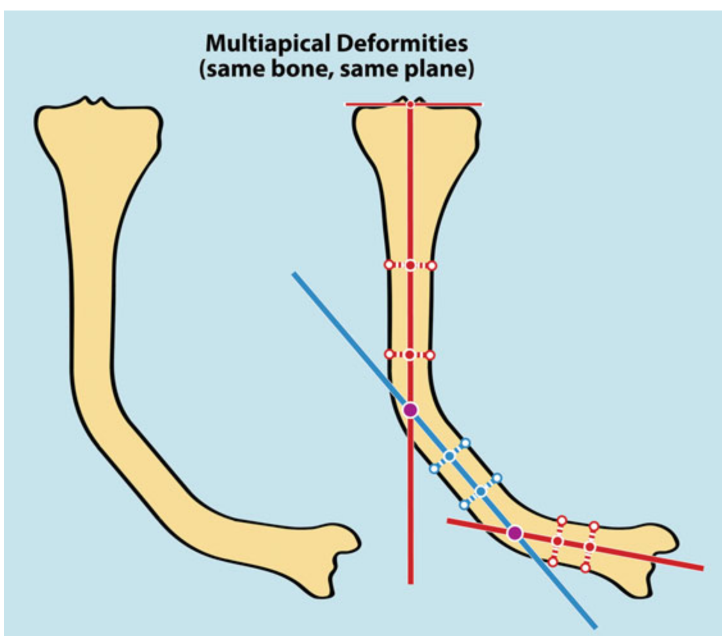

Fig. 15 Multi-apical deformities of tibia. Double CORA present at the intersection of the anatomical axes of the proximal, middle, and distal segments of the tibia

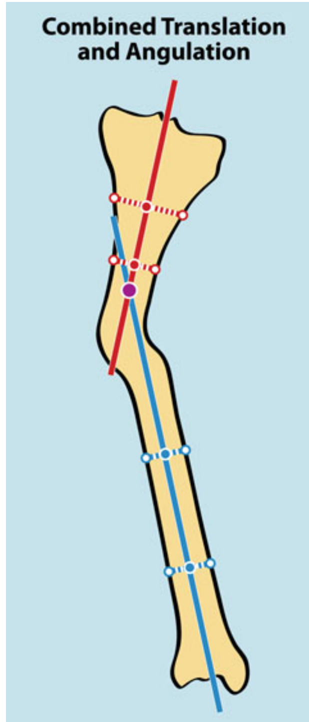

Fig. 16 When apex of the deformity and CORA do not correspond, a translational deformity is present

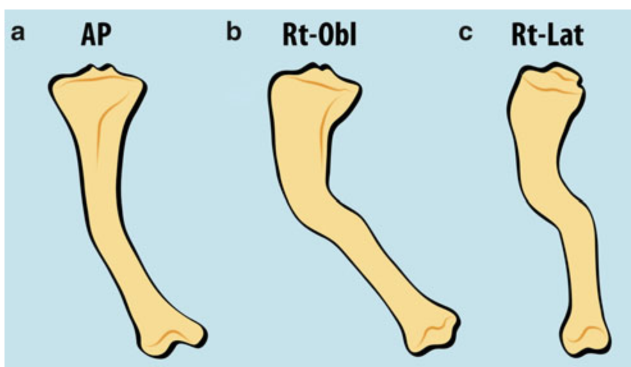

Fig. 17 Presence of multiplanar deformities in frontal plane (**a**), oblique plane (**b**), and sagittal plane (**c**). In the presence of multiplanar deformities, the deformity in the oblique plane is always greater than either the frontal or sagittal plane deformity

Determining the Apex of the Deformity or CORA (Centre of Rotation of Angulation)

– Used to define where the apex of the deformity is located within the bone.
– Determining the CORA is crucial for surgical planning of correction of any angular deformity and will serve as the site of osteotomy or hinge.
– If deformity is **diaphyseal**, the anatomical axis should be used. The apex of the deformity or CORA is the intersection of the diaphyseal lines of proximal and distal fragments (Fig. 14).

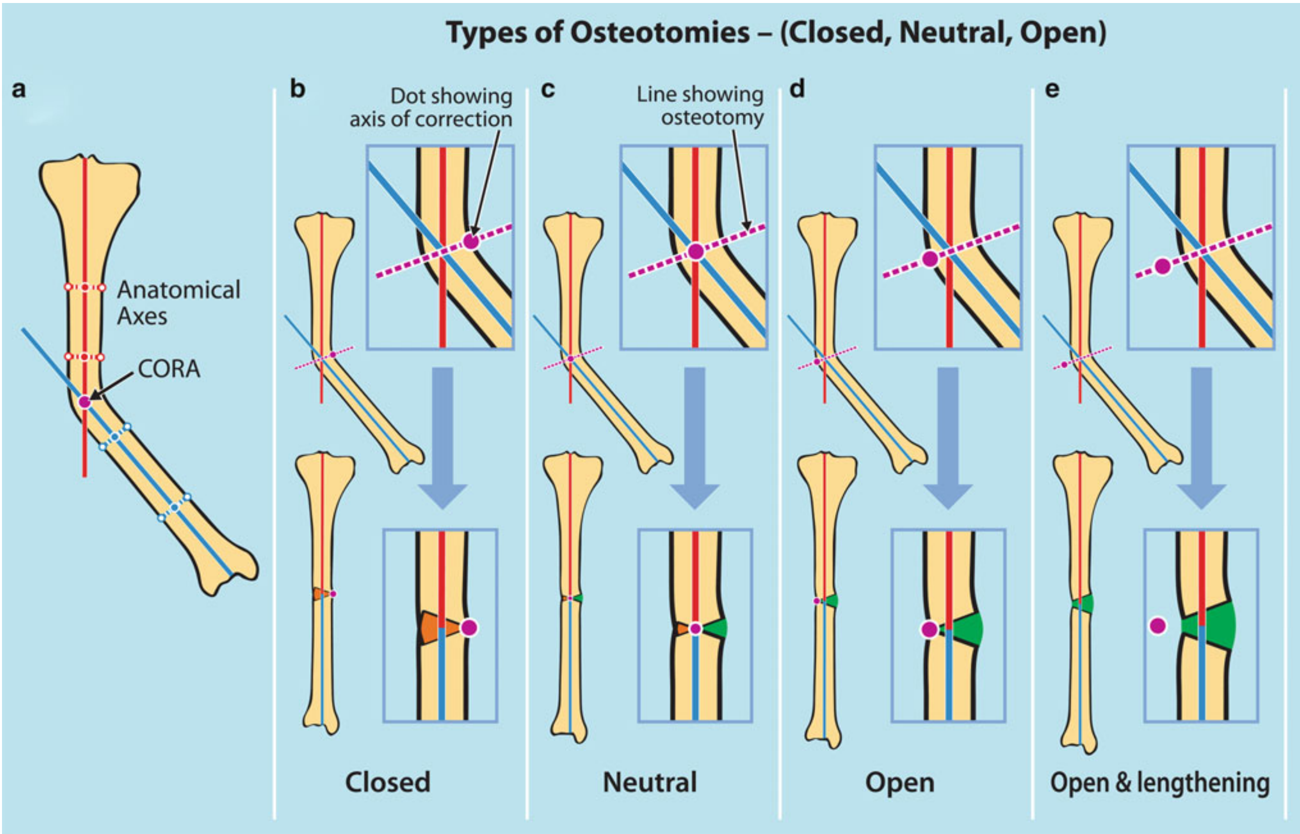

Fig. 18 Types of osteotomies and the impact of axis of correction position. All osteotomies in this figure are placed upon CORA and apex of deformity. (**a**) Mid-diaphyseal deformity. CORA and apex of deformity are the same. (**b**) If axis of correction is situated on the concave side of the deformity, a closing wedge osteotomy is produced. (**c**) If axis of correction is situated in the mid-diaphyseal area (the same as CORA and apex of the deformity), a neutral osteotomy is produced. (**d**) If axis of correction is situated on the convex side of the deformity, an opening wedge osteotomy is produced. (**e**) If the axis of correction is situated outside the diaphysis, distraction is produced, together with the opening wedge osteotomy. The further the axis of correction is from the diaphysis, the greater the distraction is

- If the deformity is **metaphyseal or juxta-articular** (epiphyseal), the CORA is determined by the intersection of a line perpendicular to the joint orientation line and the mid-diaphyseal line of the deformed segment or bone (Figs. 20 and 21).
- More than one CORA may exist in the same bone (multi-apical deformity) (Fig. 15).
- If CORA and apex of the deformity do not coincide, then there is an additional translational deformity (Fig. 16).
- If the CORA is present on both the frontal and sagittal planes, then an oblique deformity exists. The magnitude of an oblique plane deformity is always greater than what it measures in either the frontal or sagittal planes (Fig. 17).
- The impact of the anatomical location of the axis of correction on the type of osteotomy – closed, open, and neutral – is shown in Fig. 18.
- The impact of placement of the osteotomy relative to CORA and axis of correction on the resulting translation is shown in Fig. 19.

Malalignment test. This includes performing all the previously mentioned measurements: mechanical alignment of the whole lower limb and of separate bones, calculating MAD, drawing joint orientation lines, measuring joint orientation angles, and determining the site and amount of the CORA or CORAs. It should be emphasized, however, that all of these measurements are static and not dynamic.

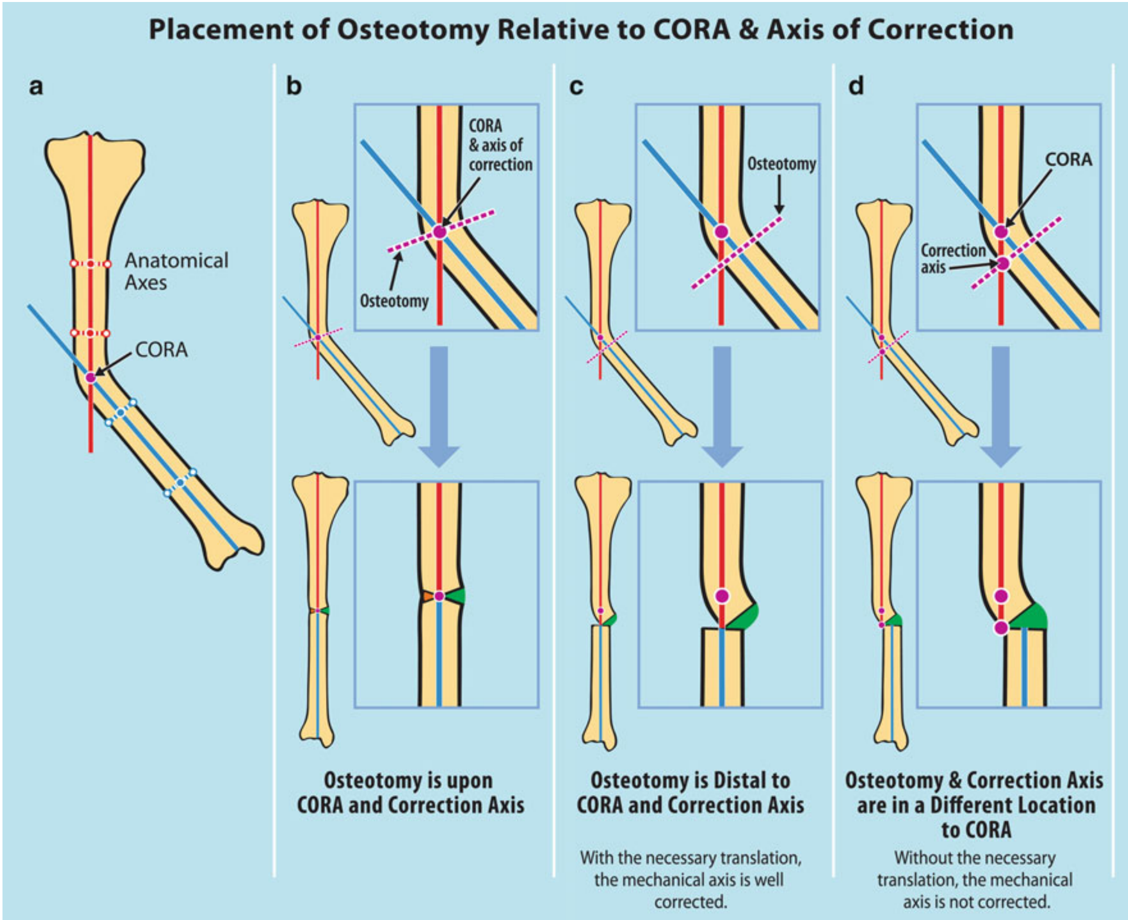

Fig. 19 The impact of placement of osteotomy relative to CORA and axis of correction. (**a**) Mid-diaphyseal deformity. CORA, and apex of deformity are the same. (**b**) Osteotomy performed upon CORA and axis of correction. (**c**) Osteotomy performed distal to CORA and axis of correction. Mechanical axis is corrected because of the translation. (**d**) Osteotomy and axis of correction are in a different location than CORA. Mechanical axis not corrected, because there is no translation

By using this systematic approach, the core 6 questions (previously mentioned) could then be answered and the deformity fully appreciated:

- What is the plane of the deformity (frontal, sagittal, or oblique)?
- What is the direction of the deformity (varus/valgus, anterior/posterior)?
- Which bone and/or joint is affected (femur, tibia, knee, or ankle joint)?
- Which segment of the bone is affected (epiphysis, metaphysis, or diaphysis)?
- Where is the apex of the deformity?
- What is the magnitude of the deformity?

Examples of step-by-step approach in the assessment of various lower limb deformities are shown in Figs. 20, 21, 22, and 23:

- Figure 20: Distal femoral valgus deformity
- Figure 21: Proximal medial tibial deformity
- Figure 22: Uni-apical mid-diaphyseal deformity of tibia
- Figure 23: Double apical diaphyseal deformity of tibia

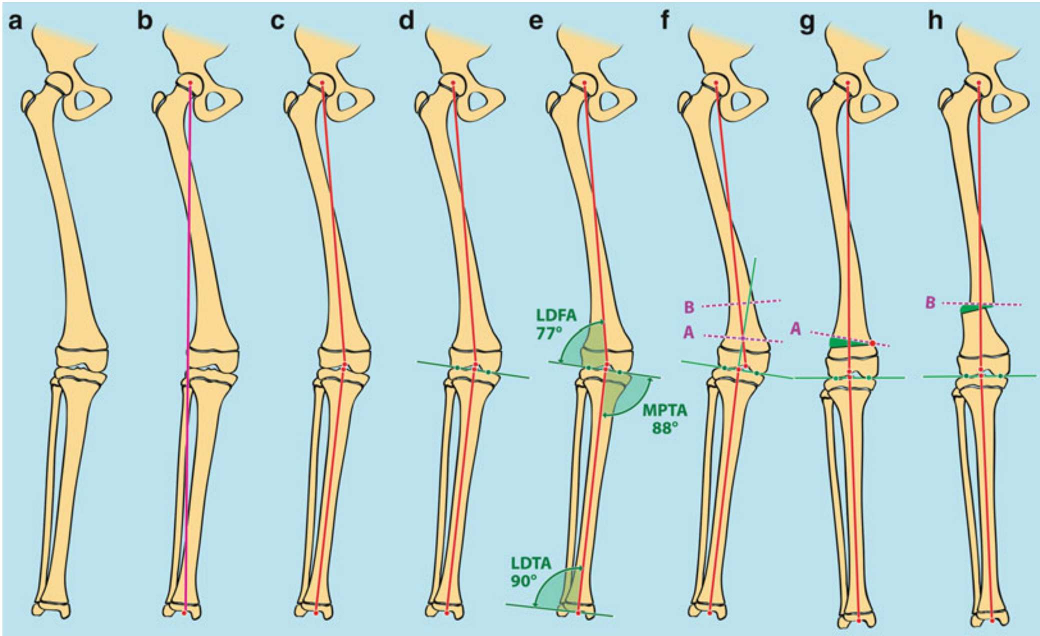

Fig. 20 Example of distal femoral valgus deformity – step-by-step approach. (**a**) Diagram showing the deformity. (**b**) Mechanical axis of entire limb showing varus malalignment. (**c**) Mechanical axis of femur and tibia. (**d**) Joint orientation line of knee. (**e**) Joint orientation angles: mLDFA 77°, MPTA 88°. (**f**) *Red dotted lines* showing two different levels of osteotomy. (**g**) If osteotomy performed upon CORA and axis of correction (situated on lateral cortex on the same line as the CORA), then an opening wedge is produced, and there is no translation. (**h**) If osteotomy performed proximal to CORA and axis of correction is on the lateral cortex on same line as osteotomy, then translation is required to maintain mechanical alignment

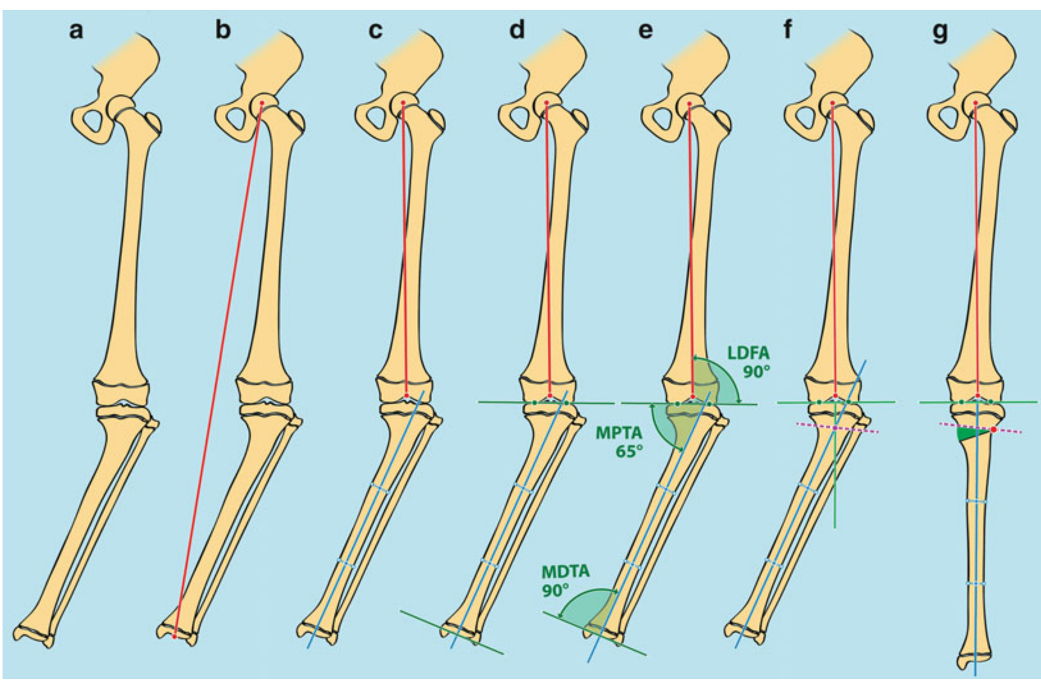

Fig. 21 Example of proximal medial tibial deformity – step-by-step approach. (**a**) Diagram showing the deformity. (**b**) Mechanical axis of entire limb showing varus malalignment. (**c**) Mechanical axis of femur and anatomical axis of the tibia. (**d**) Joint orientation lines of the knee and ankle. (**e**) Joint orientation angles: mLDFA 90°, MPTA 65°, MDTA 90°. (**f**) *Red dotted line* showing line of osteotomy at CORA. (**g**) Correction of the deformity causing an opening wedge osteotomy as apex of correction is on the convex side of the deformity (shown by the *red dot*)

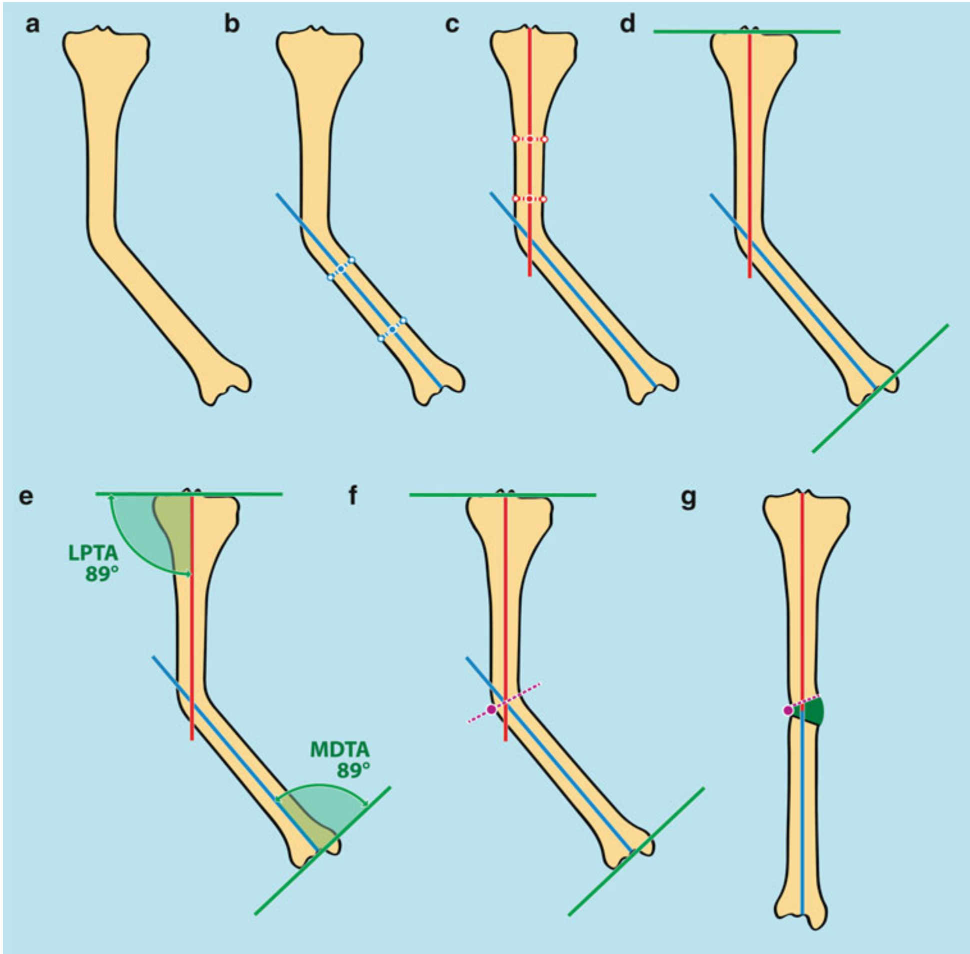

Fig. 22 Example of uni-apical mid-diaphyseal deformity of the tibia – step-by-step approach. (**a**) Diagram showing the deformity. (**b**) Anatomical axis of distal tibial segment. (**c**) Anatomical axis of proximal tibial segment and CORA. (**d**) Joint orientation lines of the knee and ankle. (**e**) Joint orientation angles LPTA 89° and MDTA 89° showing that the deformity is diaphyseal. (**f**) Osteotomy performed upon CORA. Axis of correction lies on the convex side same line as CORA. (**g**) Opening wedge osteotomy with restoration of anatomical axis of tibia

Acute Versus Gradual Correction

Several factors should be taken into consideration before deciding on whether an acute or gradual correction should be performed. These include:

– **Age of the patient**. Uniplanar deformities in very young children can be safely and successfully corrected by gradual correction (growth modulation) with 8 plates.
– **Amount to be corrected**. It is generally accepted that deformities less than 15 – 20° can be adequately and safely addressed with an acute correction, while deformities greater than this are better addressed by gradual correction.
– **Site of the deformity**. Excessive stretching of the surrounding neurovascular structures is always a concern when performing acute correction, specially if these structures are anatomically located on the concave site of the deformity, as in the case of valgus deformities of the distal femur and proximal tibia. In these cases, the common peroneal nerve is vulnerable and at risk of neuropraxia; therefore, prophylactic decompression of this nerve should be performed prior to the acute correction. The same applies around the ankle, where a tarsal tunnel release may be indicated before proceeding with an acute

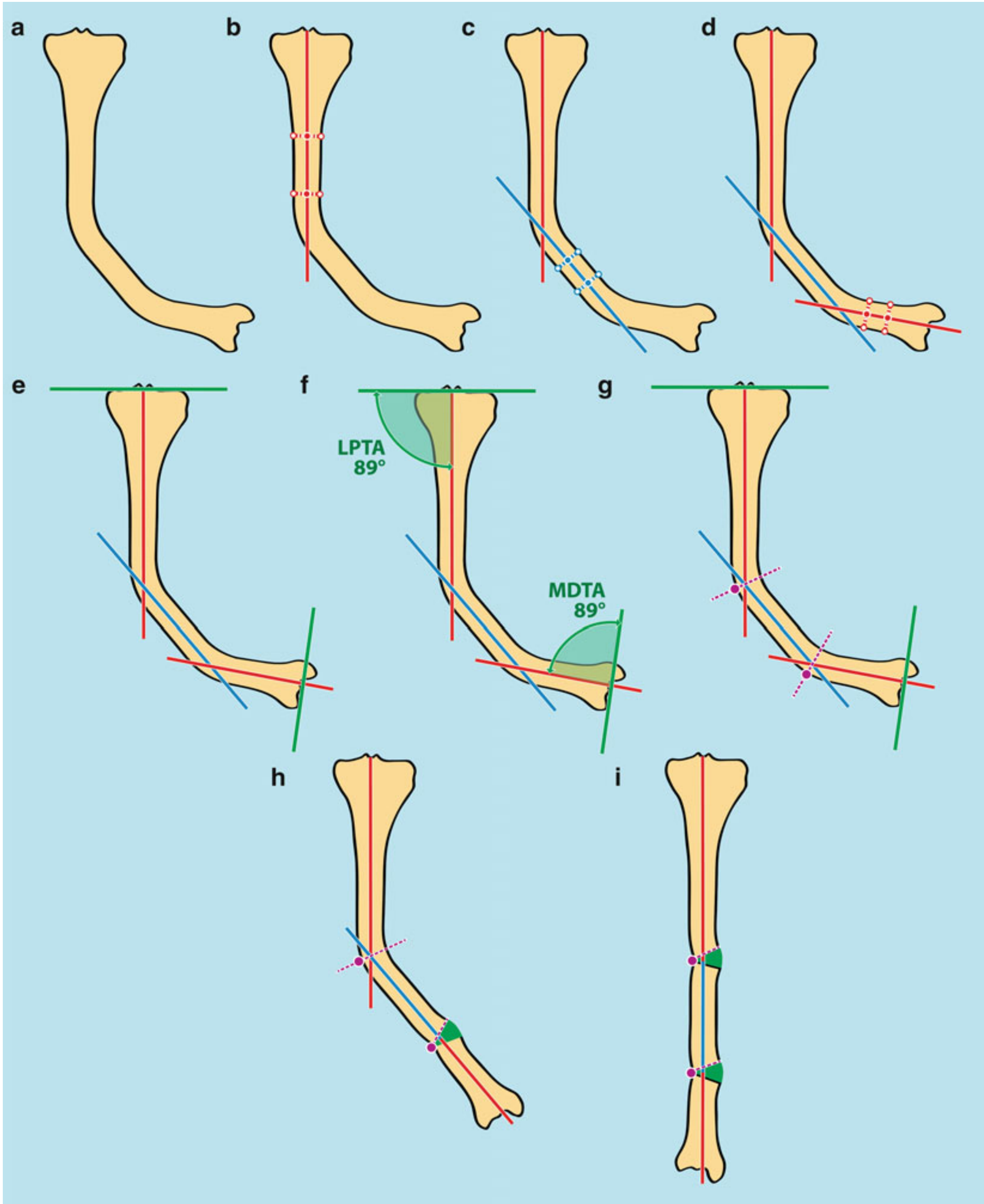

Fig. 23 Example of double apical diaphyseal deformity of the tibia – step-by-step approach. (**a**) Diagram showing deformity. (**b**) Anatomical axis of proximal segment. (**c**) Anatomical axis of middle segment. (**d**) Anatomical axis of distal segment with double CORA. (**e**) Joint orientation lines. (**f**) Joint orientation angles. (**g**) Lines of osteotomies upon both CORA. (**h**) Deformity correction at distal CORA causing an opening wedge osteotomy as axis of correction is on the convex side of deformity. (**i**) Deformity correction at proximal CORA also causing an opening wedge osteotomy as axis of correction is on the convex side of the deformity

correction. On the other hand, acute correction of diaphyseal deformities of the femur is less likely to cause neurovascular problems.

– **Status of the surrounding soft tissues**. Previous surgeries or scarring due to burns or trauma often lead to soft tissue fibrosis and disturbed anatomy. In these cases, extensive dissection should be avoided as this may further damage the soft tissues. Furthermore, the dissection may be technically difficult as all the anatomy is abnormal making it challenging to recognize the vital structures.

- **Quality of the bone to be corrected**. In some cases of severe osteopenia (such as osteogenesis imperfecta), the bones are so weak and soft that they may be unable to withstand the stresses of external fixators, and in such cases an acute correction and intramedullary stabilization may be indicated.
- **Associated limb length discrepancy**. If there is an associated limb length discrepancy, then a gradual correction that could address all the deformities simultaneously is indicated.
- **Amount of bone to be resected.** If an acute correction is contemplated, then shortening of the bone at the site of the deformity – in order to accommodate the soft tissue contractures – will probably be necessary, and this should be planned preoperatively and clearly explained to the patient and family. This is especially true for rigid foot deformities that are corrected with osteotomies and acute correction.

Preoperative planning should address all the above mentioned issues, and each case should be individualized.

Gradual Correction

In the skeletally immature patient, this could be carried out either by growth modulation with 8 plates or external fixators. In skeletally mature patients, osteotomies and gradual distraction with various types of unilateral, circular, or hybrid fixators are the only techniques available.

Advantages of Gradual Correction with 8 Plates

"The best osteotomy is NO osteotomy" (John Herzenberg). Growth modulation has radically changed our approach to the correction of long bone deformities in the skeletally immature patient. Whenever possible, it is always better to use growth modulation. It is a minimally invasive surgery compared to osteotomy. It can be performed at a very young age (as young as the age of 2 years). When correction is obtained, the plate can be removed, or one of the screws, generally the metaphyseal one, can be removed leaving the plate and epiphyseal screw in place so that if the deformity recurs it can be easily reapplied percutaneously. Most importantly, it is not a permanent correction. This may avoid more extensive surgery in the form of osteotomies whether for gradual or acute correction. However, as seen in several cases of the atlas, growth modulation is not always successful and may not yield satisfactory results in cases of severe and/or multiple deformities (adolescent Blount's, skeletal dysplasias, rickets). Furthermore, the correction with 8 plates takes a more prolonged time than with the use of external fixators. In addition, growth modulation has its maximum effect in the first decade and may be less reliable when it is applied near skeletal maturity.

Advantages of Gradual Correction with External Fixators

These are numerous and include:

1. Minimal invasive surgery and minimal soft tissue dissection. This is mostly a percutaneous technique.
2. Can generate new bone (in cases of gradual open wedge osteotomy).
3. Extremely versatile.
4. Allows adjustments during correction of the deformities.
   The inability to obtain a standing hip to ankle radiograph during surgery limits the precision of an intraoperative correction. With external fixation stabilization, the position can be changed acutely or gradually after a standing hip to ankle radiograph is obtained and the appropriate mechanical axis analysis is performed.
5. Allows certain amount of axial loading, which is beneficial for bone healing.
6. Can be used in the presence of acute and chronic infection.

7. It is easier to obtain an accurate reduction with gradual correction, specifically if multiplanar deformities are present.
8. In severe deformities, a bone resection can be avoided.
9. Less risk of neurovascular complications and compartment syndrome that may occur with acute corrections.
10. Simultaneous limb lengthening is possible
11. The use of external fixators allows immediate full weight-bearing and allows functional use of the limb.

The **disadvantages of gradual correction** include all the problems associated with prolonged time needed to wear the external fixator while the newly formed bone consolidates, necessitating multiple clinic visits and missing school days, potential for psychosocial problems, prolonged rehabilitation, and all other medical problems including pin site infection, pain, and swelling.

Therefore, we believe gradual correction using external fixators is **indicated** if there is an associated limb length discrepancy requiring lengthening by distraction osteogenesis, extensive soft tissue scarring from previous surgeries, trauma or burns, multiple complex deformities and severe bony deformities.

Acute Correction

Acute correction offers several advantages. Usually all the deformities are corrected in one surgery only, a quicker return to daily activities is usually possible (although the patient may be non-weight-bearing or toe touching) and the absence of any of the problems associated with external fixation. The use of fixator-assisted acute correction could increase the accuracy of acute correction.

Disadvantages of acute correction include a lack of post-op adjustability: No further adjustment of the correction could be made. Furthermore, any associated LLD could not be addressed at the same time.

Combined Gradual and Acute Correction

In some cases of multiple deformities, especially when both femur and tibia are affected, a viable alternative is acute correction of the deformities in one bone (usually the femur) and gradual correction of the other, as discussed in several cases in the atlas. The femoral deformities are addressed by acute correction (whether standard technique or fixator assisted), and the tibial deformities are addressed by gradual correction with external fixators. This avoids having two external devices (on femur and tibia) and allows simultaneous correction of all deformities in the affected limb, with the least "cumbersome" fixation.

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Adult Deformity: An Introduction

S. Robert Rozbruch

The term *adult reconstruction* within the orthopedic community of 2014 is typically associated with hip and knee joint replacement. In this atlas, the focus of the *Adult Deformity* section is different and is primarily on osteotomy for realignment, correction of leg length discrepancy (LLD), and reconstruction of bone defects. In the context of this book, this section will deal primarily with adult issues that do not neatly fit into the Foot and Ankle, Trauma/Post-traumatic Reconstruction, Tumor, and Upper Extremity sections.

The adult deformity section contains cases of realignment of varus and valgus deformities about the knee, extra-articular deformities in patients who need joint replacement, and failed knee replacement with bone loss and infection. Lengthening of a short residual limb after amputation to enhance prosthetic wear is also presented.

One of the biggest challenges in the adult patient is slower bone healing than in children. For this reason, techniques that integrate the use of internal and external fixation have emerged with the main benefit being a decrease in the time the patients need to wear the external fixator. Integrated fixation techniques of lengthening over a nail (LON), lengthening and then nailing (LATN), lengthening and then plating (LAP), and bone transport over a nail are featured in this chapter as well as in the Trauma, Foot and Ankle, and Pediatric sections.

The use of a fully motorized internal lengthening nail is a recent major advance in limb reconstruction surgery. Without any need for external fixation, bone lengthening may be accomplished adhering to the Ilizarov method. Femur and tibia lengthening and bone transport using internal lengthening implants are also featured in this section.

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Part I

Adult Deformity: Internal Lengthening Nail

Case 1: Femur Lengthening with Precice Internal Lengthening Nail

S. Robert Rozbruch

Contents

Abstract

This is a case illustrating a 4.5 cm femur lengthening for congenital limb-length discrepancy (LLD). The Precice internal lengthening nail was used and the recovery was fast with normal unassisted walking at 4 months.

1 Brief Clinical History

The patient is a 25 year old male with a congenital LLD of 4.5 cm. There were no associated sagittal, coronal, or rotational deformities. No previous treatment was rendered. The patient and the family were not interested in limb lengthening using external fixation at earlier points in life.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Congenital LLD of 4.5 cm
2. Short femur

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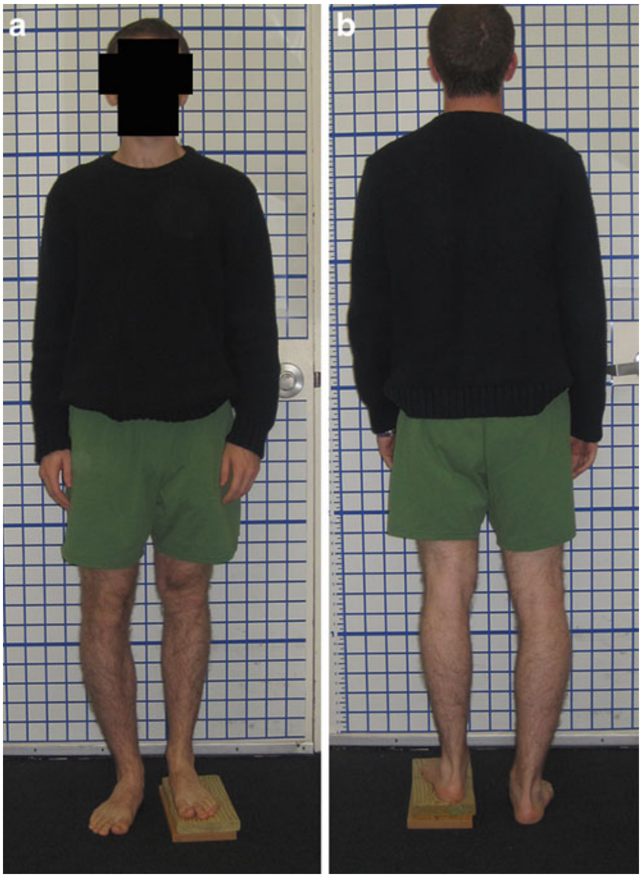

Fig. 1 (**a**) *Front* and (**b**) *back* view showing left lower extremity shortening of 4.5 cm

4 Treatment Strategy

1. Femur lengthening using an internal lengthening nail
2. Antegrade approach
3. Osteotomy at the apex of the femur anterior bow on the lateral X-ray
4. Iliotibial band (ITB) tenotomy

5 Basic Principles

1. Make osteotomy at apex of anterior bow so that a longer straight nail can be inserted.
2. Piriformis or trochanteric entry can be used based on surgeon preference. Patients less than 19 years of age should have trochanteric entry to avoid avascular necrosis of the femoral head.
3. Nail length choice and osteotomy location require planning: the goal is to have at least 5 cm of thick part of the nail in the distal segment at the end of distraction (for optimal stability), and with distraction, the thick part of the nail is pulled out of the distal segment. In this case, a 305 mm nail was used. Subtract 30 mm (starting length of the small diameter telescopic part of nail) and 45 mm (lengthening planned) and 50 mm (minimum length of thick part in the distal segment).
   In this case, 305 − (30 + 45 + 50) = 180 mm. The osteotomy must be less than 180 mm from the proximal end of the bone. In this case, 150 mm was chosen without a problem.
4. Reaming 1.5–2 mm over the diameter of the nail should be done. In this case, a 10.7 mm nail was used and the bone was reamed to 12.5 mm.
5. Although lengthening should ideally be done along the mechanical axis of the femur, when using an IM nail, lengthening is along the anatomical axis. Theoretically, this could increase valgus alignment. In a normally aligned limb, intramedullary lengthening along the anatomical axis of the femur results in a lateral shift of the mechanical axis by approximately 1 mm for each 1 cm of lengthening. In practical terms, this is not a substantial problem. Compare Figs. 2a–d, 3a–h, 4a–c, 5a and you will notice no increase in valgus. During lengthening, mild varus of the bone offsets the medialization of the distal femur.

6 Images During Treatment

See Figs. 3, 4, and 5.

7 Technical Pearls

1. Use rotation markers to prevent rotational deformity. Place rotational pins parallel to each other.
2. Correct preoperative rotational deformity (not present in this case) by placing the rotational pins with the amount of angular deformity to be corrected. Use an intraoperative goniometer. After osteotomy, correct the rotation and make the pins parallel.
3. Varus or valgus deformity (not in this case) can be corrected by performing the osteotomy at the apex of deformity; acutely correct deformity and then insert nail.

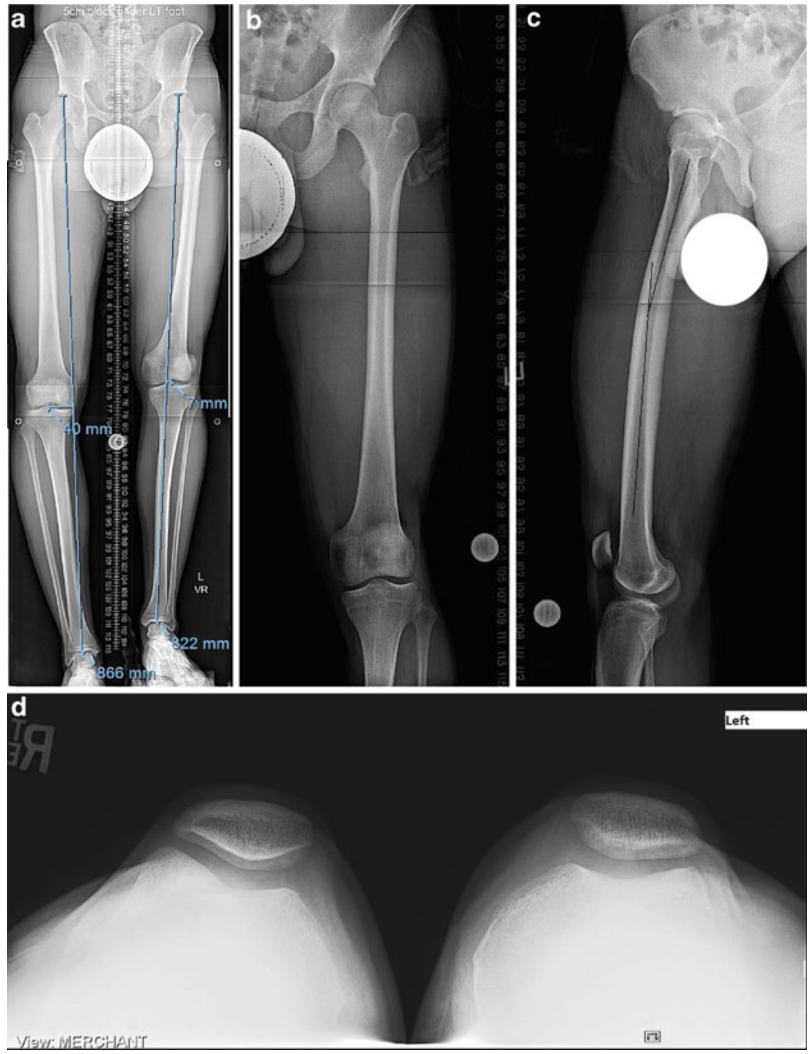

Fig. 2 Preoperative X-rays. (**a**) Standing X-ray shows LLD of 4.4 cm. MAD is normal. (**b**) AP femur showing small IM canal. (**c**) Lateral femur showing normal anterior bow with apex 15 cm distal to tip of trochanter. (**d**) Merchant view of knees showing normal patella alignment

4. Rotate osteotomy around the IM nail before insertion of locking screws to assure a complete osteotomy.
5. I prefer to insert the distal interlocking screws to prevent malrotation. The leg and rod are rotated to get "perfect circles" needed for freehand distal locking screw insertion. Then the leg is carefully positioned using the rotational pins as guides, and the proximal interlocking screws are easily inserted using the jig.

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7, and 8.

9 Avoiding and Managing Problems

1. Avoid propagation of the osteotomy to optimize the angular control of the nail. In this case, the small proximal medial propagation of the osteotomy led to mild varus.
2. If the canal diameter is greater than the IM nail at the osteotomy site, blocking screws should be inserted to prevent deformity. They work by narrowing the IM canal. Blocking screws are to be inserted in the concavity of the anticipated deformity.
3. Mark the location of the magnet in the nail on the skin. The external magnet controller must be placed directly over the nail magnet to actuate a distraction.

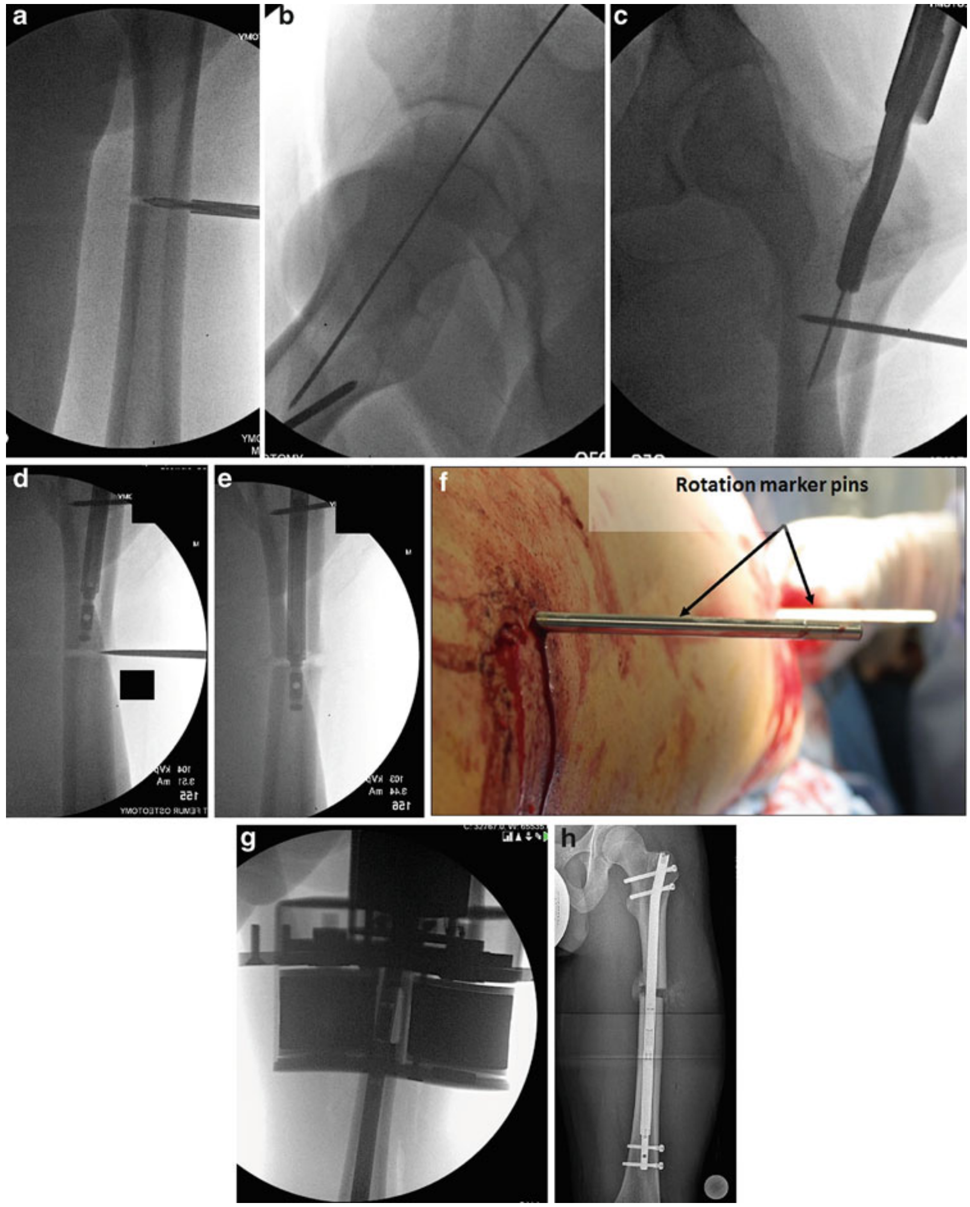

Fig. 3 Intraoperative C-arm X-ray images. (**a**) Multiple drill holes are made at intended site of osteotomy. (**b**) Proximal rotational pin is placed posterior to intended path of the nail. A second rotational pin marker is inserted into the distal femur beyond the anticipated end of the nail. Guide wire is inserted into center of trochanter. (**c**) Cannulated reamer opens path into IM canal. Note the proximal rotation marker. (**d**) After reaming with flexible reamers 1.5–2 mm over the diameter of the IM nail, the solid nail is inserted without guide wire up to the osteotomy site. The osteotomy is then completed with an osteotome. (**e**) The IM nail is then passed across the osteotomy. (**f**) The proximal and distal rotational marker pins are used to assure optimal rotational alignment. (**g**) The external magnet controller (*EMC*) is applied over the magnet in the nail. The skin is marked so that the EMC can be reliably placed for distraction. (**h**) One week after distraction started showing distraction gap of 7 mm. Note the cloud of new bone already seen

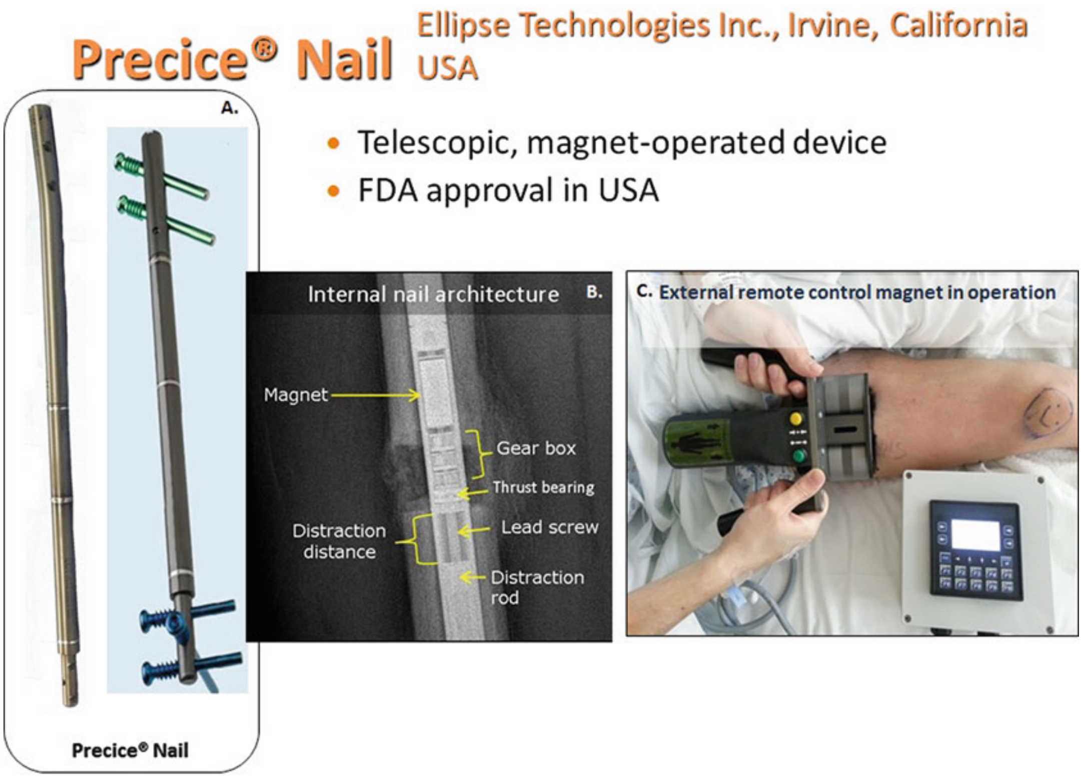

Fig. 4 (**a**) Picture of the Precice nail (Ellipse Technologies, Irvine, CA, USA). (**b**) Anatomy of the Precice nail on X-ray. (**c**) Placement of the EMC on the thigh over the magnet in the nail for distraction (see Fig. 3g)

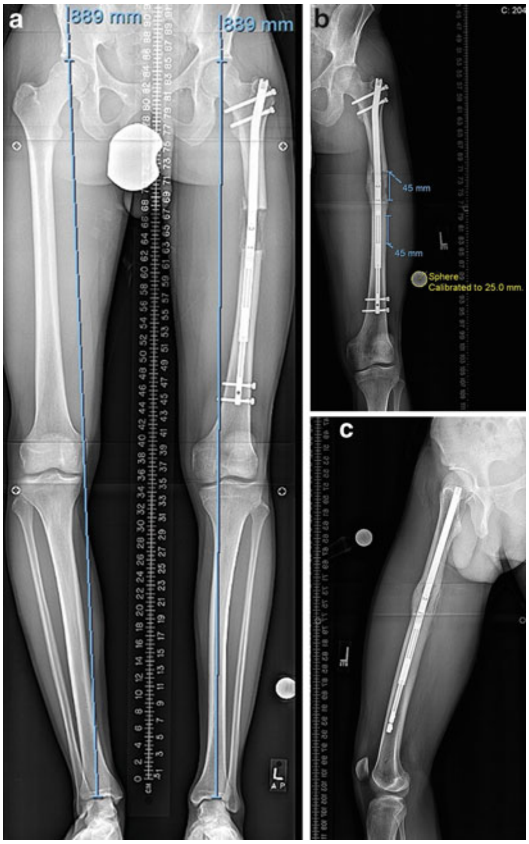

Fig. 5 (**a**) Bipedal standing X-ray at the end of distraction (50 days after surgery) showing equal leg lengths. Note MAD position relative to preoperative position (Fig. 2a). Increase in valgus did not occur. (**b**) AP and (**c**) lateral X-ray of femur 4 months after surgery showing excellent bone healing progression of 4.5 cm regenerate. Note straightening of the anterior bow of the femur. Note mild varus due to proximal propagation of osteotomy on medial cortex. Full weight bearing was allowed

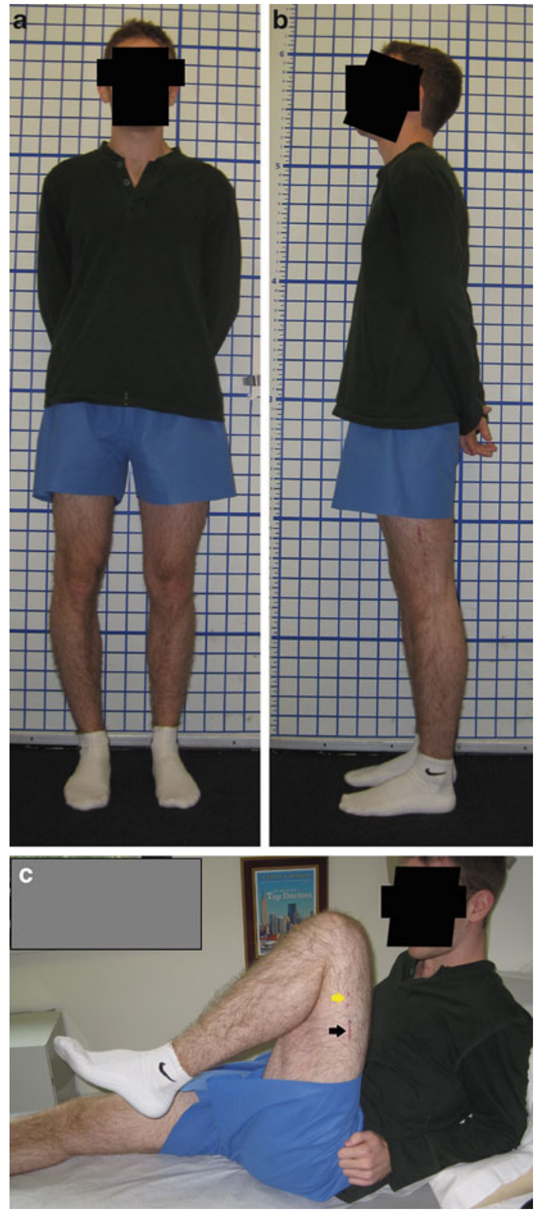

Fig. 6 Clinical photos 4 months after surgery. (**a**) *Front* view showing equal leg lengths and no deformity. (**b**) *Side* view showing full knee extension. (**c**) Knee flexion to 130°. Note the percutaneous insertion of distal locking screws (*yellow arrow*) and the incision for routine release of the iliotibial band (*black arrow*)

Fig. 7 (**a**) AP and (**b**) lateral X-rays 7 months after surgery

Fig. 8 (**a**) AP and (**b**) lateral X-rays 10 months after initial surgery and 1 week following nail removal

4. Predrill the osteotomy before reaming. This decreases pressure in the IM canal during reaming and protects against fat embolism syndrome.
5. The ITB tenotomy helps prevent knee contracture during distraction.

10 Cross-References

▶ Case 2: Tibia Lengthening with Precice Internal Lengthening Nail
▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate
▶ Case 8: Femoral Lengthening (12 cm) with Two Precice Nail Lengthenings. Management of a Broken Precice Nail During the First Lengthening

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Case 2: Tibia Lengthening with Precice Internal Lengthening Nail

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Contents

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Abstract
This is a case illustrating a 6.5 cm tibia lengthening performed for lower extremity shortening related to the hip and proximal femur. The presence of a complex hip replacement and hip joint instability led to choosing the tibia for bone lengthening. The Precice internal lengthening nail was used and the recovery was excellent. Gastrocsoleus recession was performed to mitigate an impending ankle equinus contracture.

1 Brief Clinical History

The patient is a 37 year old female with a complicated history of hip pathology from childhood. This included femoral head necrosis, fracture, and growth arrest. Ultimately, she was treated with a custom total hip replacement (THR) by a hip specialist who referred the patient to me for evaluation and treatment of a limb length discrepancy (LLD). The THR had problems of instability, which was treated with a constrained articulation. The overall LLD was 7 cm. She was comfortable wearing a shoe lift for short distances.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. LLD 7 cm
2. Short femur
3. Ipsilateral THR with proximal femur deformity and instability
4. Impending ankle equinus contracture

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Fig. 1 (**a**, **b**) X-rays showing LLD of 7 cm originating from the femur and hip. Tibia is normal. Note lateral mechanical axis deviation (*MAD*)

4 Treatment Strategy

1. Avoid lengthening the femur. The problems with a femur lengthening include risk of hip dislocation.
2. Lengthen tibia and fibula with Precice nail (Ellipse Technologies, Irvine, CA, USA).
3. Perform gastroc-soleus recession since the patient is at high risk for developing an equinus contracture of the ankle. Goal at the end of lengthening is for a plantigrade foot.

5 Basic Principles

1. There are increased risks when lengthening the femur with ipsilateral hip instability. The proximal femur deformity contributes to this instability. Femur lengthening will increase risk of hip dislocation and displacement of the prosthesis.
2. Tibia lengthening eliminates the risk to the hip.
3. Tibia lengthening will result in a knee-height discrepancy similar to the situation of using a shoe lift. This does not appear to be a clinical problem for walking.
4. Tibia lengthening has a tendency to deform into valgus and procurvatum. At the osteotomy level, if there is space between the nail and the cortex to the concavity of the

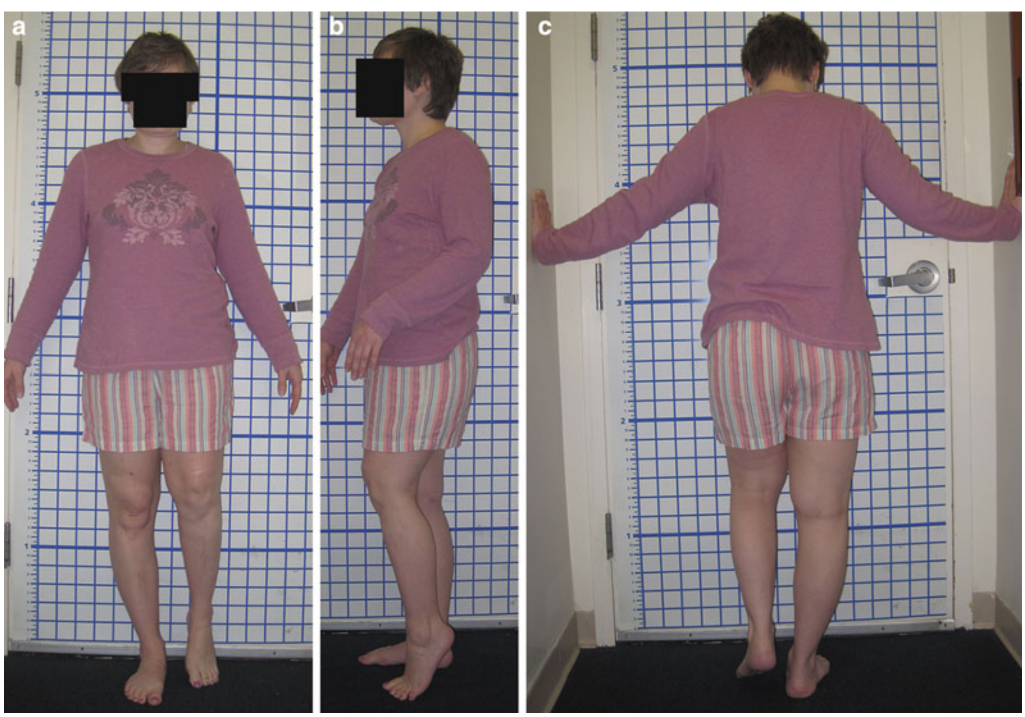

Fig. 2 (**a**) Front, (**b**) side, and (**c**) back views showing short left lower extremity and a left hip flexion contracture. Note the equinus position of her left ankle in the attempt to ambulate with a plantigrade foot. The flexibility of the ankle should be assessed in the preoperative clinical examination

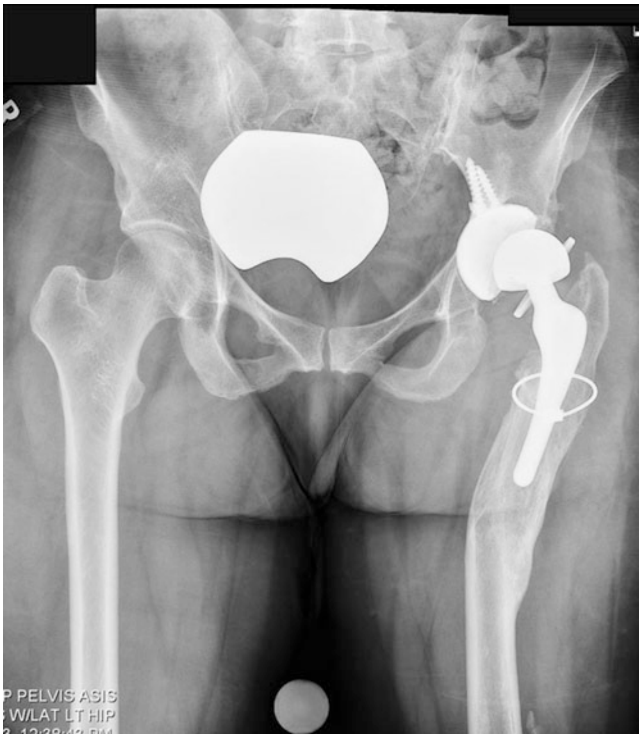

Fig. 3 AP pelvis X-ray showing custom-made THR and proximal femur deformity. Note the constrained articulation

anticipated deformity, then blocking screw(s) should be inserted. The concavity of valgus deformity is the lateral edge of the bone. The concavity of procurvatum deformity is the posterior edge of the bone.

5. The fibula should be stabilized to the tibia at the knee and ankle to prevent distal and proximal migrations, respectively.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

1. Use rotation markers to prevent rotational deformity. Place rotational pins parallel to each other.
2. Correct preoperative rotational deformity (not present in this case) by placing the rotational pins with the amount of angular deformity to be corrected. Use an intraoperative goniometer. After osteotomy, correct the rotation and make the pins parallel.
3. Varus or valgus deformity (not in this case) can be corrected by performing the osteotomy at the apex of deformity; acutely correct deformity and then insert nail.
4. Rotate osteotomy around the IM nail before insertion of locking screws to assure a complete osteotomy.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

1. Avoid propagation of the osteotomy to optimize the angular control of the nail. In this case, the small lateral propagation (Fig. 4a) of the osteotomy led to mild valgus.
2. If the canal diameter is greater than the IM nail at the osteotomy site, blocking screws should be inserted to prevent deformity. They work by narrowing the IM canal. Blocking screws are to be inserted in the concavity of the anticipated deformity.
3. Mark the location of the magnet in the nail on the surface of the skin. The external magnet controller must be placed directly over the nail magnet to actuate distraction.
4. Predrill the osteotomy before reaming. This decreases pressure in the IM canal during reaming and protects against fat embolism syndrome.
5. The gastroc-soleus recession helps prevent equinus contracture. Tibia lengthening of greater than 13 % and 42 mm are predictors that the patient will need a gastroc-soleus recession for equinus contracture.
6. Proximal and distal tibia-fibula stabilization is necessary to prevent unwanted fibula migration. Distal migration of the proximal fibula stretches the LCL and the biceps femoris insertion, and this can lead to knee flexion contracture. Proximal migration of the distal fibula can lead to ankle deformity, stiffness, and pain. Oblique screw placement provides optimal resistance to fibular migration (Fig. 4c, d).

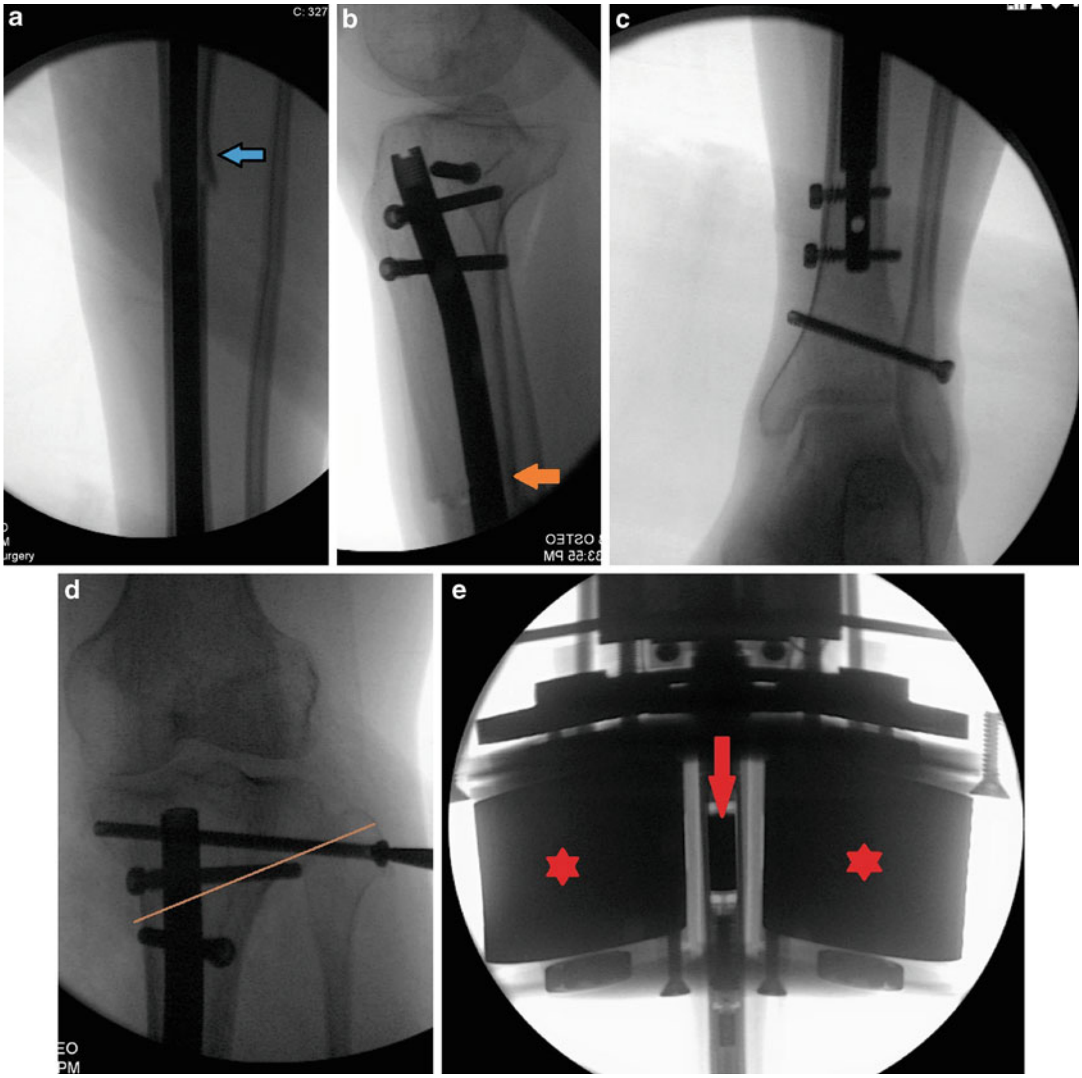

Fig. 4 Intraoperative fluoroscopy images. (**a**) AP view after insertion of nail. There does not appear to be space between the lateral border of the nail and the lateral cortex (*blue arrow*) at the osteotomy level. For this reason, a blocking screw was not inserted. (**b**) Lateral view after insertion of the nail. There does not appear to be space between the nail and the posterior cortex (*orange arrow*) at the osteotomy level. For this reason, a blocking screw was not inserted. (**c**) A syndesmosis screw is inserted to prevent proximal migration of the distal fibula. The oblique screw placement provides superior resistance to a proximal pull on the fibula. (**d**) Insertion of proximal tibia-fibula screw posterior to the IM nail. The transverse orientation does not provide optimal resistance against the fibula being pulled distally (Fig. 6a). A preferable orientation for this screw is demonstrated by the *brown line*. (**e**) The external magnet controller (*EMC*) (stars) is placed over the magnet in the IM nail (*red arrow*)

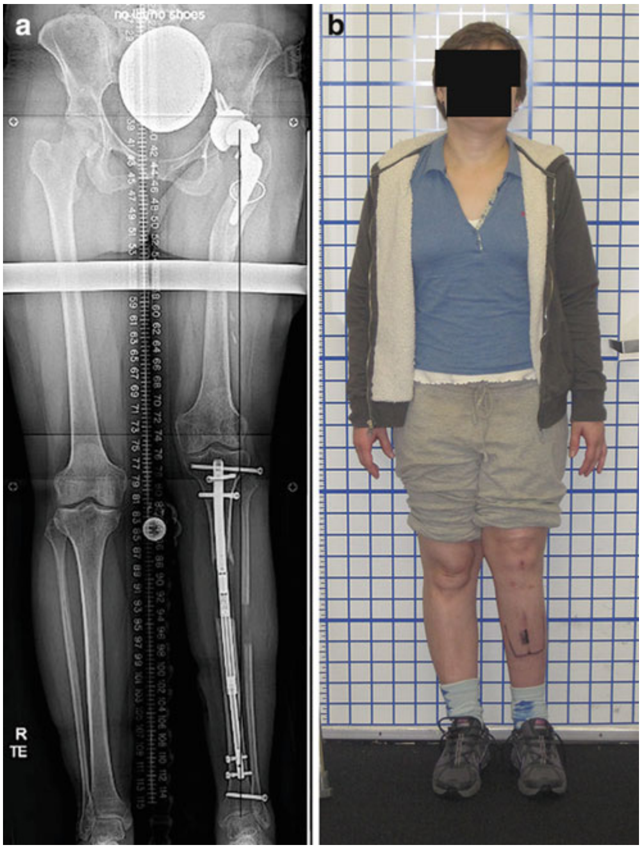

Fig. 5 (**a**) Bipedal standing X-ray at end of distraction (70 days after surgery) showing equal leg lengths. Note MAD position relative to preoperative (Fig. 1a). Mild increase in valgus did occur. (**b**) Front view at 3 months showing equal leg lengths. Note the *mark* on skin for EMC placement

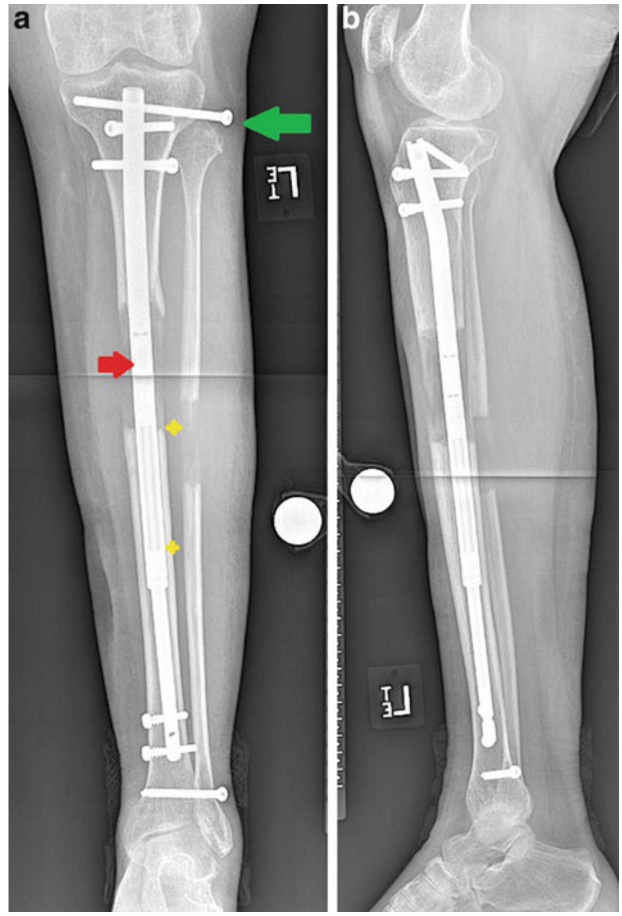

Fig. 6 Radiographs 3 months after surgery with excellent bone formation. (**a**) AP view shows distraction gap of 65 mm. This can be accurately measured on a calibrated radiograph noting the excursion of the rod (distance between the *yellow stars*). Note the proximal fibula has pulled distally despite the screw (*green arrow*). (**b**) Lateral view showing excellent alignment

Fig. 7 (**a**) AP and (**b**) lateral X-rays 12 months after surgery. MPTA is 88

Fig. 8 (**a**) AP and (**b**) lateral X-rays 14 months after initial surgery and 1 week following nail removal

Fig. 9 AP pelvis X-ray after revision of THR for infection during this interim period

10 Cross-References

- ▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate
- ▶ Case 8: Femoral Lengthening (12 cm) with Two Precice Nail Lengthenings. Management of a Broken Precice Nail During the First Lengthening

References and Suggested Reading

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Case 3: Tibial Lengthening Using a PRECICE Nail

Matthew Wagoner, Pablo Wagner, and John E. Herzenberg

Contents

Abstract

A 17 year old male, with a history of fibular hemimelia and congenital femoral deficiency, presents with a residual limb length discrepancy (LLD) on the right lower extremity of 3.5 cm. The patient previously underwent right lower limb lengthening with external fixation. There is moderate anterior-posterior knee instability. The patient underwent a right tibia lengthening using the PRECICE nail, gastrocnemius lengthening, and botulinum toxin injections to the anterior tibial and peroneal muscles. A successful outcome was obtained at the end of the treatment.

1 Brief Clinical History

This is a 17 year old male, who presented with a limb length discrepancy on the right lower extremity due to fibular hemimelia and congenital femoral deficiency. He previously underwent several lengthenings with the use of external fixation on his tibia and femur. He has a residual discrepancy of 3.5 cm. He presents to the office with hip and back pain that is resolved with the use of a shoe lift. He refuses to keep using the lift.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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Fig. 1 Front view clinical photo

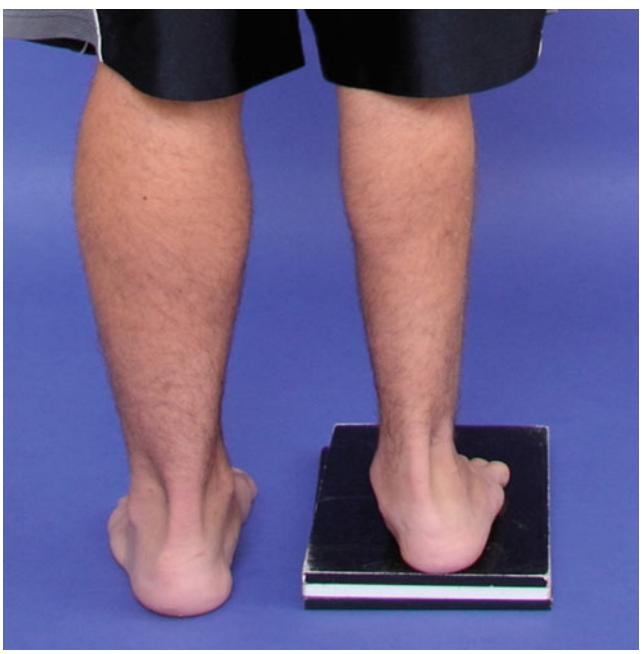

Fig. 2 Back view clinical photo showing leg and ankle valgus

3 Preoperative Problem List

1. Congenital femoral deficiency and fibular hemimelia
2. Leg length discrepancy, right shorter by 3.5 cm
3. Valgus deformity of the right tibia

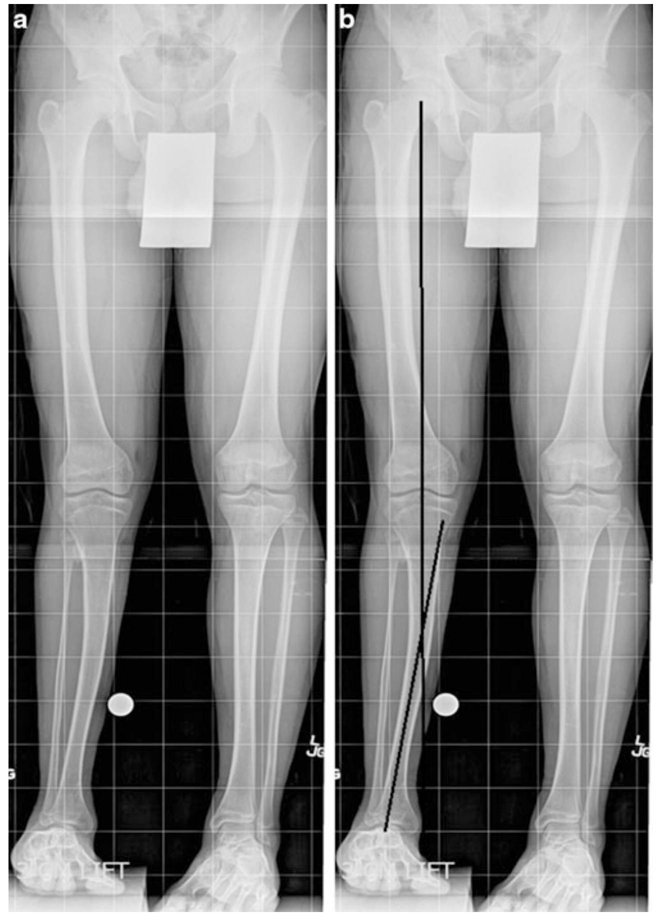

Fig. 3 (**a**) Bipedal erect leg X-ray showing valgus deformity of the tibia, LLD of 3.5 cm, and a short hypoplastic fibula. (**b**) Surgical planning to determine location of osteotomy and the magnitude of the deformity

4 Treatment Strategy

1. Stabilization of distal tibiofibular syndesmosis with screw fixation.
2. Osteotomy right tibia and fibula at the apex of deformity.
3. Perform a fibular osteotomy at the junction of the distal third and the middle third.
4. Percutaneous tibia drill holes at osteotomy site.
5. Complete the osteotomy using an osteotome.
6. Reaming of the tibia to the appropriate diameter.
7. Insertion of intramedullary limb-lengthening nail (PRECICE) into the proximal segment.
8. Insert the nail and locking screws (two proximal and two distal).
9. Prophylactic anterior compartment fasciotomy.
10. Gastrocnemius lengthening (Vulpius).
11. Injection of botulinum toxin into the right anterior tibialis and peroneal muscles.

Fig. 4 Lateral X-ray of the tibia

Fig. 5 Place a distal syndesmotic screw

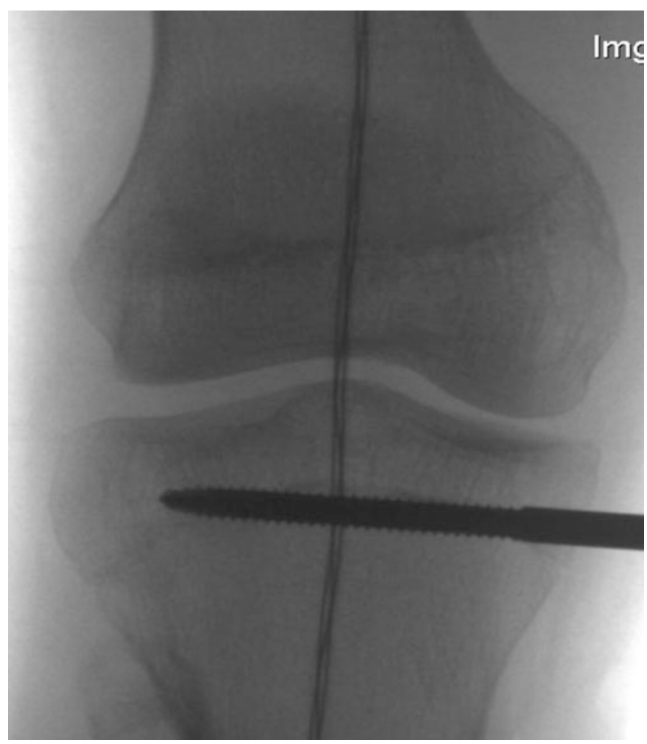

Fig. 6 Check mechanical axis after osteotomy; intraoperative external fixator is stabilizing the position

5 Basic Principles

As for any lengthening, soft tissue contractures are a frequent challenge. Minimize this risk by performing a prophylactic peroneal nerve release, an anterior fasciotomy, and a gastrocnemius lengthening.

Perform osteotomy at the apex of the valgus deformity. If the nail does not fill the intramedullary canal at that level, consider using blocking screws adjacent to the osteotomy site in the concavity of the deformity (editor's comment, SRR).

Follow the patients closely to ensure that no complications are happening during the distraction process. Allow weight bearing as tolerated only when there is bone healing in 3/4 cortices. Before that, only 30 % of weight bearing should be allowed to prevent nail breakage.

6 Images During Treatment

See Figs. 5, 6, 7, 8, 9, and 10.

Fig. 7 Before intraoperative lengthening

Fig. 8 After intraoperative lengthening. See difference in osteotomy space under magnet following 1.5 mm of lengthening

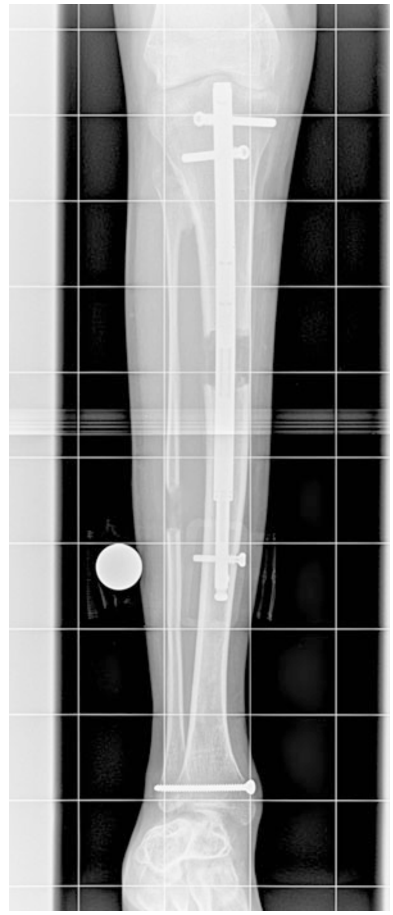

Fig. 9 AP tibia X-ray at the end of lengthening

7 Technical Pearls

For valgus tibia corrections, use a slightly lateral tibial entrance point (this case). Another method to aid in the valgus correction is to slightly internally rotate the nail directing the Herzog bend medially. Stabilize the tibia during the nail insertion using axial pressure from the knee and the help of an assistant. An external fixator can be used to help stabilize the tibia while inserting the nail. This will help for an appropriate nail placement. In the diaphyseal area, use the drill hole technique to perform the osteotomy. In the metaphyseal area, use a Gigli saw. If the osteotomy is in the metaphyseal area, use blocking screws (Poller screws)

Fig. 10 Lateral tibia X-ray at the end of lengthening

Fig. 11 AP view of the healed tibia

to avoid proximal segment malalignment. Always test the nail before the end of the case by lengthening 1.5–2 mm acutely. This will allow you to see if the nail is lengthening on fluoroscopy.

In this case, additional correction of valgus could have been obtained with use of lateral blocking screws adjacent to the osteotomy site to push the nail medial at the osteotomy site (editor's comment, SRR).

8 Outcome Clinical Photos and Radiographs

See Figs. 11, 12, 13, and 14.

9 Avoiding and Managing Problems

Make sure that the nail is working by acutely lengthening it in the OR. During the patient's follow-up, increase or decrease the PRECICE lengthening speed depending on the appearance of the regenerate on the X-rays. If hypertrophic callus is present, then speed it up. If regenerate quality is poor, then slow the lengthening down. If a premature consolidation should occur (bone healing before the end of the distraction), perform a new percutaneous osteotomy distal to the previous one. In cases of partial or delayed union, perform a nail dynamization (removal of proximal or distal locking screws) and add bone graft.

Fig. 12 Lateral view of the healed tibia

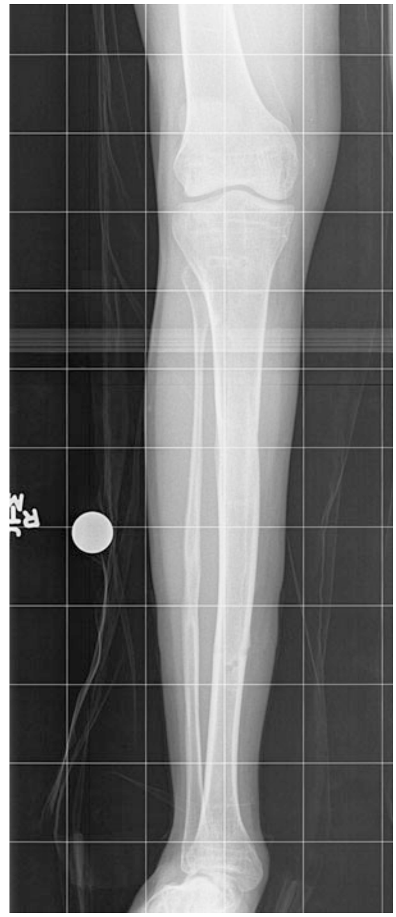

Fig. 13 AP view after removal of nail

Fig. 14 Lateral view after removal of nail

10 Cross-References

▶ Case 1: Femur Lengthening with Precice Internal Lengthening Nail

11 See Also in Vol. 1

Case 41: Fibular Hemimelia: Paley Type 3

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Case 4: Both Femur and Tibial Shortening Caused from Hemi-hyperthropia Treated Simultaneously with Two Antegrade Precice Nails

Metin Kucukkaya

Contents

Abstract

Hemihypertrophy is a genetic disorder characterized by overgrowth of one-half of the body in comparison with the other half. Overgrowth may affect only one part of the body such as the legs and arms. Furthermore, hemihypertrophy may proportionally affect both femur and tibia and may also affect malleolar height. Lengthening of both femur and tibia using external fixators is troublesome. New-generation lengthening nails have clear advantages for correcting deformities and lengthening the lower limb.

This section presents a 22 year old female patient with shortening of the femur and tibia on the left side caused by hemihypertrophy on the right side. The patient was treated simultaneously with two antegrade Precice (Ellipse Technologies, Irvine, California, USA) internal lengthening nails for both femur and tibia.

1 Brief Clinical History

A 22 year old female was admitted with a 6 cm limb length discrepancy (LLD) on the left side. Hemihypertrophy was diagnosed on the right side at 7 years of age. The LLD increased as she grew. She had 3 cm shortening of the femur, 2 cm shortening of the tibia, and 1 cm shortening of malleolar height. She could walk on her toes without using a shoe lift; however, she complained of limping and back pain after walking. No deformity or soft tissue contracture was observed on the lower limbs.

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Fig. 1 (**a**, **b**) Clinical photographs and preoperative long-standing radiograph with LLD compensated for by using plates and the patellae oriented anteriorly. (**c**) Note that the malleolar height difference also increased LLD by 1 cm

2 Preoperative Clinical Photographs and Radiographs

See Fig. 1.

3 Preoperative Problem List

- A total of 6 cm LLD on the left side consisted of 3 cm of femoral shortening, 2 cm of tibial shortening, and 1 cm of malleolar shortening.

4 Treatment Strategy

Antegrade application of lengthening nails in both femur and tibia at the same stage.

Simultaneous gradual lengthening of both femur (3.5 cm) and tibia (2.5 cm).

5 Basic Principles

The LLD was determined from the physical examination and plain radiographs. The malalignment test (Paley 2002) and the "end point first method" (Thaller et al. 2014) were used for preoperative planning.

Femoral lengthening using an intramedullary nail occurs along the anatomical axis. It results in coronal plane translation of the knee relative to the mechanical axis. To prevent malalignment, the distal fragment should be translated laterally during the index operation. However, this correction can only be performed using a retrograde nailing technique. Preoperative planning of this case revealed that 3.5 cm femoral lengthening would not create an important deviation on the mechanical axis.

Fig. 2 (**a**) Tibial nailing was performed with the patient in the supine position on a radiolucent operating table with the knee in a semi-flexed position. (**b**) Antegrade nailing of the femur was performed with the patient in the lateral decubitus position. Note that two parallel 6 mm Schanz pins were inserted into the proximal and distal segments before the osteotomy. (**c**) The anteroposterior X-rays of both femur and tibia during the early postoperative period. (**d**) Clinical pictures during the distraction period. Note the knee function. (**e**) Distraction of the Precice internal lengthening nail using external remote controller. (**f**) Long-standing radiograph after a total of 6 cm of lengthening. Note that pelvic balance was gained

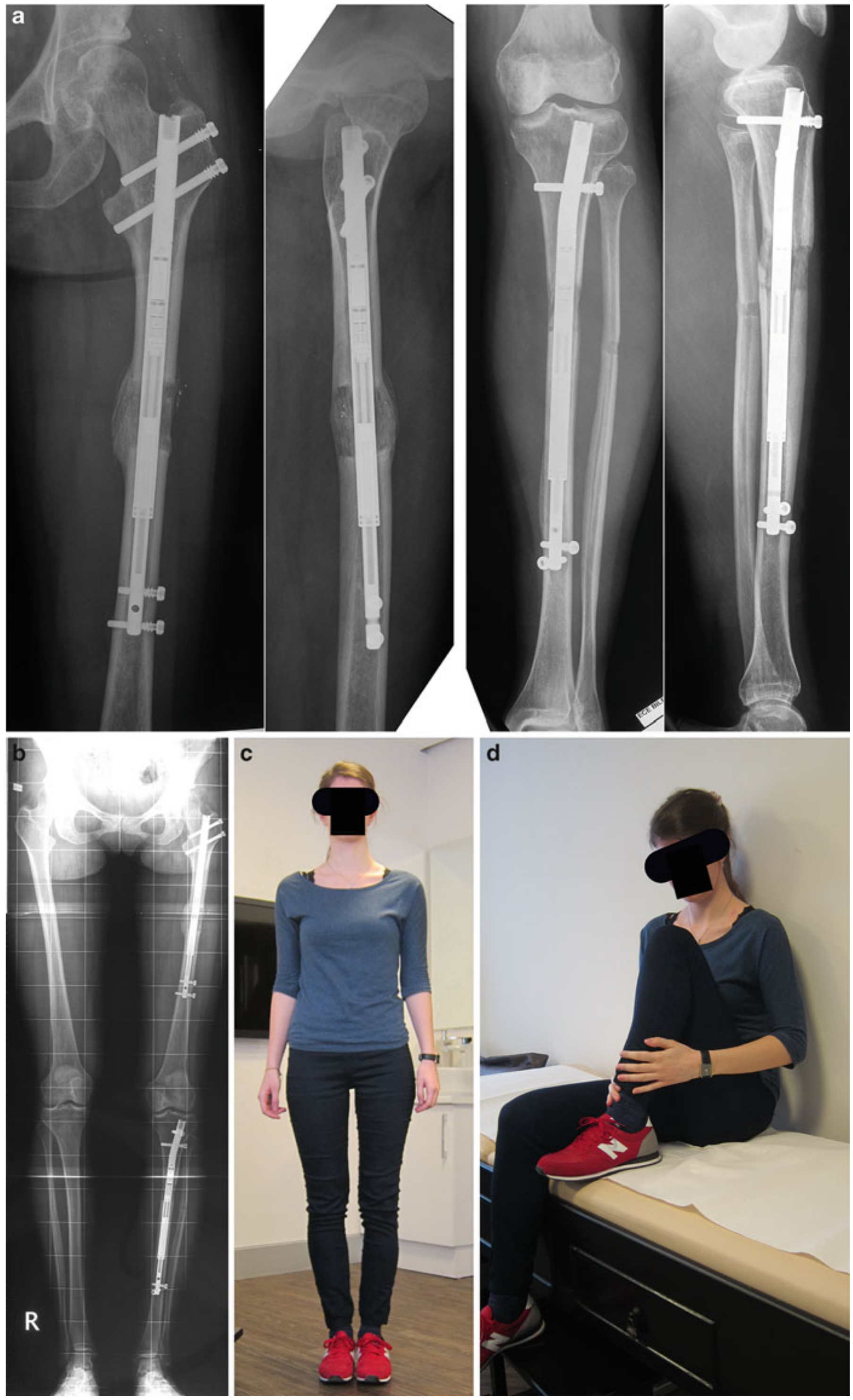

Fig. 3 (**a**) Anteroposterior and lateral X-rays after consolidation of both the femur and tibia. (**b**) Long-standing radiograph after the 6 cm lengthening at 6 months. (**c**) Clinical photographs after treatment. (**d**) Note the knee function

Therefore, an antegrade nailing technique was preferred to avoid knee penetration.

6 Images During Treatment

See Fig. 2

7 Technical Pearls

7.1 For Tibial Nailing

- A transverse incision at the lower pole of the patella was used for tibial nailing.

- A tourniquet was used during initial exposure and the fibular osteotomy.
- The entry point for tibial nailing and the osteotomy level were planned preoperatively. The tibial osteotomy was performed 10 cm below the joint line.
- A fibular osteotomy was performed after inserting and locking the nail to prevent malrotation.

7.2 For Femoral Nailing

- A longitudinal 2 cm incision was used for the antegrade femoral nailing.
- Two parallel 6 mm Schanz pins were inserted into the proximal and distal segments before the osteotomy to prevent malrotation of the femur after the osteotomy. The first Schanz pin should be placed at the level of the lesser trochanter, and it should be placed posterior to the reamer and nail passage.
- Distraction was started on postoperative day 5 and was performed at 0.6 mm/per day in two equal increments in both the femur and tibia.

8 Outcome Clinical Photographs and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

- A tourniquet should not be used during reaming of the canal because of the risk of thermal necrosis.
- Excessive reaming and high-speed reaming of the medullary canal using a rigid reamer can cause necrosis of the bone and result in poor bone regeneration at the distraction site.
- Use of a tibiofibular screw to stabilize both the proximal and distal tibiae-fibulas will prevent distal migration of the proximal fibula and will prevent proximal migration of the distal fibula. It will ensure that the fibula separation and lengthening will equal the tibial lengthening. This was not done in this case but is routinely recommended by the editor (comment by S. Robert Rozbruch, MD).

10 Cross-References

► Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate
► Case 37: Ipsilateral Secondary Hip Osteoarthritis and Leg Length Discrepancy: Treated Simultaneously with Total Hip Replacement and Motorized Lengthening

11 See Also in Vol. 1

Case 19: Femoral Shortening (14 cm) and Deformity Treated with Acute Correction and Two Consecutive Retrograde Fitbone Applications

References and Suggested Reading

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Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate

Metin Kucukkaya and Ozgur Karakoyun

Contents

Abstract

Combined lower extremity deformities affecting both the femur and tibia can be corrected by well-planned one-stage correction with double osteotomies around the knee. During the femur lengthening and deformity correction using straight lengthening nails, lengthening along the anatomical axis requires detailed preoperative planning in order to prevent axis deviation. When combined deformities affecting the tibia and femur involve extreme shortening, a one-stage correction with a lengthening nail and a plate requires precise planning and surgical technique. In this chapter, we present a case of a 14 year old female with combined deformities affecting both the femur and tibia, complicated by a 9-cm femoral shortening resulting from physeal arrest. The patient was treated using a retrograde femoral motorized lengthening nail and a tibial plate.

1 Brief Clinical History

A 14 year old female with combined deformities affecting both the femur and tibia complicated with a 9-cm femur shortening presented to us. These deformities were caused by an open femur fracture resulting from a traffic accident when she was 6 years old; the fracture around the distal femoral physis was treated using closed reduction and percutaneous pinning. As she grew, leg-length discrepancy (LLD) and deformities developed as a result of the physeal arrest. She could walk on her toes without a shoe lift but complained of limping and back pain after walking. There was no soft tissue contracture at the hip.

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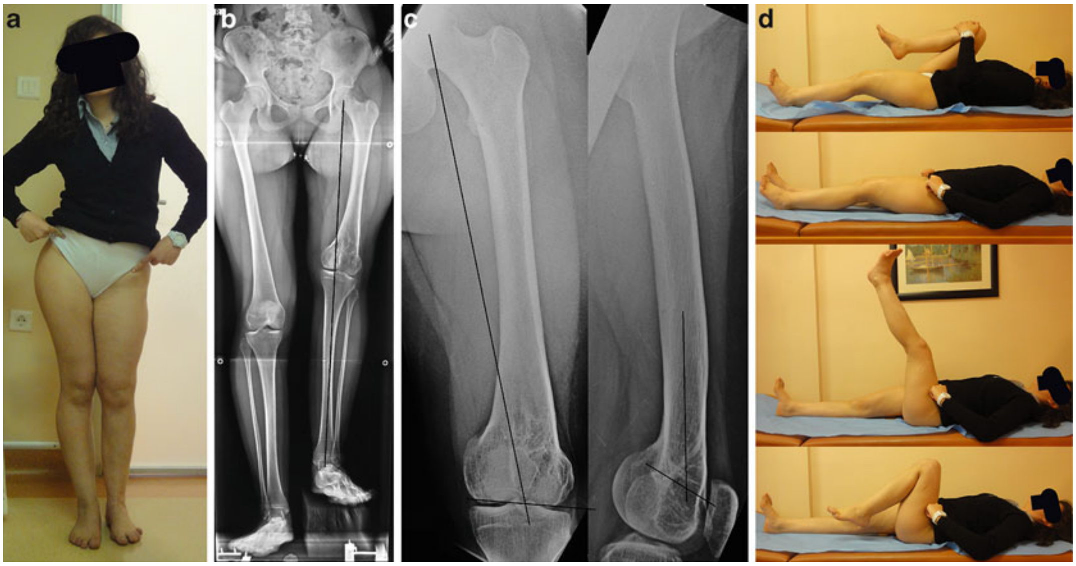

Fig. 1 (**a**, **b**) Clinical photos and preoperative long-standing radiograph (LSR) with the leg-length difference compensated for using plates. Note the patellae were oriented anteriorly. Note the varus femur and valgus tibia resulting in oblique joint line. (**c**) Preoperative AP and lateral views of the right femur. Note the varus and apex anterior deformity of the distal femur. (**d**) Clinical photos of her joint range of motion. Note that there is an extension limitation of the left knee

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

- Deformities of the femur, including shortening of 9 cm and angulation in the oblique plane of 22° (apex anterolateral). There is varus noted on the AP X-ray and apex anterior deformity noted on the lateral X-ray.
- 15° valgus of the tibia.
- Deviation of the mechanical axes of the femur and tibia and joint line obliquity.

4 Treatment Strategy

- Acute angular correction and simultaneous lengthening of the femur using a motorized lengthening nail (Fitbone-TAA 24.5 cm, maximum stroke 80 mm, Wittenstein, Ingersheim, Germany) (Baumgart et al. 2006)
- Decompression of the peroneal nerve before correction of the tibia deformity
- Acute angular correction by closed-wedge osteotomy of the tibia and plate fixation

5 Basic Principles

The LLD and angular deformity were assessed from physical examination and plain radiographs. Preoperative planning of the amount of acute correction of both bones relied on the malalignment test (Paley 2002) and the reverse planning method (Baumgart 2009). The entry site, canal diameter, osteotomy site, and positions of the blocking screws for retrograde nailing were determined using X-rays, and the size of the tibial bone wedge was determined by the tibial templating.

Preoperative templating on the LSR revealed that acute correction of femur deformity in both frontal and sagittal planes would correct 2 cm of the 9-cm length deformity, while acute correction of the tibia deformity by closed-wedge osteotomy would shorten the leg by 1 cm. In summary, acute correction of the combined deformities affecting both the femur and tibia would immediately lengthen the leg by 1 cm. Thus, the maximum 8-cm stroke

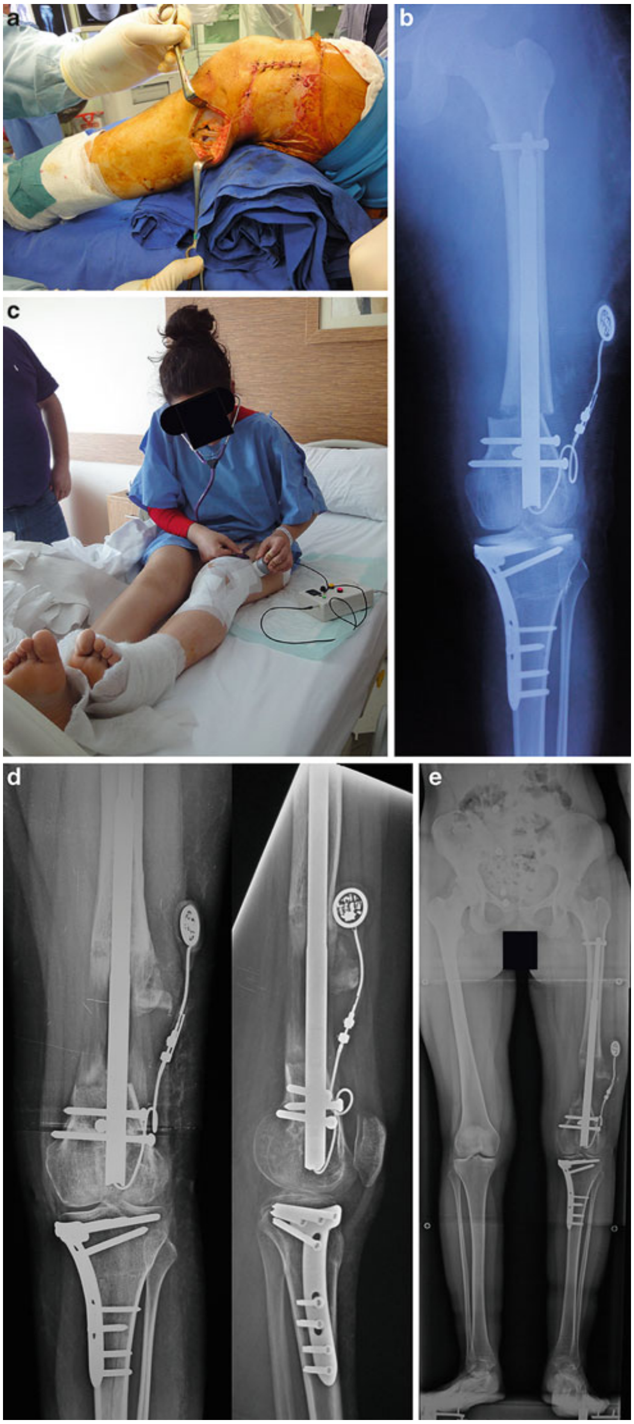

Fig. 2 (**a**) As acute varus correction of the tibia can stretch the peroneal nerve around the fibular head, the peroneal nerve was released to prevent tension after acute correction. (**b**) X-rays in the early postoperative period show acute correction of both sites. Note the position of the blocking screw in the femur. (**c**) Distraction of the osteotomy site was started with 1 mm/day at postoperative 5th day using the external transmitter. (**d**, **e**) X-rays and LSR at 3 months after 8 cm of distraction

of the femoral motorized lengthening nail was predicted to be sufficient to correct the remaining length deformity.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

During the operation, the patient was supine on a radiolucent operating table. A radiopaque grid plate was used for the intraoperative assessment of the joint line inclination. The lengthening nail was placed as described in another chapter, in this case, atlas "Case 19: Femoral Shortening (14 cm) and Deformity Treated with Acute Correction and Two Consecutive Retrograde Fitbone Applications" (Vol. 1 of this bookset).

The length of the medial resected cortex (c) on the tibia can be determined by the true tibial width (TW) at the level of the osteotomy multiplied by the tangent of the resected wedge angle ($c = TW \times \tan \mu$) instead of preoperative templating (Brown and Amendola 2000).

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

To prevent peroneal nerve stretching around the fibular head caused by acute varus correction of the tibia, the nerve can be decompressed before correction of the deformity.

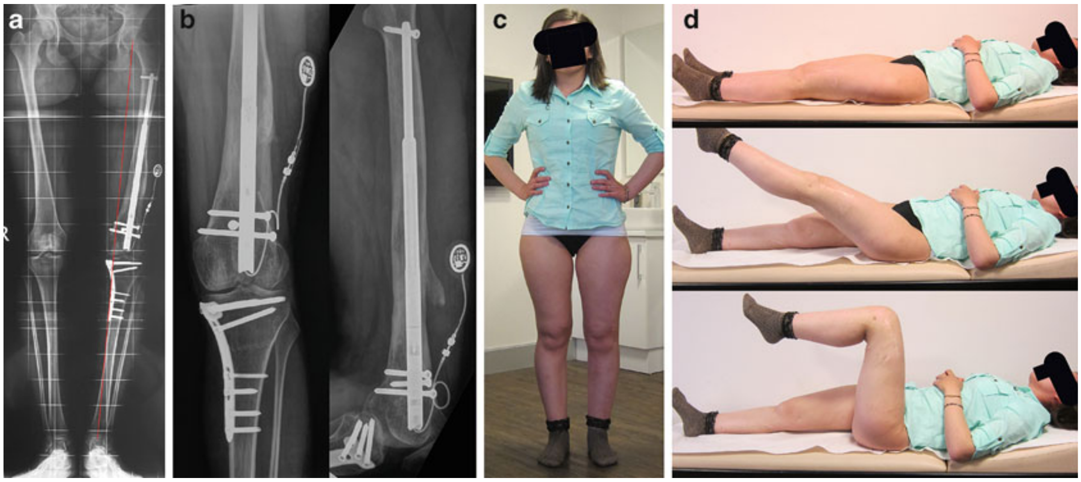

Fig. 3 (**a**, **b**) LSR and standard X-rays at 1 year postsurgery. MAD is medial but clinical appearance is normal with equalization of leg lengths. (**c**, **d**) Clinical photos of function after treatment. Note full knee extension but some loss of flexion

10 See Also in Vol. 1

Case 19: Femoral Shortening (14 cm) and Deformity Treated with Acute Correction and Two Consecutive Retrograde Fitbone Applications

References and Suggested Reading

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Case 6: Congenital Femoral and Tibial Shortening Internally Lengthened with an ISKD and a Precice Nail

Pablo Wagner and John E. Herzenberg

Contents

Abstract

This is a 50 year old patient with a long-standing history of congenital femoral deficiency (CFD) and fibular hemimelia. In addition, he had a femur fracture on the same side with a secondary malunion. The patient had a 6 cm leg length discrepancy. An intramedullary lengthening of his right femur and tibia was offered. The femur was lengthened with an ISKD (intramedullary skeletal kinetic distractor) (Orthofix Inc.) and the tibia with a PRECICE (Ellipse Technologies). A successful final outcome was obtained.

1 Brief Clinical History

This is a 50 year old male with a history of CFD and fibular hemimelia. He had a shortening of 6 cm on his right lower extremity, 3 cm of the tibia, and 3 cm of the femur. In addition to the congenital short femur, he had a femur fracture that was treated conservatively in the past resulting in a malunion with external rotation and posterior translation deformity. In 2011, an ISKD was implanted into the femur for a 3 cm lengthening and deformity correction. In 2012, a PRECICE nail was inserted into the tibia for a 3 cm lengthening.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

Right femur shortening

Right femur deformity – external rotation and posterior translation

Right tibial shortening

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Fig. 1 Erect leg X-ray demonstrates a 6 cm limb length discrepancy (LLD)

Fig. 2 Lateral femur X-ray showing the malunion

4 Treatment Strategy

Femur ISKD:

Iliotibial band release.
Drill holes at osteotomy site.
Transitory external fixator.
Reaming of the proximal fragment.
Complete osteotomy.
Correct deformity.
Reaming of the distal fragment.
Insert and lock the nail.
Remove external fixator.

Tibia PRECICE:

Peroneal nerve decompression.
Anterior compartment fasciotomy.
Proximal and distal tibiofibular syndesmotic screws.
Fibula osteotomy.
Drill holes at osteotomy site.
PRECICE insertion to the osteotomy site.
Complete osteotomy.
PRECICE insertion and locking screw placement.
Test lengthening with the external remote controller.

5 Basic Principles

Given that these nails are not cannulated, the osteotomy should be performed while under external fixation stabilization. The other option is to have the nail inserted in the proximal segment, perform the osteotomy, and pass the nail immediately after the osteotomy is performed. Always perform soft tissue (nerve/tendon/compartment) releases for lengthenings.

Fig. 3 Fibular osteotomy

Fig. 4 Calcaneotibial screw. This was done to prevent equinus contracture during tibial lengthening

Fig. 5 AP ankle showing the calcaneotibial screw, the syndesmotic screw, and the distal tip of PRECICE nail

Fig. 6 Femoral manual reaming after femoral osteotomy

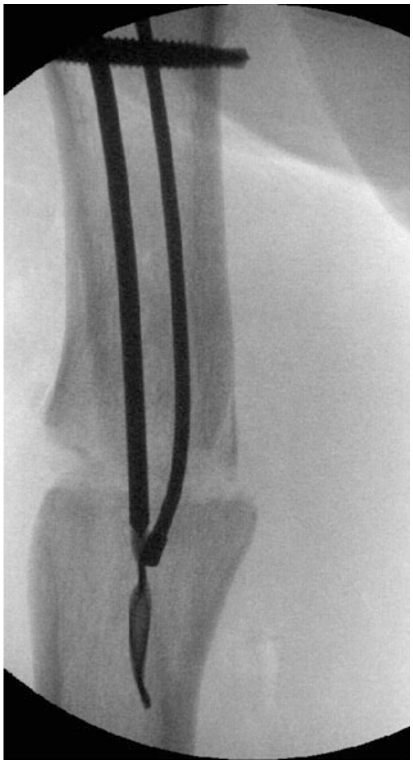

Fig. 7 Guide wire passage helped by hand reamer

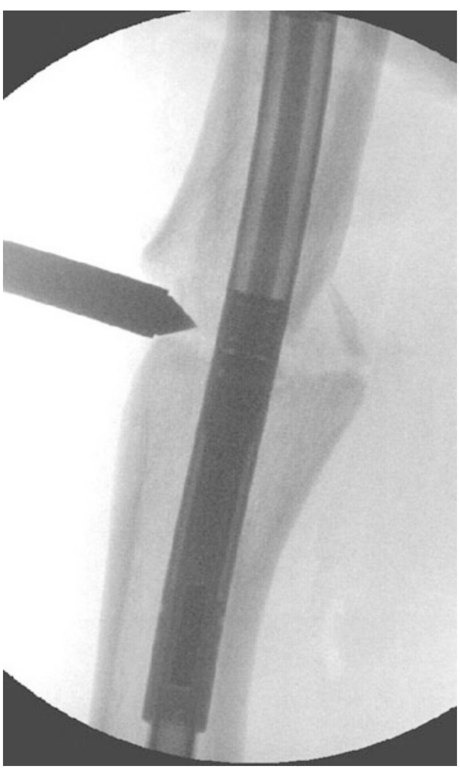

Fig. 8 ISKD nail in place. Application of graft through sleeve

Fig. 9 AP X-ray of the femur at the end of distraction

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, and 8.

7 Technical Pearls

It is frequent that around the malunion site, there is sclerotic bone filling the medullary canal. In these cases, a manual reamer can be used to create the medullary canal to allow the guide wire insertion.

Bone graft obtained from the reamings may be inserted directly into the osteotomy site through the sleeves (Fig. 8) designed for locking screw insertion.

For preoperative equinus deformities that are not fully corrected with Achilles lengthening, a calcaneotibial screw can be used. This prevents equinus from worsening during the lengthening.

Fig. 10 AP X-ray of the tibia at the end of distraction

Fig. 11 Outcome erect leg X-ray. Note there is some increase in lateral MAD compared to the preoperative erect leg X-ray

8 Outcome Clinical Photos and Radiographs

See Figs. 9, 10, and 11.

9 Avoiding and Managing Problems

During the lengthening stage, maintain a rigorous physical therapy program to keep joint range of motion and avoid joint subluxations.

With the PRECICE, modulate the lengthening speed according to the bone callus formation seen in X-rays to avoid delayed or nonunions. With the ISKD, this is not possible. In this case, a delayed union of the lateral femoral cortex (ISKD) was observed.

The tibia has a tendency to drift into valgus during lengthening. An anterior to posterior blocking screw in the concavity of the anticipated deformity may have prevented the valgus in this case. Specifically, the blocking screw could have been placed along the lateral aspect of the nail just proximal to the osteotomy site. This would serve to narrow the IM canal and prevent the lateral translation of the nail just proximal to the osteotomy site.

10 Cross-References

- ▶ Case 1: Femur Lengthening with Precice Internal Lengthening Nail
- ▶ Case 8: Femoral Lengthening (12 cm) with Two Precice Nail Lengthenings. Management of a Broken Precice Nail During the First Lengthening

11 See Also in Vol. 1

Case 50: Femoral Lengthening and Rotational Correction with a Precice Nail in a Patient with Congenital Femoral Deficiency and Femoral Retroversion

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Case 7: Femoral Lengthening with Fitbone Nail Treated with “Sandwich Technique” to Remedy Non-union Then Lengthened with Precice Nail at Allogenous Fresh Frozen Strut Graft Site

Metin Kucukkaya and Sami Sokucu

Contents

Abstract

The rigid reamer system allows the insertion of a straight motorized lengthening nail in patients with narrow medullary canals. In these patients, excessive reaming or high-speed reaming might cause bone necrosis and result in poor bone regeneration at the distraction site. This section presents a case of a 16 year old female with a 9 cm femoral shortening who had treated with “sandwich technique” for poor bone regeneration that developed after lengthening with a motorized nail. The patient was subsequently treated with a retrograde Precice (Ellipse Technologies, Irvine, CA, USA) lengthening nail at fresh frozen allograft site to equalize leg lengths.

1 Brief Clinical History

A 13 year old female patient was admitted with congenital deformity and 10 cm LLD 3 years ago. The patient was first treated with motorized nail (Fitbone, Wittenstein; Ingersheim, Germany) and poor bone regeneration was developed after 6 cm lengthening. We reviewed all of the patient’s X-rays and found that the cortical bone around the nail was thinner at the end of the distraction period compared to beginning. At 10 months, the motorized nail was replaced with a thin standard nail and the distraction site was treated using a fresh frozen allograft strut combined with autogenous cancellous bone graft (“sandwich technique”) (Gogus et al. 2007). Solid consolidation was obtained

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Fig. 1 (**a**, **b**) Clinical photos and preoperative long-standing radiograph (LSR) with the patellae oriented anteriorly. There were 10 cm femoral shortening and valgus deformity at left femur. (**c**) Anteroposterior views of the femur during lengthening with motorized nail. Note that the cortical bone around the nail was thinner at the end of the distraction period compared to beginning. (**d**) The motorized nail (thickest part is 12 mm) (Baumgart et al. 2006) was replaced with a thin standard nail (10 mm × 30 cm,Trigen Meta-Nail, Smith & Nephew). Intraoperative photo of "sandwich technique". Dual onlay strut allografts combined with autogenous cancellous bone graft were wrapped with cables besides the intramedullary nail (Gogus et al. 2007). (**e**) Early and late anteroposterior and lateral views of the femur after exchange nailing. Solid consolidation was obtained 5 months after bone grafting. Note that the cortical bone around the nail thickened again after exchange nailing. (**f**) LSR when she was 14 years old. With further growth, the LLD increased to 9 cm

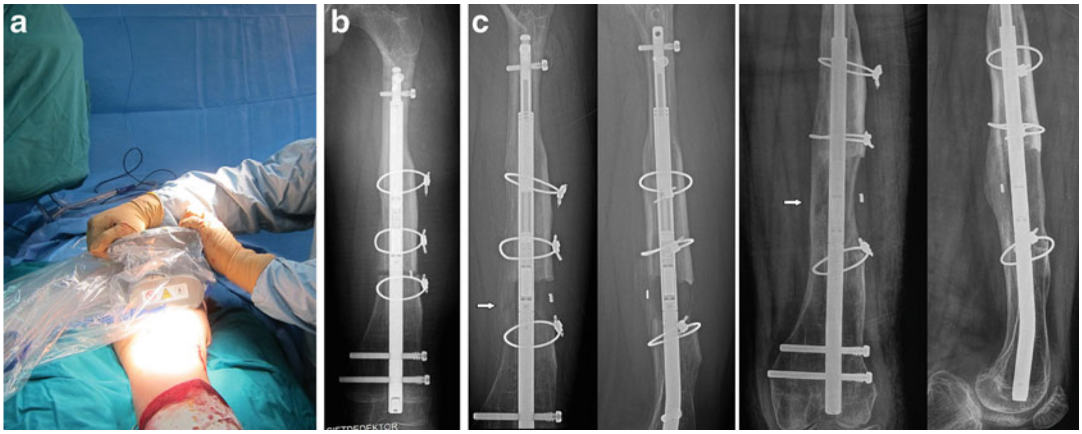

Fig. 2 (**a**) Testing of the Precice lengthening nail using external remote controller to ensure it is working properly at the end of the operation before awakening of the patient. (**b**) Early postoperative anteroposterior X-ray. The osteotomy was performed at the incorporated fresh frozen allograft strut site. (**c**) Anteroposterior and lateral views of the femur at 1 month and 6 months. A 65 mm lengthening was completed. Distraction of the osteotomy site was started with 1 mm/day at postoperative 5th day using with the external remote controller. Note that good bone healing was seen at the distraction area

5 months after bone grafting. We observed that the cortical bone around the nail thickened again after exchange nailing. Now the patient was 14 years old, and after further growth, the LLD reached to 9 cm.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2 and 3.

3 Preoperative Problem List

- Femoral shortening of 9 cm.
- There was an intramedullary nail in the femur.

4 Treatment Strategy

- Removing of the existing intramedullary nail from the femur.
- Lengthening of the femur with Precice nail (10.7 mm with, maximum stroke 65 mm, PRECICE® Intramedullary Limb Lengthening System-Ellipse Technologies, Inc. USA).

5 Basic Principles

The most important aspects for the success of bone distraction are an intact medullary blood supply and preservation of periosteum and soft tissue envelope. The rigid reamer system allows the insertion of a straight motorized lengthening nail in patients with narrow medullary canals. Over-reaming and high-speed reaming using a rigid reamer can cause necrosis of the bone and may cause poor bone regeneration at the distraction site.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

The operation was performed with the patient in the supine position on a radiolucent operating table. Radiopaque grid plate was used for intraoperative alignment. Technical pearls for lengthening nails were followed as in the chapter "Case 19: Femoral Shortening (14 cm) and Deformity Treated with Acute Correction and Two Consecutive Retrograde Fitbone Applications" (Vol. 1 of this bookset).

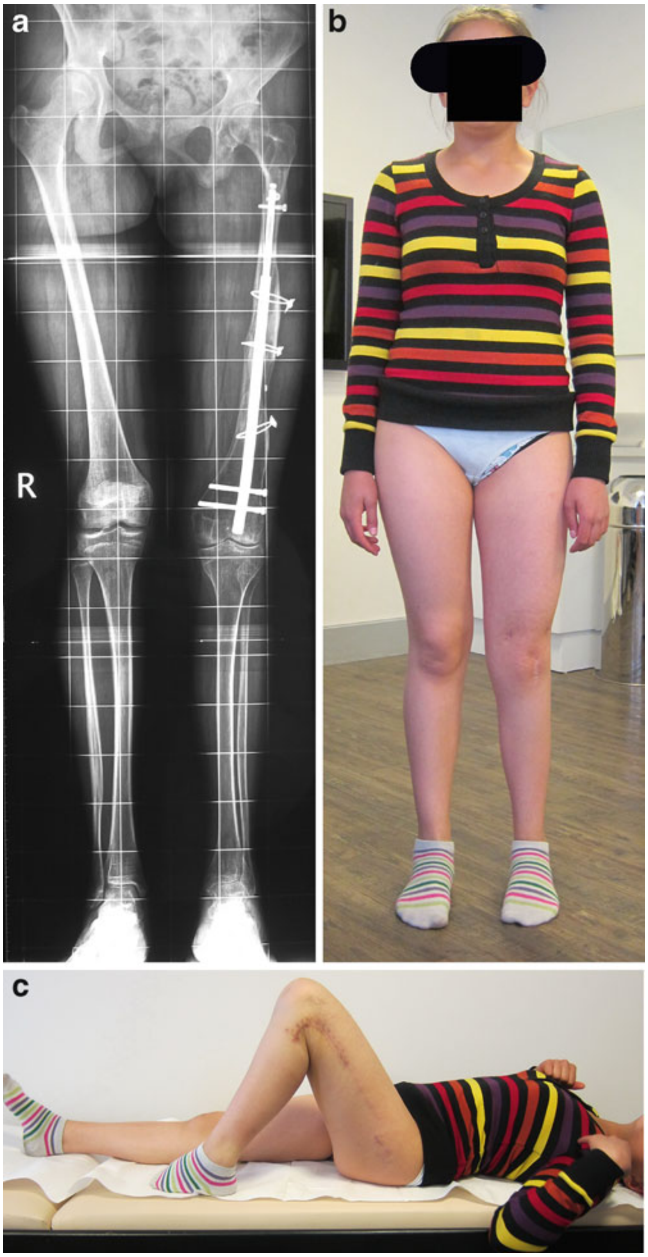

Fig. 3 (**a**) LSR at 1 year after treatment. The remaining LLD was 3 cm. (**b**, **c**) Clinical photos and function after treatment

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

The reaming should be done gently to avoid compromising the bone circulation and the medullary canal should not be over-reamed more than 0.5 mm to the nail.

Editor comments by S. Robert Rozbruch, MD:

In the growing child, the predicted LLD at maturity should be noted as the overall goal. Damage to the distal femur growth plate may have led to additional LLD in this case. In patients with narrow intramedullary canals, care should be taken to avoid insertion of an excessively large nail. The reaming needed to insert a large nail can damage the bone and compromise ability of bone regenerate to heal.

10 See Also in Vol. 1

Case 19: Femoral Shortening (14 cm) and Deformity Treated with Acute Correction and Two Consecutive Retrograde Fitbone Applications

References and Suggested Reading

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Case 8: Femoral Lengthening (12 cm) with Two Precice Nail Lengthenings. Management of a Broken Precice Nail During the First Lengthening

Metin Kucukkaya

Contents

Abstract

Treatment of limb length discrepancy is achieved with surgical limb lengthening using systems applied externally, internally, or their combination. The new-generation lengthening nails have clear advantages like less scar tissue formation, easier rehabilitation, and pain management than with the use of external fixation (Thaller et al., Injury 45:S60–S65, 2014). The new-generation Precice nail has both shortening and lengthening functions. Technical complications or implant breakage rarely occurs with this type of nail but can occur. This section presents a case of a 24 year old female having 12 cm femoral shortening whose treatment required two Precice (Ellipse Technologies, Inc.) lengthening nails as the former one was broken. The strategy for dealing with a broken internal lengthening nail is described.

1 Brief Clinical History

A 24 year old female was admitted to our center with gait abnormality. She had a history of right femoral fracture around distal femoral growth plate when she was 6 years old. The limb length discrepancy (LLD) increased as she grew. She had a 12 cm femoral shortening. She could walk on her toes without using a shoe lift. No soft tissue contracture was detected at the hip, knee, and ankle joints

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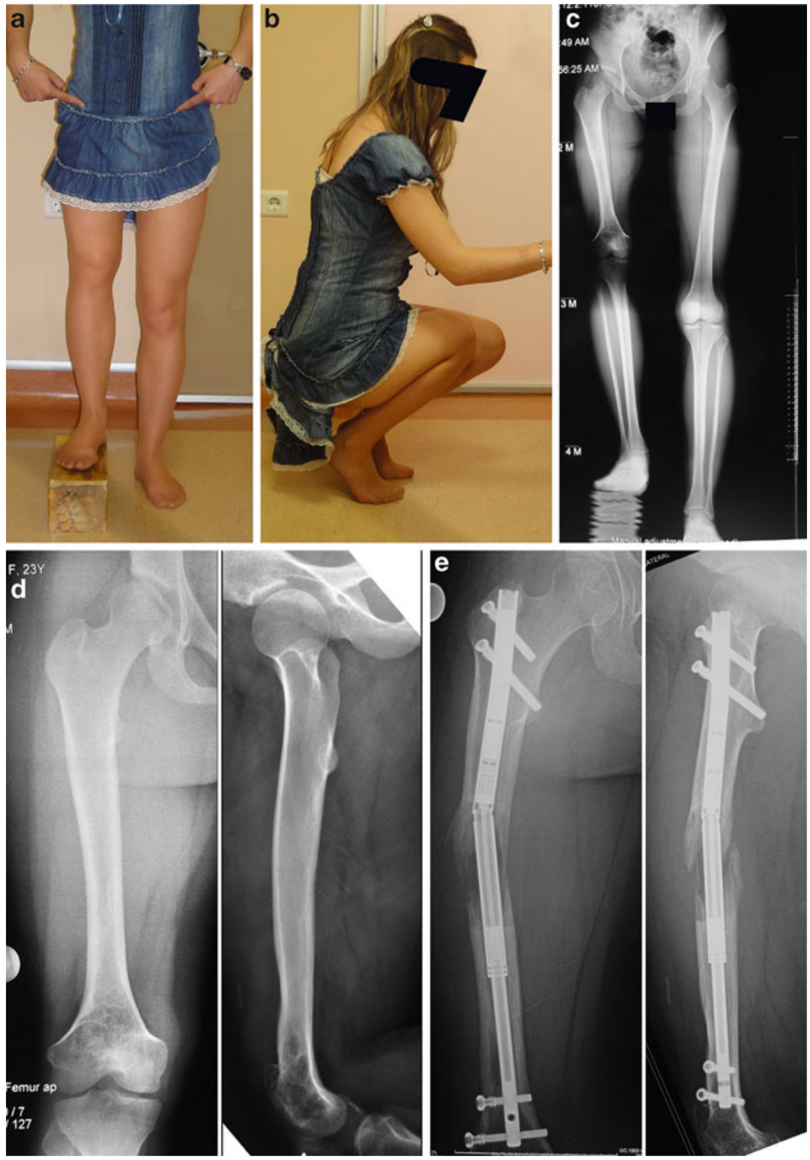

Fig. 1 (**a**, **b**) Preoperative clinical standing and squatting photos (**c**) Preoperative long-standing radiograph (LSR) with the leg-length difference compensated for using plates and the patellae oriented anteriorly. Note that medial mechanical axis deviation of 12 mm. (**d**) Preoperative anteroposterior and lateral views of the right femur. Note that narrow medullary canal in the distal part of the femur. (**e**) Anteroposterior and lateral radiographs of the broken nail during the consolidation period following initial lengthening. This occurred after a fall

during physical examination. The extremity was initially lengthened by 6.5 cm with antegrade application of a Precice femoral lengthening nail. During consolidation phase of initial lengthening, she fell down and the nail broke. The proximal fragment of the broken nail was extracted via proximal femoral approach while the distal fragment was extracted by hammering a pin which was driven proximally from distal femur. A standard femoral intramedullary nail (Smith & Nephew, Trigen TAN) was then inserted following the broken nail removal. The patient was followed until the bone healed. The femoral intramedullary nail was exchanged with a new intramedullary Precice lengthening nail to treat the remaining discrepancy (Figs. 1, 2, and 3)

Fig. 2 (**a**) Intraoperative fluoroscopic view of broken lengthening nail and varus stress test view exhibiting bending and pathological movement. (**b**) Stages of the broken nail removal. A thick K-wire is driven to push distal part of the broken nail to extract the nail completely. After clutching the proximal fragment of the nail, distal fragment is hammered with a K-wire and the nail is completely extracted. (**c**, **d**) Postoperative anteroposterior, lateral, and long-standing radiographs of right femur following the exchange of broken nail with standard femoral intramedullary nail. Bone is healed and there is residual LLD. (**e**, **f**) After consolidation period, 6 months postoperatively, a new Precice nail was inserted and a new osteotomy at a different site was performed and distraction was started

Fig. 3 (**a**) Anteroposterior and lateral X-rays after consolidation. (**b**) LSR after the 5.5 cm lengthening at 7 months. Note that pelvic balance was gained. (**c**) Clinical photos after a total of 12 cm lengthening. (**d**) Note the knee and hip function

2 Preoperative Clinical Photos and Radiographs

See Figs. 1a–e.

3 Preoperative Problem List

- The broken lengthening nail in the femur
- Femoral shortening of 5.5 cm

4 Treatment Strategy

- Extraction of both proximal and distal parts of Precice intramedullary nail
- Nailing with standard femoral intramedullary nail without shortening
- Achievement of consolidation without shortening
- Following consolidation, performing a new Precice lengthening nail to treat the remaining discrepancy

5 Basic Principles

When using an intramedullary nail, the femoral lengthening occurs along the anatomical axis. It results in coronal plane translation of the knee relative to the mechanical axis and an increase in valgus (lateral shift of the mechanical axis). In this case, 12 cm femoral shortening and 12 mm medial mechanical axis deviation were determined on the LSR. Also medullary canal at the distal part of femur was so narrow just to fit the thinner part of the lengthening nail. Preoperative planning revealed that 12 cm femur lengthening would correct the mechanical axis. Therefore, an antegrade nailing technique was preferred.

6 Images During Treatment

See Figs. 2a–f.

7 Technical Pearls

- The broken nail removal and insertion of second lengthening nail operations were performed with the patient in the lateral decubitus position on a radiolucent operating table with the knee in a semi-flexed position.
- The standard entry point for retrograde femoral nailing was used to push distal part of the broken nail with a thick pin.
- After reaming the medulla, a new classic femoral intramedullary nail was inserted into the previous canal.

8 Outcome Clinical Photos and Radiographs

See Figs. 3a–d.

9 Avoiding and Managing Problems

- Separation and fragmentation of the broken nail would be the major problem. To prevent separation of the proximal and distal part of the broken nail, a thick pin was inserted and adapted to distal part of the broken nail and hammered to push the distal part proximally. This technical trick provided us with the ability to achieve en block removal of the broken parts of the nail.
- After extraction the broken nail, shortening of the femur would be another major problem. To maintain length, gentle traction was applied to the leg to maintain the length of the femur.
- After consolidation with standard femoral nail, a new osteotomy at a new location was performed.

10 Cross-References

▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate

11 See Also in Vol. 1

Case 19: Femoral Shortening (14 cm) and Deformity Treated with Acute Correction and Two Consecutive Retrograde Fitbone Applications

References and Suggested Readings

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Case 9: Limb Lengthening of 14 cm with Simultaneous Deformity Correction of Femur and Tibia by Fully Implantable, Electric Driven Lengthening Nails

Peter Helmut Thaller and Tobias Helfen

Contents

Abstract

Neisseria meningitidis are the typical agents of a severe septic shock with fulminate disease especially in childhood. There are a lot of late complications as impaired soft tissue and deformities of the limbs with discrepancies in the growing skeleton. In the present case of a 20 year old girl, a lower leg length discrepancy (140 mm) and malalignment on the left side due to meningococcal sepsis in childhood were uneventfully corrected by fully implantable systems in two operative steps despite large scars and severely impaired soft tissue. The current case deals with the impaired bone growth and a resulting malalignment and lower limb discrepancy as late complications of a meningococcal sepsis. Cases like this are commonly corrected by external fixation with a high risk of pin tract complications, remaining malalignment, and patient discomfort. In conclusion, fully implantable intramedullary lengthening nails may be an excellent alternative to external fixation, even in difficult cases.

1 Brief Clinical History

A 20 year old girl presented with a 140 mm leg length discrepancy, malalignment, and impaired soft tissue on the left leg. She had acquired meningococcal sepsis at an age of 5 years.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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Fig. 1 Clinical presentation in the acute phase, in childhood

Fig. 2 Clinical presentation at baseline

Fig. 3 Radiological presentation at baseline – 14 cm LLD and malalignment

3 Preoperative Problem List

(a) Leg length discrepancy (140 mm).
(b) Malalignment (mLDFA 99°/ MPTA 93°) around the knee. Femur varus and tibia valgus are present.
(c) Impaired soft tissue with extensive and fragile scars.

4 Treatment Strategy

To avoid problems with the extensive scar areas and impaired soft tissue situation, we decided to apply fully implantable lengthening nails for the correction of the LLD and the distal femoral and proximal tibial deformity simultaneously. The stroke of very short, custom-made first femoral lengthening nail could provide 4 cm of lengthening. The second femoral lengthening nail could be chosen 4 cm longer. It could correct the remaining femoral discrepancy of 6 cm with the second step.

Treatment was planned in two operative steps:

(A) – Valgus osteotomy of the distal femur
– Antegrade femoral lengthening nail FITBONE© SAA 1340/300
– Varus osteotomy of the proximal tibia
– Tibial lengthening nail FITBONE© TAA 10/12
(B) – Removal of the femoral lengthening nail SAA 1340/300
– Minor valgus osteotomy of the distal femur
– Implantation of a second femoral distraction nail SAA 1360/360

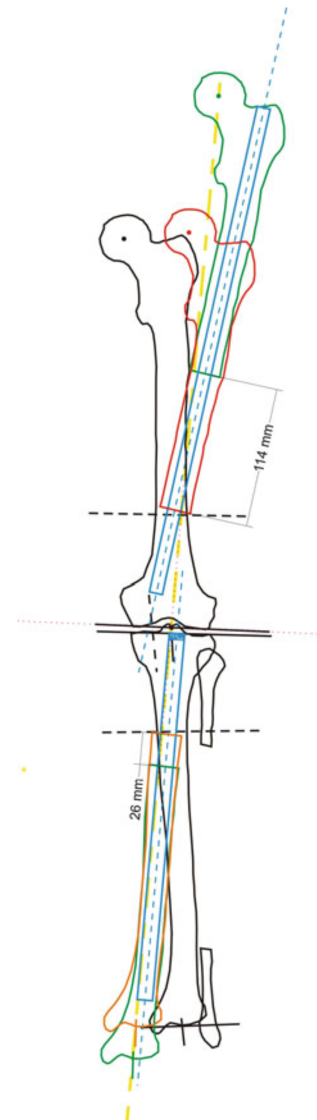

Fig. 4 Planning of lengthening and deformity correction of the femur and tibia – digital end-point-first planning (Corel DRAW®)

5 Basic Principles

Meningococcal sepsis can cause severe skeletal deformities and impaired soft tissue (Barre 2014). Fully implantable lengthening nails need meticulous analysis, planning, and performance of surgery because in contrast to external fixation, there is no chance for change without another surgery. Proper radiographic analysis is a prerequisite (Betz et al. 1990). There are various lengthening systems for distraction osteogenesis. There are mainly mechanically (Cole et al. 2001; Guichet 1999), electromotive-driven (Betz et al. 1990), and magnetic-driven systems (Thaller et al. 2014).

We have clinical experience with five different systems. In this case we applied two different electromotive-driven distraction nails (FITBONE®) for simultaneous distraction osteogenesis and deformity correction of the femur (SAA system) and tibia (TAA system). The energy is applied through the closed skin by induction from a transmitter to a subcutaneous antenna and via a cable into the nail. An electric motor and a gearing provide the distraction force. There are two basically different systems. The more common telescoping active actuator (TAA) was applied for the tibia. This system is less stable and tends to shorten after the

Fig. 5 Course of the 1st distraction

Fig. 6 Radiological result 12 months after the first operation, prior to the second step

distraction. Mainly because of the huge supracondylar malalignment, we applied the more stable sliding active actuator SAA system for the femur. This system is for antegrade femur only. It is more stable and allows huge supracondylar deformity corrections simultaneously. The system is non-telescoping. The interlocking in the end of a slotted hole in the mid-femur is pulled by the actuator. Thus the nail's end slides into the proximal femur and lengthens distally.

See Fig. 4.

6 Images During Treatment

See Figs. 5, 6, and 7.

7 Technical Pearls

The leg length correction with fully implantable systems particularly in cases with impaired soft tissue is an excellent option. Fully implantable systems cannot only be used for the isolated extension: Alignment and torsional deviation can be corrected with this system as well. In the further course an earlier rehabilitation and a lower rate of late complications were described.

With digital end-point-first planning (e.g., with *Corel DRAW®*), the immediate postoperative status before lengthening can be planned. Especially for long antegrade femoral nails and distal osteotomy, strengthening of the medullary canal by rigid reamers is inevitable to avoid multiple osteotomies. The surgical technique is minimally invasive to protect fragile soft tissues. In the second step of lengthening, an additional fine-tuning of the alignment was planned and successfully performed (see tip of the femoral nail in Fig. 6).

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

Complex defects, deformities, or leg length discrepancies are usually corrected by external fixator systems. There are complications like pin infections, multiple scars, prolonged hospital stays, and secondary deformities reported. Fully implantable intramedullary distraction nails can solve some of those problems. In contrast to external fixation, there is no chance for later corrections without revision surgery. Therefore successful treatment of such a severe malalignment combined with huge leg length discrepancy requires meticulous diagnostics, analysis, and planning (end-point-first planning). Intraoperative result should correspond exactly to the preoperative planning (X-ray grid method). The follow-up during distraction phase should be weekly or biweekly.

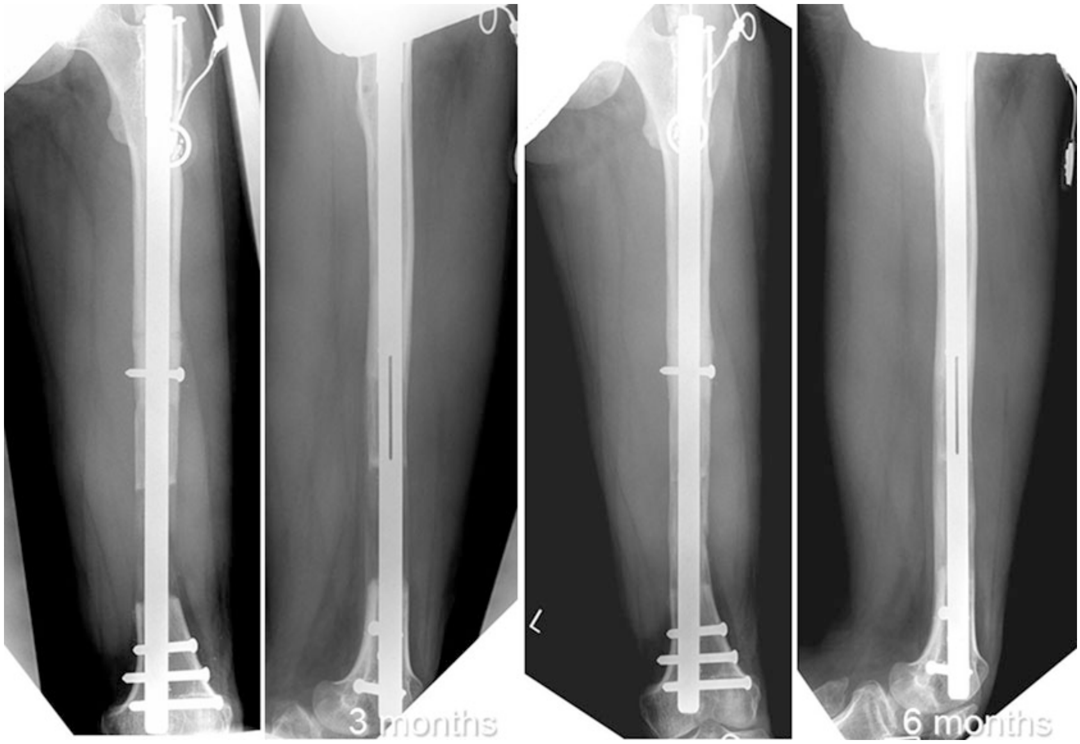

Fig. 7 Course of consolidation after the second distraction (the older callus from the first lengthening is noted more proximally)

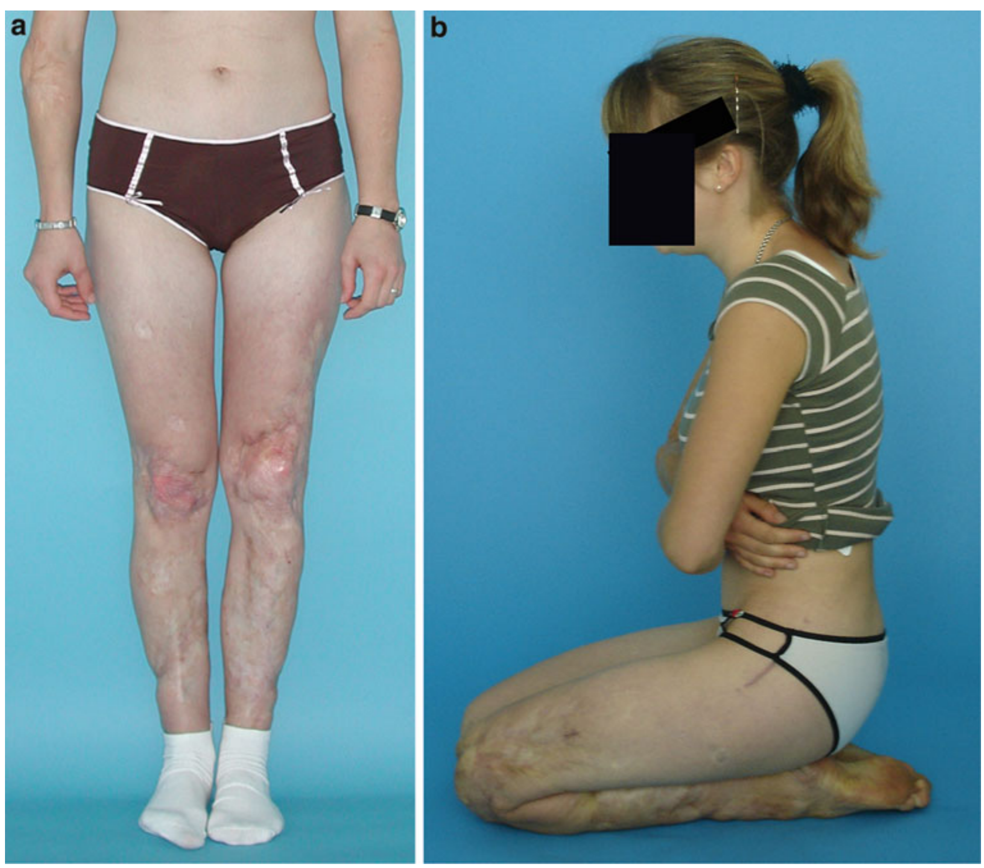

Fig. 8 (**a**–**b**) Clinical result and function after removal of all implants

Fig. 9 Radiological result months after removal of all implants

10 Cross-References

▶ Case 4: Both Femur and Tibial Shortening Caused from Hemi-hyperthropia Treated Simultaneously with Two Antegrade Precice Nails

▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate

▶ Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique

▶ Case 35: Acute Correction with Marrow (Intramedullary Canal) Narrowing Technique and Subsequent Lengthening Over Nail for the Femoral Shortening Combined with a Deformity

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Case 10: Malaligned and Short Femur Associated with Vascular Deficit – 2 Stage Realignment and Lengthening with Custom Made Magnetic Driven Intramedullary Nail

Peter Helmut Thaller and Felix Frankenberg

Contents

Abstract

A teenage boy presented with a post-traumatic leg length discrepancy (LLD) of 7 cm with bifocal femoral deformity, impairment of soft tissue and a long, segmental defect of the superficial femoral artery. Limb lengthening and deformity correction was performed in a two-staged project. After partial consolidation of a bifocal osteotomy and realigment with a customized, straight tibial nail, lengthening was then performed with a custom-made, magnetic-driven lengthening nail (MDLN/Phenix©) in the second step.

In the latter part of the distraction period, a vascular impairment occurred. It could be solved uneventfully by controlled, minor backtracking of the MDLN and subsequent reduction of the distraction rate. This caused a low distraction index of 0.68 mm/day. Nevertheless, bone formation was excellent with early weight-bearing (weight-bearing index: 16.2 days/cm).

The main issues for the successful treatment of this case of LLD and bifocal deformity with soft tissue and vascular impairment were meticulous analysis and planning (End point first planning method – EPF), a staged procedure to reduce risks, and a custom-made MDLN with the option of non-invasive controlled shortening.

1 Brief Clinical History

The 13 year old was rolled over by a car at the age of 7. He suffered a severe soft tissue, vascular and bone defect of the right femur. After successful limb salvage, he experienced some unsuccessful attemps of reconstruction. He presented with a post-traumatic leg length discrepancy (LLD) of 7 cm with bifocal femoral deformity, impairment of soft tissue and a long, segmental defect of the superficial femoral artery. Due to a condylar deformity, knee joint flexion was reduced to 10–90° with no instability. The boy was provided with a cochlea implant due to a sensorineural hearing loss in early childhood when he was 3.

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

- Bifocal deformity of the right femur
- Leg length discrepancy of 70 mm
- Compromised vascular supply of the leg -only by collateral circulation
- Impaired soft tissue

4 Treatment Strategy

- Proper digital analysis (Corel DRAW©) with long-standing radiographs and lateral views, additional CT scans for torsion and vascular disorder

Fig. 1 Leg length discrepancy (LLD) of 7 cm, impaired soft tissue

Fig. 2 Bifocal deformity and LLD in long standing radiograph (*LRS*) and in lateral view

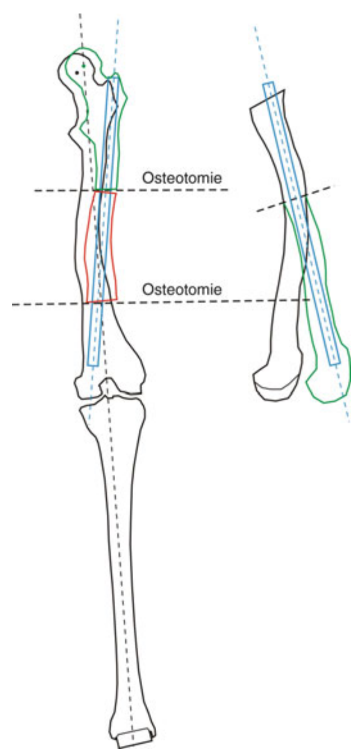

Fig. 3 End point first (*EPF*) planning – first step: bifocal osteotomy

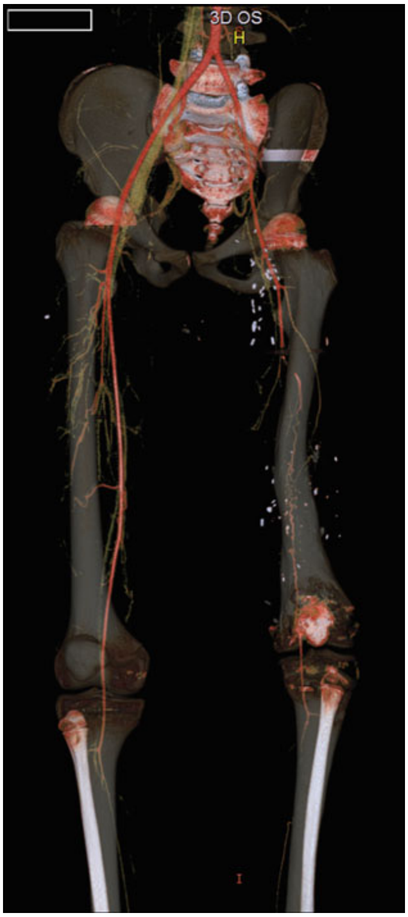

Fig. 4 CT angiography – long segmental vascular defect of superficial femoral artery

Fig. 5 Customized Tibial nail (ETN, DepuySynthes©) with multi directional, stable interlocking options. *Left side*: Off the shelf with Herzog curvature, *Right side*: Customized, straightened (sterile/onsite) in the shape of the future MDLN

- Digital planning (EPF) of both steps of surgery
- Straightening the femur with a bifocal osteotomy and a customized tibial nail (ETN, DepuySynthes© for multiangular stable proximal interlocking options of the short proximal fragment)
- Early exchange of the solid nail to the MDLN
- Distraction with 1 mm/day 5 days after surgery (pausing or reshortening in case of vascular problems)
- Weekly or bi-weekly follow-up, intensive physiotherapy, partial weight-bearing until proof for at least unicortical regenerate

Fig. 6 Rigid reaming with protective steel sleeve – Schanz Screws for intraoperative control of torsion

5 Basic Principles

Limb lengthening and deformity correction with distraction osteogenesis is still mostly performed by external fixation (EF), which has associated pin tract infection, soft tissue problems, malalignment, long EF time and discomfort. Nailing procedures for limb lengthening and deformity correction require meticulous analysis, planning and performance of surgery because in contrast to external fixation, there is no opportunity for change without another

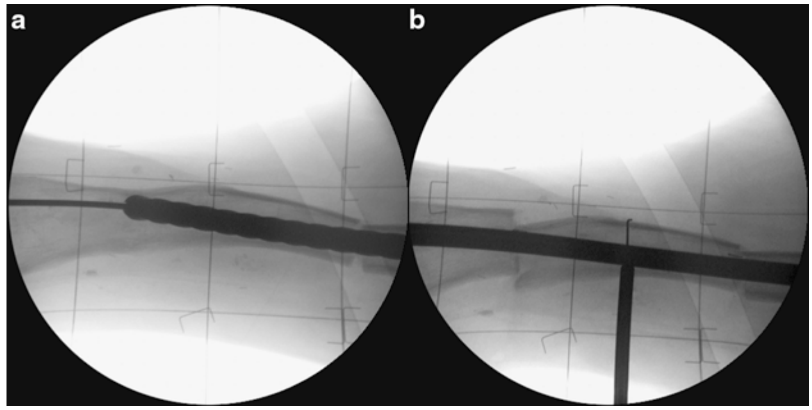

Fig. 7 Rigid reaming for bifocal osteotomy (**a**), insertion of blocking screw to stabilize the mid shaft fragment (**b**)

surgery. A single-stage treatment with a fully implantable lengthening nail with a bifocal osteotomy would have assumed greater risk related to instability and bone formation. Proper radiographic analysis is a prerequisite (Thaller et al. 2005). Planning can be performed by end point first (EPF) planning on paper or digitally, e.g. with Corel DRAW©. The choice of the lengthening nail is essential. Various off-the-shelf implants were known at the time of the treatment but were felt to have critical limitations: The formerly widespread Albizzia nail (Guichet 1999) had adequete stability but had no option for shortening. The Fitbone© nail (Betz et al. 1990) provided controlled lengthening, but about one-third of the telescopic nails (TAA) were noted to reshorten accidentally (Krieg et al. 2011). One-third of the ISKD© nails were known to have uncontrolled fast or slow distraction (Krieg et al. 2011). The vascular impairment was the most concerning problem for limb lengthening in the present case and required excellent lengthening and shortening control. At the time of treatment, among all the lengthening nails, there was no implant available which could provide non-invasive intermediate shortening except the custom-made MDLN (PHENIX©) (Thaller et al. 2013). All osteotomies are performed as soft tissue–sparing drill bit osteotomies via stab incisions. Intra-operative control e.g. by X-ray grid (XRG) technique is essential for proper alignment. Finally, close follow-up during the distraction and also the first part of the consolidation period is recommended to timely reveal problems with distraction rate, bone formation, instability of bone and adjacent joints, soft tissue and, especially in this case, neuro-vascular problems.

6 Images During Treatment

See Figs. 5, 6, 7, 8, 9, 10, 11, and 12.

Fig. 8 Early consolidation of bifocal osteotomy

7 Technical Pearls

- Digital EPF planning (Fig. 3)
- Two-stage procedure to reduce risks
- Rigid reaming with protection of entry point by steel sleeves (Fig. 6)

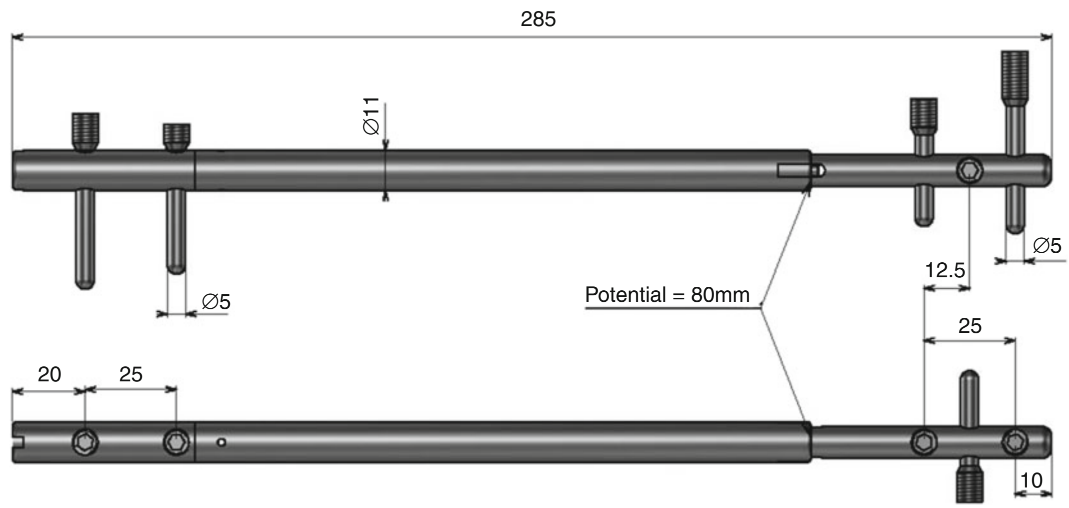

Fig. 9 Custom made magnetic driven lengthening nail (MDLN), PHENIX©, 11/285 mm, stroke 80 mm

Fig. 10 X-rays AP and lateral immediately after second surgery with custom made MDLN

- Bifocal osteotomy (stab incisions/drill bit/minimally invasive) (Fig. 7)
- Customized, staightened (sterile/on-site) tibial nail to improve proximal stability (Fig. 5)
- Custom-made MDLN with option for controlled, non-invasive shortening and re-lengthening (Fig. 8) to safely deal with vascular impairment

8 Outcome Clinical Photos and Radiographs

With increasing bone formation, early weight-bearing was possible (weight-bearing index: 16.2 days/cm). Since the patient was from a long-distance developing country, his last follow-up was 7 months after the first surgery. At that time, gait was almost unimpaired, knee range of motion was close to status from before the surgeries (ROM knee: 5–70) and X-rays showed a stable regenerate with only a minor (less than one quarter of the circumference) lack of regenerate and with progressive improvement (Figs. 13 and 14).

Fig. 11 Distraction procedure three to four times a day with strong neodymium magnet (grade N45, equivalent to a holding force on iron of about 300 kg)

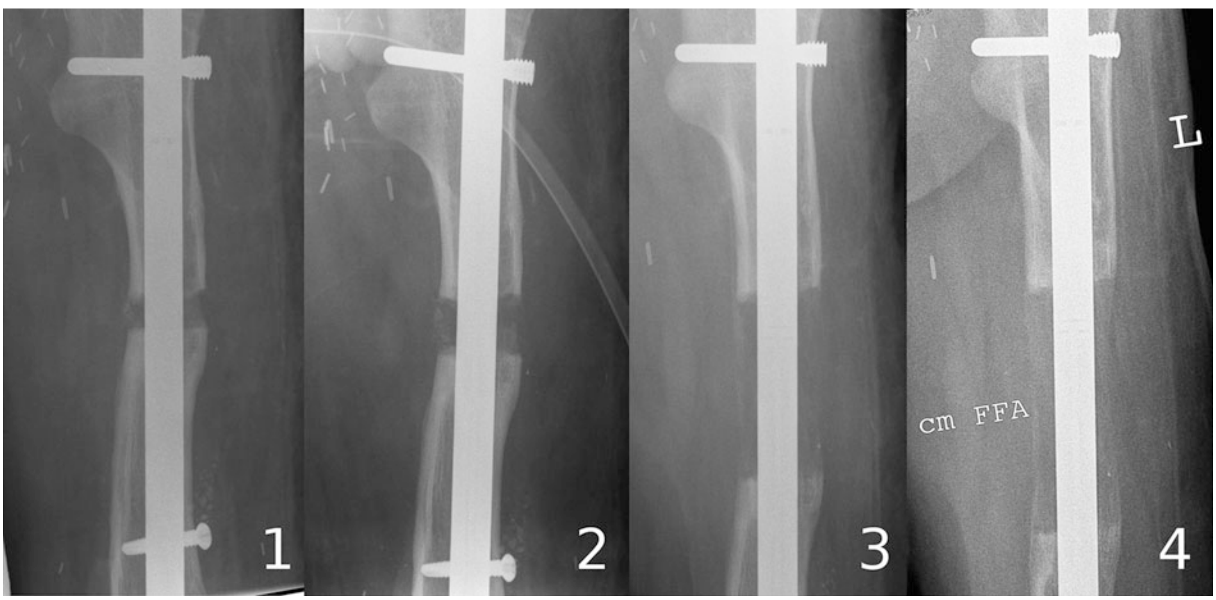

Fig. 12 Course of distraction at 1st day (**1**), 1st week (**2**), 1st month (**3**) and after 2 months (**4**) (prior to minor reshortening for vascular recovery)

9 Avoiding and Managing Problems

The most important safety issue in this lengthening case was the vascular impairment. A two-stage procedure with a minimally invasive approach and first and foremost a device with proper control and the option to re-shorten could provide a treatment with controlled risks. Meticulous analysis and planning of both steps were essential. Stable locking options of a customized tibial nail could stabilize the fragments after the bifocal osteotomy. In the later course of distraction, a temporary neuro-vascular impairment could be resolved by minor backtracking and re-lengthening with a slower distraction rate.

Fig. 13 Long standing Radiograph (*LSR*) and lateral view 7 months after first surgery

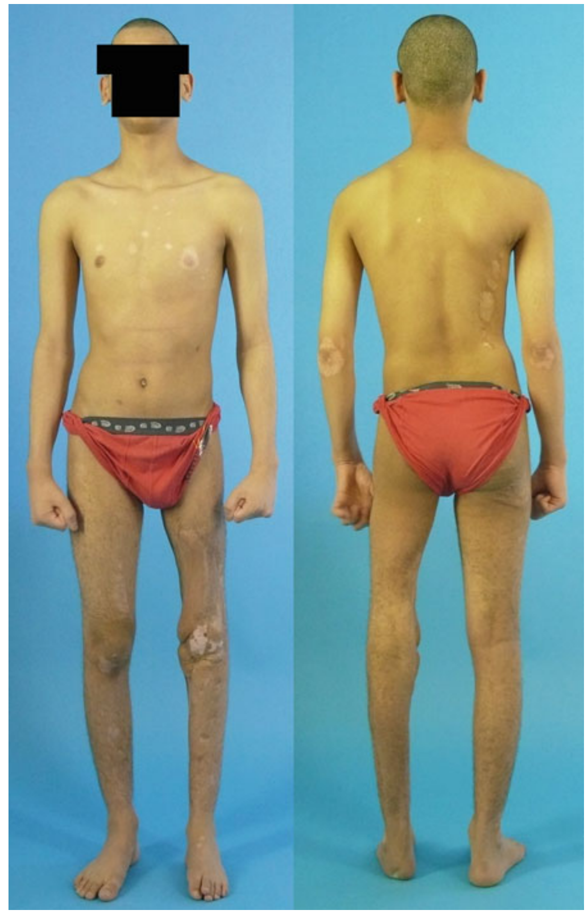

Fig. 14 Clinical outcome, full weightbearing, showing correction of LLD and normal alignment

10 Cross-References

- ▶ Case 4: Both Femur and Tibial Shortening Caused from Hemi-hyperthropia Treated Simultaneously with Two Antegrade Precice Nails
- ▶ Case 9: Limb Lengthening of 14 cm with Simultaneous Deformity Correction of Femur and Tibia by Fully Implantable, Electric Driven Lengthening Nails
- ▶ Case 35: Acute Correction with Marrow (Intramedullary Canal) Narrowing Technique and Subsequent Lengthening Over Nail for the Femoral Shortening Combined with a Deformity

Acknowledgements We thank Mrs. Hella Thun and Mr. Joachim Gräbe for their processing of X-ray images and clinical pictures.

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Case 11: Partial Union After Lengthening, A New Concept in Bone Healing

Pablo Wagner, Burkley Jensen, and John E. Herzenberg

Contents

Abstract

A patient with a 5 cm limb length discrepancy secondary to congenital femoral deficiency was treated with lengthening of the affected femur using a Precice nail. This resulted in partial union described as bone consolidation in just two out of four cortices. In this case, absence of bone bridging was found in the anterolateral femur. The partial union was repaired using bone graft and stem cell injection. Full union was achieved.

1 Brief Clinical History

The patient is an active and healthy skeletally mature 16 year old female who had two previous femoral lengthenings with an external fixator. The current lengthening was performed using the Precice nail. During this lengthening, incomplete bone healing was observed during the consolidation phase. Only two of four cortices achieved solid bone healing. The anterolateral cortices did not form callus.

2 Preoperative Clinical Photos and Radiographs

Five months post internal lengthening procedure (Figs. 1 and 2)

3 Preoperative Problem List

1. Partial femoral union s/p Precice nail. No bone formation on the anterolateral cortices
2. Risk of implant failure

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Fig. 1 AP femur X-ray. Note lateral cortical deficit

Fig. 2 Lateral femur X-ray. Note anterior deficit

4 Treatment Strategy

1. Repair of partially united femoral defect
2. Use of graft harvest from contralateral femur using the RIA reamer (Synthes, Paoli, PA)
3. Augmentation with stem cells obtained from iliac crest aspiration
4. Augmentation grafting to repair partial union of the femur: stem cells plus bone graft application

5 Basic Principles

A lack of normal bone healing is commonly categorized as delayed union, malunion, or nonunion. Not included in these descriptions is a partial union. A partial union is described as a complete union of two of the four bone cortices. It is not complete circumferential bone healing given that two of four cortices are not healed, and it is not a delayed union/nonunion given that there is advanced bone healing in two of four cortices. The incomplete bony healing increases the risk of implant failure.

6 Images During Treatment

No images during surgery. See text for details

7 Technical Pearls

A partially united bone healing site is amendable to open repair with augmentation of autogenous graft. Through a limited approach, the fibrous union is resected. To insert the graft around the partial union, develop pockets under the periostium by elevating it using a periosteal elevator. Place the graft inside these pockets around the partial union. One can also add bone morphogenic protein (BMP) to this graft. In this case, cancellous bone was obtained from an RIA reamer (Snythes, Paoli, PA) from the femur. Direct stem cell injection of the partial union was performed. Cancellous graft was soaked in stem cells prior to its placement around the partial union.

Fig. 3 AP femur X-ray: complete union circumferentially at the osteotomy site

Fig. 4 Lateral femur X-ray: complete union circumferentially at the osteotomy site

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

Screening patients preoperatively for risk factors such as obesity, osteoporosis, alcoholism, smoking, poor bone quality, and vitamin and nutritional deficiencies. Intraoperative considerations involving surgical technique and fixation choice: Avoid heat necrosis while performing the osteotomy. Use constant saline infusion on the drill bit to prevent overheating. Make sure that Vitamin D levels were measured and supplemented if necessary.

In this patient, two prior lengthenings may have led to some compromised vascularity of the bone. Attempt to make osteotomy through native (not previous regenerate) if possible. Also, consider a longer latency and slower distraction rate when bone may be compromised.

10 See Also in Vols. 1 and 2

Case 39: Delayed Regenerate Bone Formation in a Seven Year Old Boy with Fibular Hemimelia Undergoing Tibial Lengthening (Vol. 1)
Case 20: Distraction of Hypertrophic Nonunion (Vol. 2)

References and Suggested Reading

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Part II

Adult Deformity: Femoral Deformity

Case 12: Bilateral Distal Femoral Osteotomy, Opening Wedge with Plate, for Genu Valgum

S. Robert Rozbruch

Contents

Abstract

This is a case of bilateral genu valgum. The source of the deformity is the femur. Staged bilateral distal femoral osteotomy (DFO) using acute correction with an open-wedge and plating technique was performed.

1 Brief Clinical History

The patient is a 27 year old female who is unhappy with her leg alignment. She has had knee pain for several years. Her wide-based gait was awkward and her inner thighs rubbed together. She was self-conscious about the appearance of her legs and avoided wearing short pants or skirts.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Bilateral genu valgum

4 Treatment Strategy

1. Left DFO open wedge with locked plate. Over correct mechanical axis line to medial tibial spine.
2. Graft the open wedge with allograft freeze-dried cancellous chips combined with demineralized bone matrix (DBM) putty.
3. Right DFO 6–8 weeks later.

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Fig. 1 (**a**, **b**) *Front* and *back* views showing bilateral genu valgum with wide-based stance

5 Basic Principles

1. Realignment of the mechanical axis helps normalize forces across the knee.
2. The CORA (apex of deformity) is periarticular. Since the osteotomy will be proximal to the CORA, translation of the distal fragment would be necessary.
3. With this open-wedge technique, it is desirable to maintain the integrity of the medial cortex and avoid translation.
4. The planning method (1) described in Fig. 2 above allows the surgeon to intentionally place the apex of the deformity in a practically convenient location and avoid the need for translation.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

1. Fill open wedge with freeze-dried allograft chips and DBM.
2. Do not cut medial cortex.

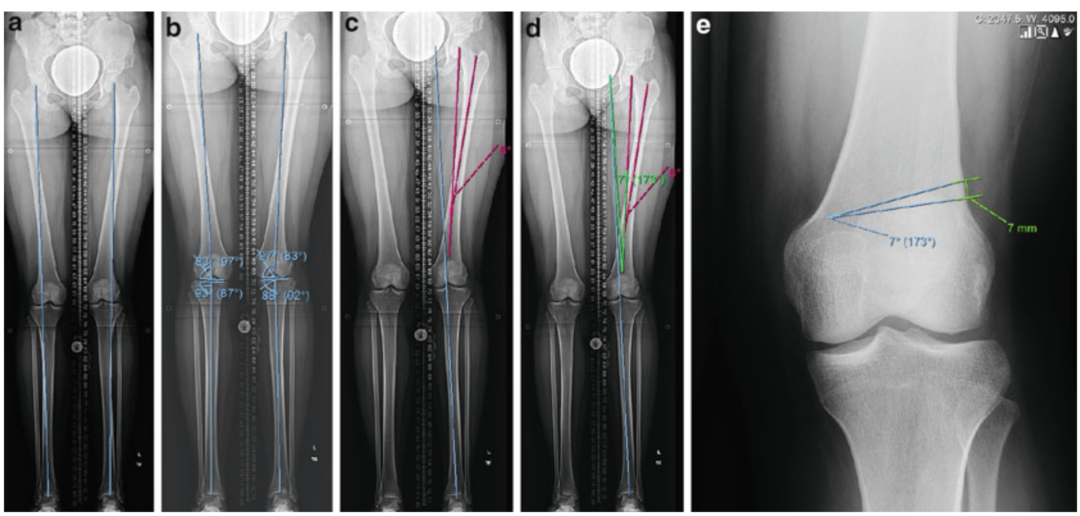

Fig. 2 (**a**) Standing X-ray shows bilateral lateral mechanical axis deviation (*MAD*). (**b**) Joint orientation angles demonstrate that the deformity is coming from the femurs. The LDFAs are 83°. The MPTAs are normal at 87 and 88°. (**c**) Surgical planning: Step 1, draw a line (*blue*) from center ankle through medial tibial spine and extend to hip level to where femoral head should be after correction. Step 2, draw an anatomic axis line (*pink*) and a 6° mechanical axis line (*pink*) from that originating from the center femoral head. This is the proximal femur mechanical axis. This is extended to the desired osteotomy location. (**d**) The angle (*green lines*) between the femoral axis line and a line from the osteotomy to the new femoral head center represents the desired correction (7°). (**e**) The length of the opening wedge can be drawn on a calibrated X-ray. In this case, it is 7 mm

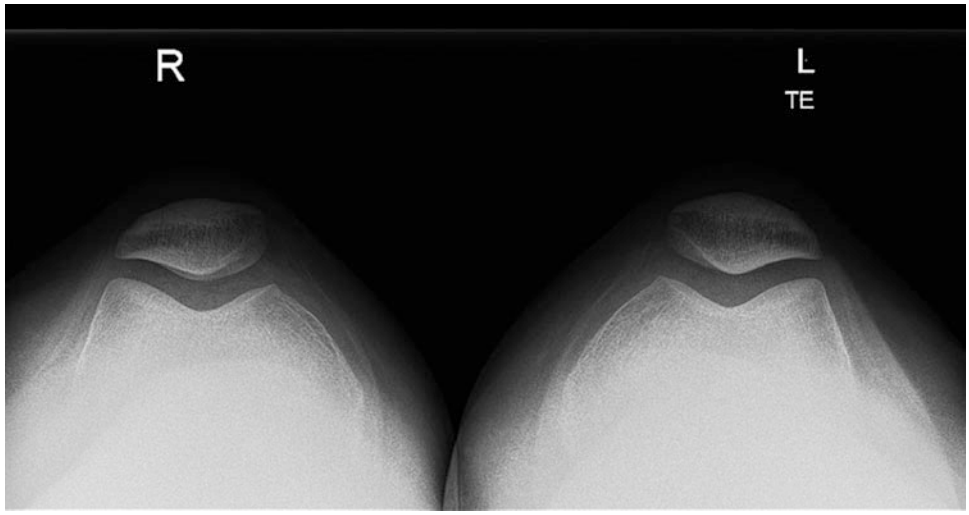

Fig. 3 Merchant views of both knees show no patella tilt or subluxation

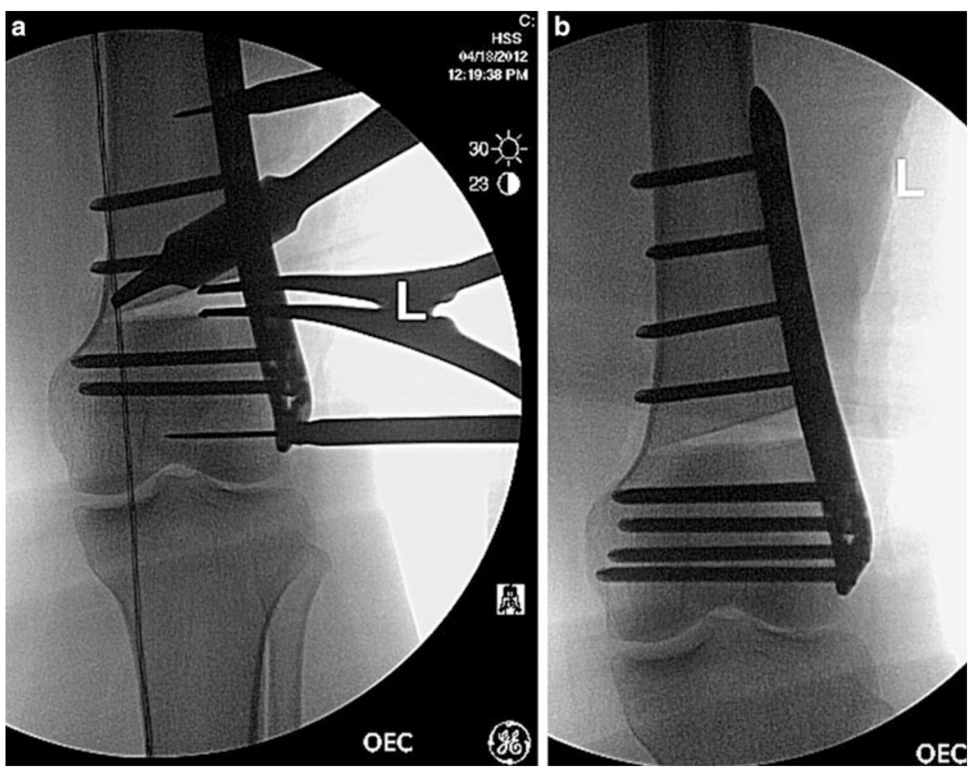

Fig. 4 Intraoperative fluoroscopy images of the first side. (**a**) The osteotomy is hinged open with a laminar spreader based on the preoperative plan. The medial cortex is not cut and acts as the hinge. The lateral locked plate is applied, and after two screws are placed in both the distal and proximal segments, the alignment is checked intraoperatively. (**b**) The final construct has five locked screws in the distal segment and four bicortical locked screws in the proximal segment. This shows the open wedge before bone graft has been inserted

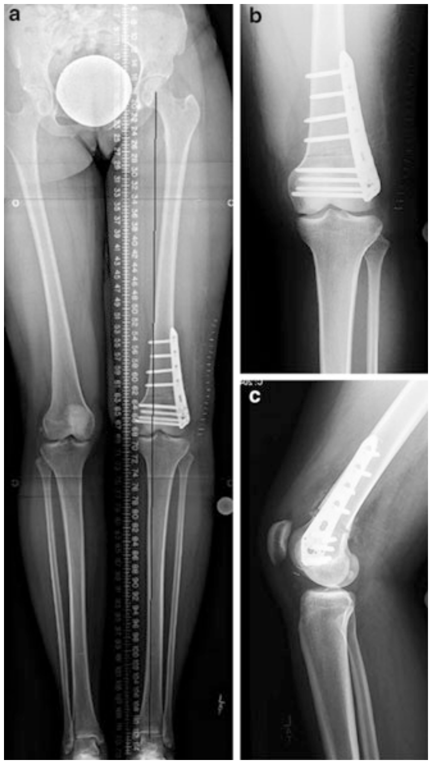

Fig. 5 Radiographs 2 weeks after left-sided surgery. (**a**) Erect leg X-ray shows correction of the MAD (**b**, **c**) AP and lateral X-rays showing bone graft in place

3. Place laminar spreaders anterior and posterior so there is room for the plate on the lateral surface.
4. If there is sagittal plane deformity, increased gap can be created anterior or posterior to correct extension or flexion deformities.
5. Check alignment during surgery by running a taut bovie cord or long metal rod from the center hip to center ankle, and check the MAD at the knee (Fig. 4a).
6. If there is lateral patella subluxation (not seen in this case), add a lateral retinacular release. That combined with the medialization of the patella insertion (from the DFO) will usually correct the patella malalignment.
7. No brace or cast is used. Patients are instructed to use two crutches for 6 weeks and limit weight bearing to 30 lb. After 6 weeks, full weight bearing is allowed.

Fig. 6 The right side was done using the same technique 7 weeks later. (**a**) Opening of the lateral-based wedge and application of the plate (**b**) after bone graft insertion. Note the locked plate can be off the bone as seen here at the top of the plate

Fig. 7 Erect leg X-ray 1 year later showing slight overcorrection of the MAD, which was the goal

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

1. Avoid fracture of the medial cortex. An intact medial cortex without translation is needed for this technique. A small medial plate can be placed if there is instability at the medial cortex.
2. Avoid unintentional sagittal plane deformity with inadvertent asymmetrical opening of the osteotomy.

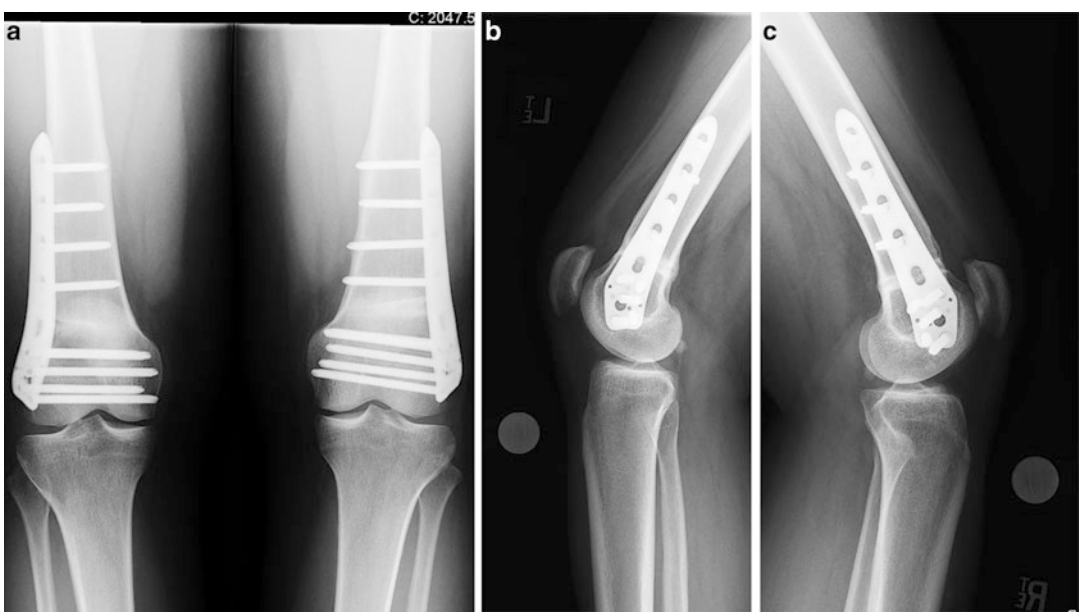

Fig. 8 (**a**–**c**) Knee X-rays 1 year after surgery showing bony union

Fig. 9 Front (**a**), side (**b**), and back (**c**) clinical photos 1-year postsurgery showing correction of deformity and a happy patient

10 Cross-References

▶ Case 15: Periarticular Femur Deformity and LLD: A Modern Approach
▶ Case 26: Correction of Valgus-Torsion Deformity of the Femur and Varustorsion Deformity of the Lower Leg Accompanied with LLD

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Case 13: Complex Femoral Deformity: Acute Correction and IM Nail Fixation

Mahmoud A. El-Rosasy

Contents

Abstract

The use of circular external fixator for gradual correction of complex limb deformities is a relatively safe method with great accuracy depending on the surgeon's experience. Since the external fixator is cumbersome for the patient, a more convenient fixation method can be used in carefully selected cases. Provided that the resultant leg length discrepancy after treatment is less than one inch and is acceptable to the patient, then, acute correction of diaphyseal deformities and fixation with a statically locked intramedullary nail can be successful yielding a gratifying result to both the patient and the surgeon. The magnitude of the deformity and direction of correction should be considered to avoid sudden stretch of the neurovascular bundle. Another consideration is the soft tissue condition and history of deep infection which would preclude the use of internal fixation. Complex diaphyseal deformity of a long bone may need more than one osteotomy to restore the normal mechanical axis. Resolution of the deformities into one CORA (center of rotation of angulation) to achieve correction through one osteotomy is an attractive idea having the advantage of longer bone segments for stable fixation. Careful preoperative planning is mandatory to determine the osteotomy level and the nail-insertion point.

1 Brief Clinical History

The case of a 22 year old male patient, he has right congenital femoral deficiency and fibular hemimelia. Femoral lengthening was done for him, elsewhere, to equalize limb lengths using an Ilizarov external fixator. The patient did not tolerate the procedure and developed anxiety which required psychiatric consultation and prompted premature removal of the fixator. Due to early fixator removal and tightness of soft tissues (iliotibial tract

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Fig. 1 (**a**, **b**) Preoperative radiographs show 27° valgus deformity of the distal femur in the frontal plane and 20° procurvatum deformity in the sagittal plane (deformity analysis was done using the anatomical axis method). (**c**) Preoperative clinical photos show the valgus and external rotation of the knee and compensatory internal tibial torsion

which was not released at the time of external fixator application), the femur developed a valgus and procurvatum deformity. Clinically the iliotibial tract was found to be very tight on the lateral aspect of the thigh. Limb length discrepancy was measured clinically using the block method and was found to be 1.5 cm. The knee and ankle joints showed full range of motion. The anterior drawer test for deficiency of the anterior cruciate ligament was positive, due to congenital deficiency of cruciate ligaments; however, the knee was fairly stable.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

- Multiplanar femoral deformity – valgus and procurvatum.
- Soft tissue contracture mainly the iliotibial tract.
- Hypoplastic femur with narrow and partially blocked medullary canal as a result of previous lengthening.
- The patient is not willing to have any external fixator applied to his limb due to his unpleasant experience with the previous surgery.

4 Treatment Strategy

Release of the tight iliotibial tract was performed percutaneously before the bony procedure. Our plan was to acutely correct the deformity through one osteotomy and fix the femur internally with a statically locked IM nail. The osteotomy should be partially opening wedge osteotomy, to correct some of the limb length discrepancy (LLD), and partially closing wedge osteotomy to retain reasonable bone contact to ensure bone healing. Moreover, percutaneous multiple drill holes osteotomy to preserve the soft tissue envelope at the osteotomy site and to retain the bone reaming extrusion from the drill holes as local autograft.

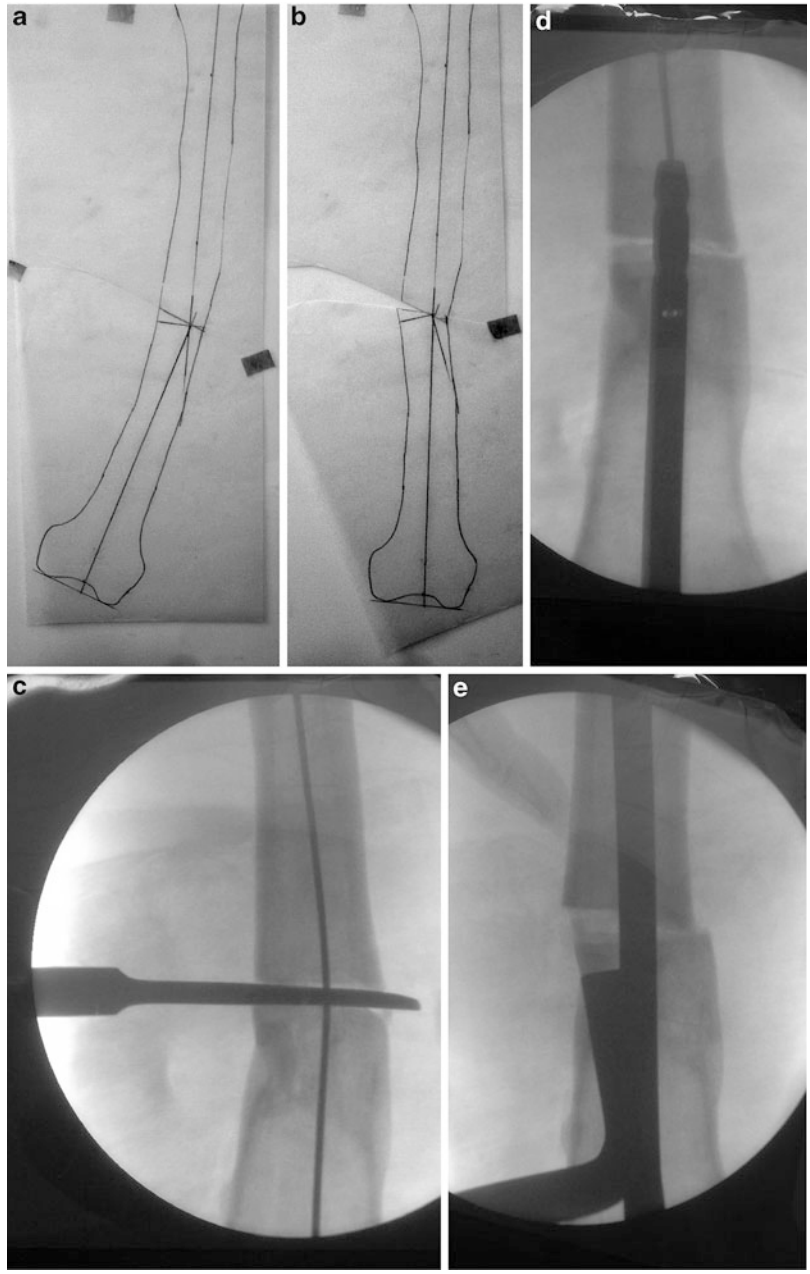

Fig. 2 (**a**, **b**) Preoperative tracing of the femur for preoperative planning of deformity correction, osteotomy location, and feasibility of intramedullary nail insertion. Acute correction will result in a laterally open wedge osteotomy with limb lengthening of 1.5 cm and angle of correction (apical angle of the wedge) of 27°. (**c–e**) Intraoperative image intensifier photos show: insertion of the guide wire after opening the medullary block using a rigid hand-reamer, osteotomy of the bone in the presence of the guide wire, insertion of the nail and progressive opening of the wedge, and medial translation of the distal segment as the nail is advanced in the medulla of the femur

5 Basic Principles

The anatomical method for deformity analysis should be used to make sure that the nail could be inserted in the medulla of the bone. Moreover, the procedure should be performed on paper tracings preoperatively to plan the osteotomy cuts and nail-insertion point.

Editor's comment: Mechanical axis planning on a hip to ankle standing X-ray can be used to predict if the anatomical axis correction will result in complete mechanical axis alignment (SRR).

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

Of paramount importance is the localization of the osteotomy level and then making multiple drill holes, as a medullary vent, before reaming the medulla of the femur. This serves as a vent to decrease intramedullary pressure and

Fig. 3 (**a–c**) Immediate postoperative radiographs show restoration of the femoral anatomical axis and sound fixation using a statically locked retrograde femoral nail

lower risk of fat embolism which can occur from reaming of a closed medullary cavity.

In adult patients who are walking with LLD since childhood, they usually develop fixed pelvic obliquity as a compensatory mechanism, so that measurement of LLD in adult patient should be done clinically by using multiple blocks under the shorter limb to avoid unnecessary lengthening.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

Careful preoperative planning and patient counseling are mandatory. The medullary vent is essential to avoid fat embolism and allows the release of the medullary bone debris around the osteotomy site as a local autograft. Percutaneous osteotomy should be performed whenever possible to maintain the soft tissue envelope, and impaction of the osteotomy site after nail insertion helps to avoid delayed or nonunion.

Editor’s comment: Fixator-assisted nailing and blocking screw insertion are adjuvant techniques to the IM nailing that can be used to achieve optimal alignment. Blocking screws can be used to hold the nail in the optimal desired position at the osteotomy site and in the metaphyseal segment. This is useful if the medullary canal is wider than the nail at the osteotomy site. Fixator-assisted nailing can also be used to increase precision in selected cases. The external fixator can be used intraoperatively to stabilize the osteotomy in the optimal position while the intramedullary nail is inserted. The fixator is then removed before leaving the operating room. Acute correction of valgus and procurvatum deformity does stretch the peroneal nerve which may be at risk for neuropraxia. Prophylactic peroneal nerve decompression may be considered to decrease the possibility of nerve injury (SRR).

Fig. 4 (**a**–**c**) Follow-up radiograph and clinical photos show consolidation of the osteotomy and great improvement in limb alignment. Mild residual valgus is apparent on the clinical photos. The neurovascular exam was normal

10 Cross-References

▸ Case 23: Complex Deformity After PFFD Treatment – Multifocal, Gradual Correction on Femur and Tibia with Monolateral External Fixation

11 See Also in Vol. 2

Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity

Case 5: Computer Assisted External Fixation at Femur Two-Level Posttraumatic Complex Deformity

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Case 14: Femoral Shaft Varus Above a Total Knee Replacement Treated with a Circular Hexapod Fixator

Petr Skomoroshko, Leonid N. Solomin, Viktor Vilensky, and Fanil Sabirov

Contents

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Abstract

This chapter describes the operative treatment of deformity of the femur in a patent with a stemmed total knee endoprosthesis. The extracortical clamp device (ECD) and the computer-assisted hexapod Ortho-SUV Frame were used. The ECD is a special device which allows fixation of bone fragment without the necessity to perforate both bone cortices and cavity which contains the endoprosthesis stem. The use of hexapod frame simplifies correction and increases accuracy.

1 Brief Clinical History

A 66 year old female had persistent left knee pain after revision knee replacement. She had left femur malunion and post-traumatic knee arthritis that was treated 5 years earlier with primary total knee replacement, without correction of femur diaphyseal deformity. After 4 years, the knee prosthesis had developed loosening. A revision total knee arthroplasty was done in another clinic, again without femur deformity correction. She feels persistent intermittent pain during ambulation.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

(a) Left femur diaphyseal deformity of 23° varus
(b) Presence of revision knee prosthesis implant with stems

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Fig. 1 Left MAD = 30 mm medial; LDFA = 100°

Fig. 3 Front view showing varus

Fig. 2 The implant components are stable

4 Treatment Strategy

Plan is to correct femur varus by 23° gradually with hexapod external fixator Ortho-SUV Frame.

5 Basic Principles

(a) The long stem of the prosthesis in the intramedullary canal makes fixation difficult. We use the extracortical clamp device (ECD) which is a special device that allows fixation of a bone segment without the necessity to perforate the bone cortex.
(b) Using the hexapod frame simplifies the correction.
(c) Realignment is expected to improve loading through the knee joint.
(d) Normal mechanical axis and LDFA may prevent knee prosthesis loosening.
(e) The alternative treatment using a plate and cables requires a large open approach and an acute correction of deformity. This has disadvantages but could also have been used to treat this patient (Editor's comment- SRR).
(f) Correction of the diaphyseal deformity prior to TKR would have been the preferred approach in this patient but was beyond our control (Editor's comment- SRR).

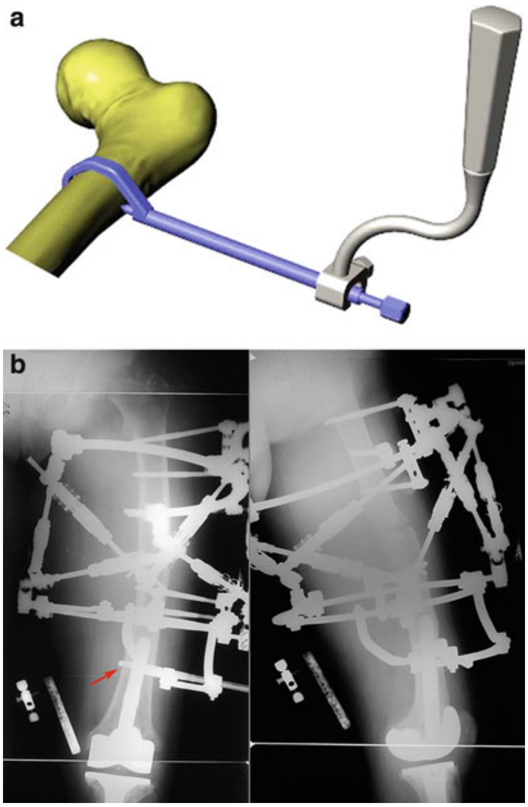

Fig. 4 (**a**) Schematic view of the ECD. (**b**) Radiographs after surgery. Note the ECD (*red arrow*) providing fixation around the femur region with the prosthesis stem

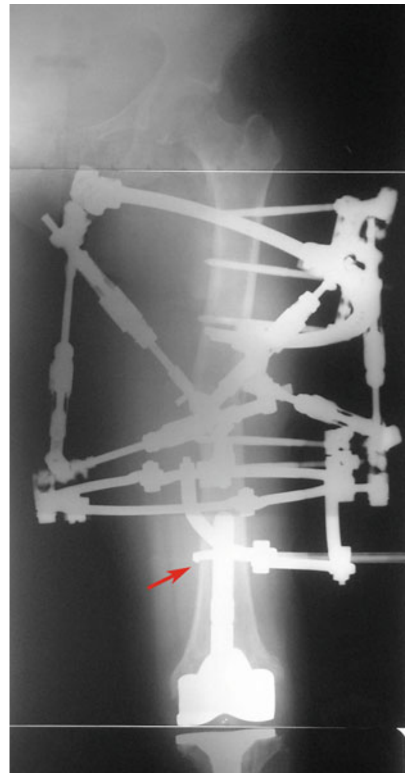

Fig. 5 Correction of varus. The ECD (*red arrow*) has provided satisfactory stability

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

(a) The ECD is an effective device which provides rigid fixation in the periprosthetic deformity.
(b) Insertion of the ECD requires a small open approach to insert the clamp around the bone.
(c) Correction of left femur varus and MAD can be done effectively with the hexapod frame. A multiple drill hole osteotomy is used.

Fig. 6 *Front view* showing left femur realignment with the hexapod frame in place

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

Fig. 7 Mechanical axis and LDFA are normalized

Fig. 8 *Front view* showing excellent realignment

9 Avoiding and Managing Problems

(a) The correction of the deformity was done gradually. Use of the structure at risk (SAR) points prevented any nerve or vascular disorders. The optimal rate also created a good environment for callus formation.
(b) Active antibiotic therapy and close method of pin-site management were used to prevent infectious complications.

10 Cross-References

▶ Case 28: Femoral and Tibial Rotational Deformity Treated with Fixator Assisted Nailing and Gradual Correction with the Taylor Spatial Frame

11 See Also in Vol. 2

Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity
Case 5: Computer Assisted External Fixation at Femur Two-Level Posttraumatic Complex Deformity
Case 21: Computer Assisted External Fixation and then Nailing at Both Lower Legs Non-unions Accompanied with Complex Deformities

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Case 15: Periarticular Femur Deformity and LLD: A Modern Approach

Austin T. Fragomen

Contents

Abstract

Periarticular deformity of the distal femur has been treated successfully with external fixation. Often a ring fixator is required to keep the osteotomy distal enough for accurate realignment. Although with the use of a fixator, one is able to achieve correction of the deformity and length, it comes with great discomfort, scarring, and impingement to knee motion. The LAP (lengthening and then plating) technique was designed to reduce the time in the frame by early conversion to a plate. This technique was complicated by difficulty controlling the distal femoral fragment, infection, and plate failure. With the introduction of a reliable internal lengthening nail, the problem of periarticular deformity and leg length discrepancy (LLD) can be reassessed. In the following case, a distal femoral plate is used to achieve an acute correction of a procurvatum deformity, and an internal lengthening nail is used proximally for limb length equalization providing an all-internal alternative to a complex problem.

1 Brief Clinical History

This is an 18 year old female who presented with a history of right distal femur fracture at the age of 10 years old. She was treated with casting at that time. She complained of an LLD and an inability to extend her knee fully. On exam she was noted to lack 13° of knee extension. Her femoral rotation showed a 15° external rotation deformity of the right femur which was confirmed by a CT version study. Radiographs showed an LLD of 40 mm with the right side short.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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Fig. 1 Clinical photos show the LLD (**a**) and flexion deformity (**b**). In the supine position on the OR table, the right leg is seen to assume a flexed and externally rotated position (**c**). Under anesthesia the right hip is seen to have 90° of external rotation (**d**) and 20° of external rotation (**e**). This was 15° more externally rotated than the opposite limb

3 Preoperative Problem List

1. Growth plate arrest yielding a complex deformity pattern
2. LLD 40 mm
3. Procurvatum deformity of the distal femur 13°
4. External rotation deformity 15°

4 Treatment Strategy

1. Distal femoral opening wedge osteotomy to correct the procurvatum deformity acutely reestablishing full knee extension. Some length would be restored through this osteotomy. Rotation was not corrected through this osteotomy due to concerns about negative effects of the patellar tracking. Plate fixation and bone grafting of the osteotomy site were planned.
2. Proximal femoral osteotomy to correct rotation acutely around a Precice (Ellipse Technologies Inc., Irvine, CA, USA) internal lengthening IM nail. Gradual lengthening to correct the residual LLD.
3. This is all planned in one surgical stage.

5 Basic Principles

The CORA of the deformity was felt to be too distal to be corrected with a retrograde IM nail. An osteotomy proximal to the CORA would require excessive translation, and an osteotomy at the CORA would create a small distal fragment that would be difficult for the IM nail to control. Therefore, a plate was used to stabilize the osteotomy which was made near the CORA. This all-internal approach to these problems spared the patient from the difficulties of external fixation of the thigh, which would have been amplified, given her large thigh size.

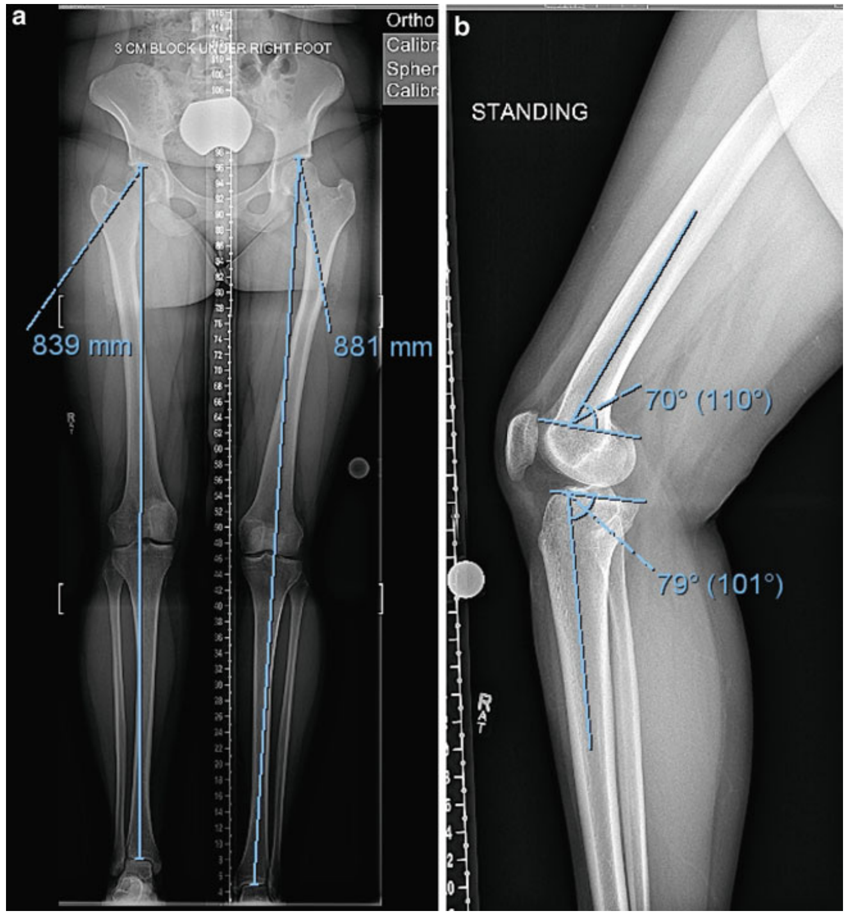


Fig. 2 A 51″ AP standing, bipedal radiograph demonstrates the LLD (**a**). Hip to ankle discrepancy measures 42 mm and pelvic height discrepancy is 40 mm. The lesser trochanter on the right is not seen as well as the left lesser trochanter: a subtle sign of an external rotation deformity. The lateral radiograph (**b**) shows a flexion deformity of the distal femur with a posterior distal femoral angle of 70°

6 Images During Treatment

See Figs. 3 and 4.

7 Technical Pearls

The continuous passive motion (CPM) machine is useful to encourage early knee flexion. Toe-touch weight bearing is mandatory both to prevent nail fracture and dysfunction. Using Steinman pins in the femur to mark rotation will provide for a correct realignment of rotation intraoperatively. Correction of the sagittal plane deformity is as much a clinical measurement as a radiographic one. The posterior distal femoral angle is often challenging to measure, making the planning for degrees of correction less accurate. In this case an anterior hinge was left intact, and the osteotomy was extended until the knee achieved full extension. The osteotomy was then stabilized with a lateral plate in this position (Fig. 3a). The IM nail and proximal osteotomy were performed first in this case to avoid excess stress on a distal osteotomy site during adduction of the leg.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

9 Avoiding and Managing Problems

Lengthening needs to be monitored with office visits every 2 weeks. Radiographs are scanned visually for the amount of length at the regenerate, amount of length of the nail itself, hardware condition, and quality of regenerate. The rate of lengthening can be altered at each visit. This will help prevent premature consolidation.

The length of the plate and IM nail needs to be measured preoperatively to ensure that there is adequate room for both implants. The level of the osteotomies is an integral part of the implant choice as well. The sagittal radiograph will show the normal bowing of the femur. This is a straight nail so one must decide between cutting the bone at the apex of the bow and straightening it or preserving the bow and using a shorter nail.

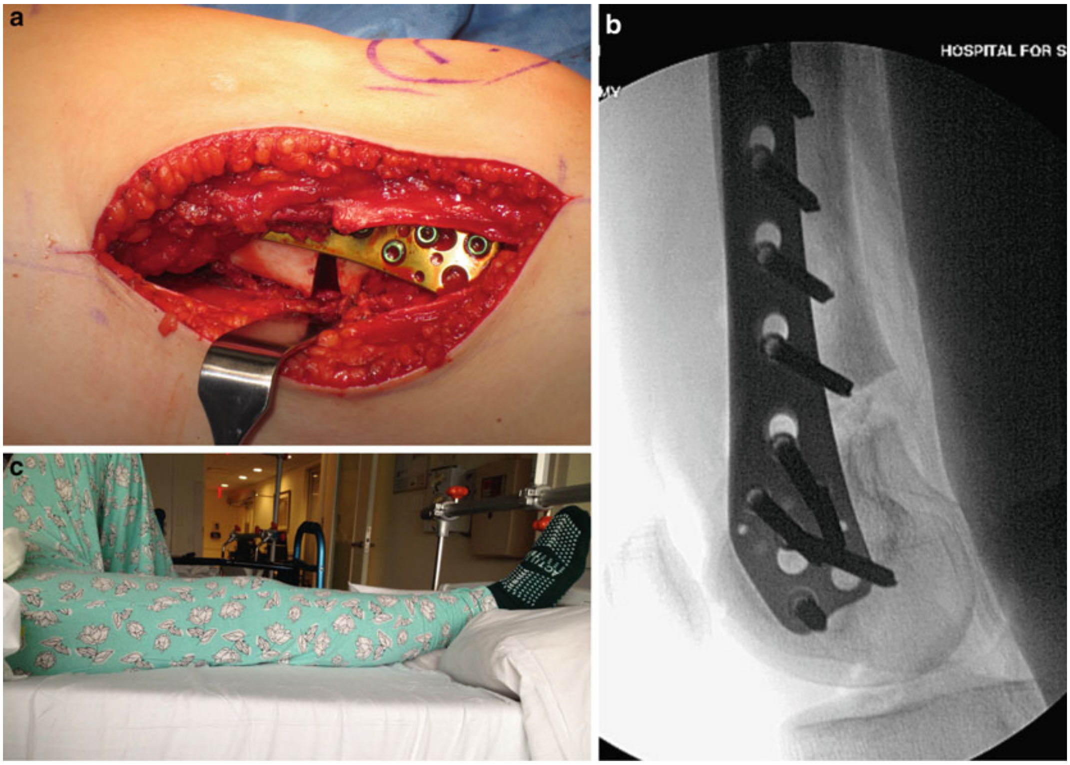
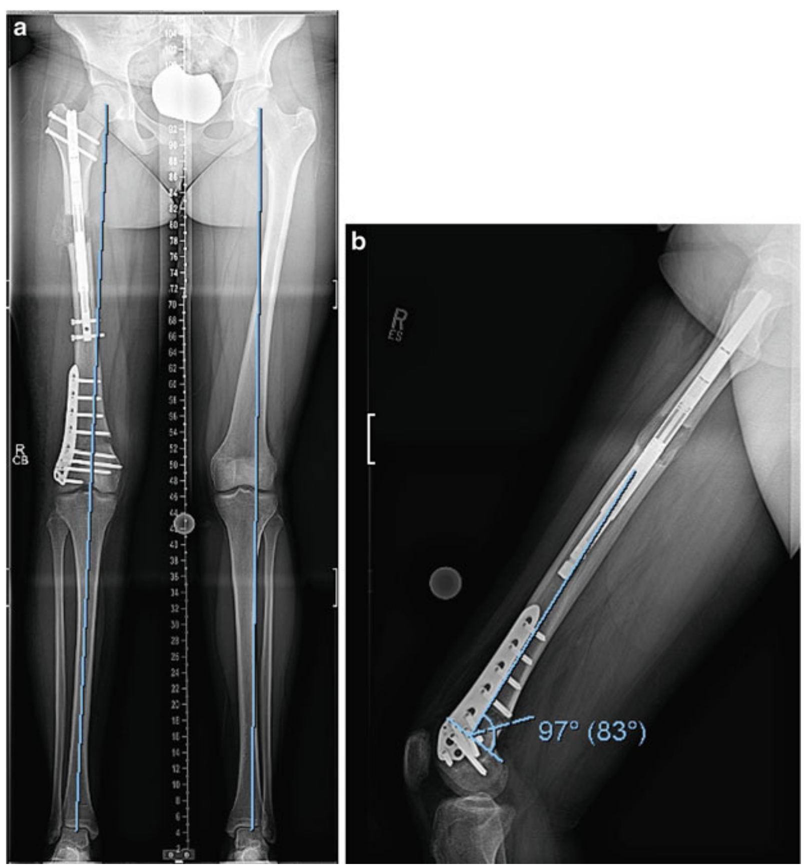


Fig. 3 This intraoperative photo (**a**) shows the posterior opening wedge osteotomy with the lateral plate in place. The osteotomy site was then grafted with demineralized bone matrix and freeze-dried cancellous bone chips. The fluoroscopy film of the distal femur (**b**) shows the plate position and alignment. Full knee extension is seen immediately post-op (**c**)

Fig. 4 The alignment was maintained and length equalized (**a**), and the sagittal alignment was improved to allow full knee extension (**b**). The lesser trochanter is similar in size and contour to the contralateral hip indicating correction of the rotational deformity



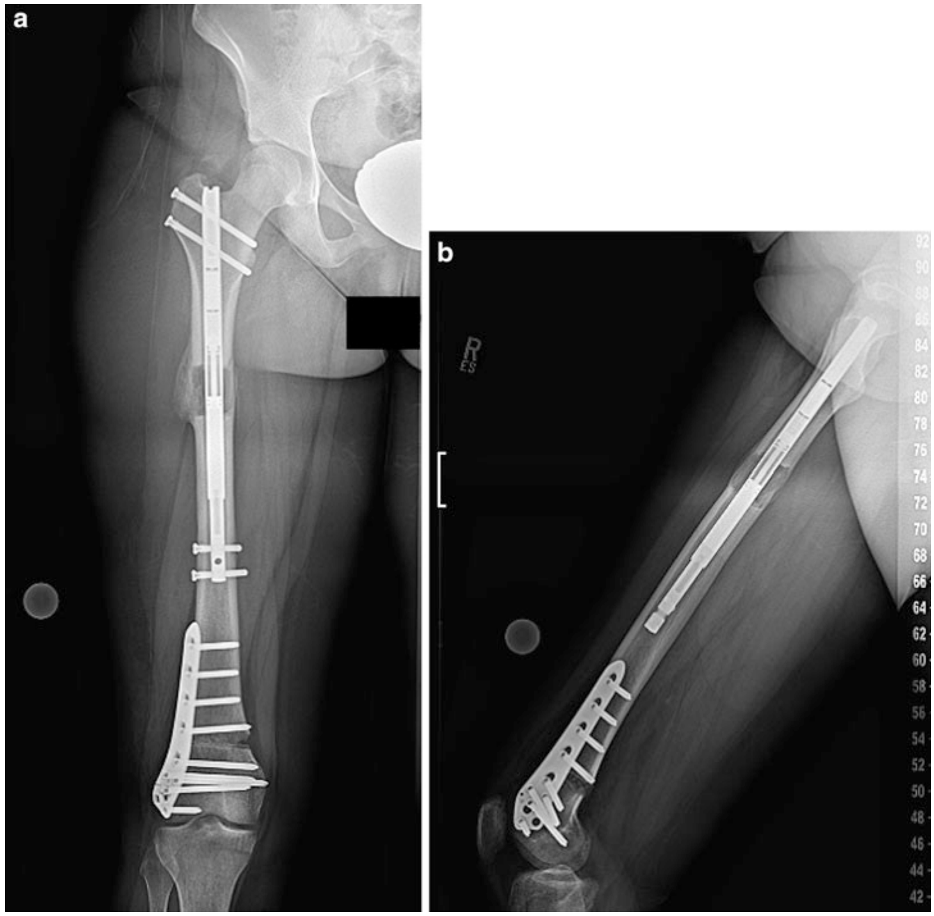


Fig. 5 Final X-rays show healing at both osteotomy sites 4 months post surgery (**a** and **b**)

Over-reaming by 2 mm or more is recommended to allow for smooth sliding of the nail in the IM canal. The lengthening nail should be inserted without difficulty.

10 Cross-References

- ▶ Case 1: Femur Lengthening with Precice Internal Lengthening Nail
- ▶ Case 4: Both Femur and Tibial Shortening Caused from Hemi-hyperthropia Treated Simultaneously with Two Antegrade Precice Nails
- ▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate
- ▶ Case 8: Femoral Lengthening (12 cm) with Two Precice Nail Lengthenings. Management of a Broken Precice Nail During the First Lengthening
- ▶ Case 13: Complex Femoral Deformity: Acute Correction and IM Nail Fixation

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Part III

Adult Deformity: Tibial Deformity

Case 16: Correction of Bilateral Genu Varum for a High Level Athlete

Austin T. Fragomen

Contents

Abstract

The correction of genu varum for patients with medial compartment osteoarthritis is a well-established treatment with the goals of reducing knee pain and slowing the progression of knee arthritis. A full correction of the varus and even overcorrection are needed to achieve these goals. The use of osteotomy in patients with genu varum to prevent arthritis from ever occurring is more controversial. The following case will present the story of an elite soldier whose job requires him to be in top physical condition. His experience with realignment surgery and the ability to recover and surpass his pre-op athleticism will be described.

1 Brief Clinical History

This is a 33 year old male who is part of the US special forces who began experiencing medial knee pain with running and other high-impact activities. He had bilateral genu varum since childhood and attributed the pain to this deformity. He was found to have varus deformity limited to the coronal plane involving the right proximal tibia and the left proximal tibia and distal femur. He was interested in anatomic reduction of the deformities with external fixation with the goal of return to high-impact activities surpassing his pre-op function.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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Fig. 1 Bilateral genu varum is noted with left-sided deformity more severe

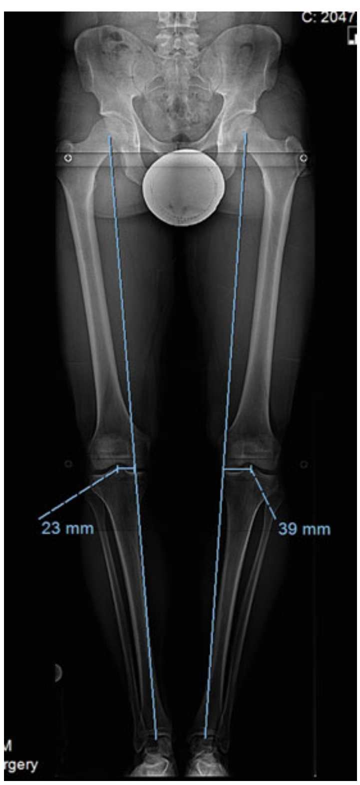

Fig. 2 51″ standing, bipedal radiograph shows bilateral medial mechanical axis deviations (39 mm medial on *left* and 23 mm medial on *right*)

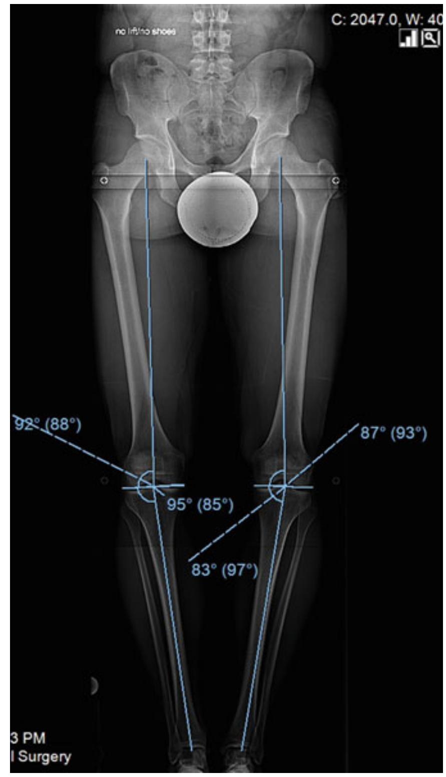

Fig. 3 The right-sided varus is evenly distributed in both the femur and tibia making either bone reasonable for osteotomy and full correction (*Right* LDFA = 92, MPTA = 85). The left lower extremity shows a left tibial varus of 4° and femoral varus of 6° (*Left* LDFA = 93, MPTA = 83)

3 Preoperative Problem List

1. Bilateral symptomatic genu varum without arthritis
2. High-level athlete

4 Treatment Strategy

The plan was to correct the left side first including both femoral and tibial osteotomy. The femoral osteotomy was done with an acute correction method using static external fixation. Osteoplasty of the ipsilateral tibia with external fixation was performed simultaneously. The tibial deformity was corrected gradually to ensure a perfect mechanical axis alignment. The right side was corrected 6 weeks later. This gave the left side adequate time to heal. The left side then became the strong side and supported the newly operated right side. Right side correction required only the tibial osteotomy and a uniplanar fixator.

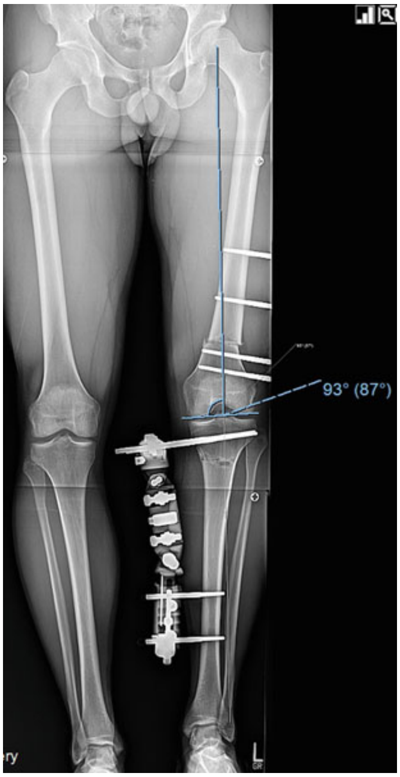

Fig. 4 The radiograph shows an acute correction of the femoral deformity with an LDFA of 87°. The tibia must now be corrected to an MPTA of 87° as well

Fig. 5 This front view of the patient shows a full correction of left-sided varus. The medial tibial and lateral femoral uniplanar frames can be seen

5 Basic Principles

Femoral osteotomy with external fixation can be done percutaneously, with minimal blood loss and allows immediate post-op weight bearing. Femoral osteotomy with a plate requires an open approach to the femur, is associated with greater blood loss, and requires protective weight bearing. Opening wedge osteotomy with plating also requires bone grafting.

Gradual correction of the tibial deformity is accomplished with external fixation. Uniplanar deformity is addressed with a monolateral frame, whereas multiplanar and oblique plane deformities are more effectively corrected with circular fixation. Hydroxyapatite-coated, tapered, 6 mm half pins provide excellent fixation. Patients perform adjustments at home after a short latency period. Deformity correction proceeds at 1 mm per day and takes from 10 to 21 days. The alignment is adjusted until the desired mechanical axis is achieved as measured on 51″ standing radiographs.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

The use of cannulated half pin insertion technique has made the application of unilateral external fixators more accurate. A wire is used to find the ideal insertion point for the first half pin. A cannulated drill is slid over the wire and both cortices are drilled. The half pin is then placed into the drill hole. Monolateral fixators are extremely unforgiving and this method has made application easier.

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

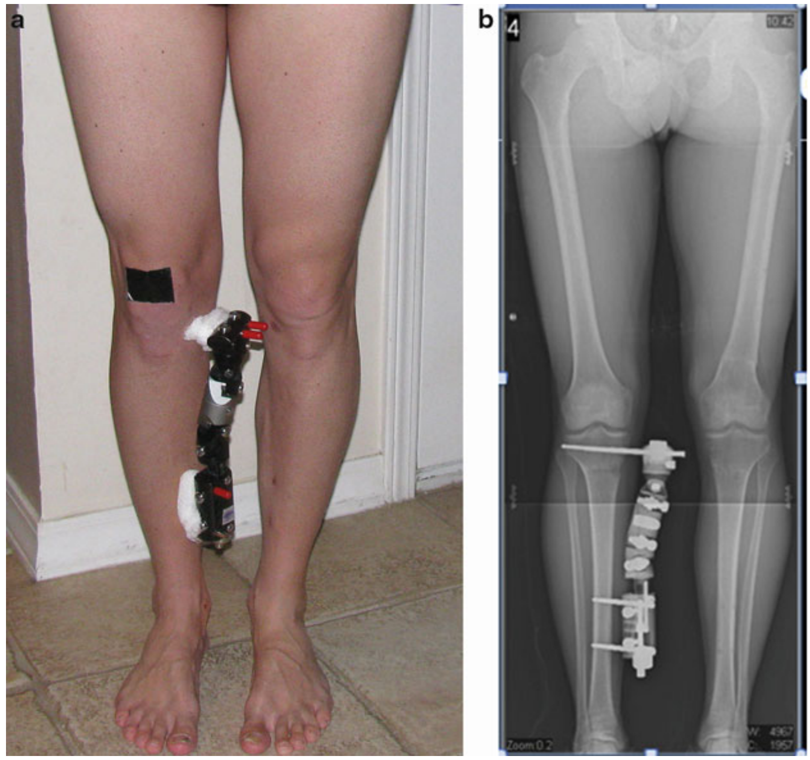

Fig. 6 (**a**, **b**) The front view and long X-ray show the right side monolateral frame and a corrected right alignment. The left-sided frames have been removed 6 weeks after the right-sided osteotomy. The correction is done and the patient is waiting for consolidation

Fig. 7 This front view photo was taken 1 year after the last surgery. The patient is seen with straight legs and is quite fit

Fig. 8 The patient is able to dead-lift more weight than presurgery and without pain

9 Avoiding and Managing Problems

In active patients tibial fracture through a pin hole is a concern as is collapse of the newly formed regenerate bone. Although these complications are extremely rare, they remain a concern immediately post frame removal. The protocol used after frame removal includes the use of a hinged knee brace with a maximum of 50 % weight bearing for 2 weeks. Patients are then allowed to discontinue the brace and progress to full weight bearing after obtaining a new X-ray. Patient can then resume low-impact exercises. Running and sports are allowed 3 months after frame removal.

10 Cross-References

▶ Case 14: Femoral Shaft Varus Above a Total Knee Replacement Treated with a Circular Hexapod Fixator
▶ Case 18: Gradual Correction of Distal Tibial Varus Deformity
▶ Case 25: Correction of Windswept Rotational Deformity with Fixator Assisted Plating Technique
▶ Case 27: Correction of Varus Deformity of the Femur and Tibia in Patient with LCL Laxity
▶ Case 46: Correction of Varus Deformity of the Femur in a Patient with Knee Fusion

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Case 17: Computer Assisted External Fixation for Aesthetic Changing Lower Limb Shape

Pavel Kulesh and Leonid N. Solomin

Contents

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Abstract

This is an example of preoperative planning and operative treatment for aesthetic changing of lower limb shape using external fixation. In this case, we performed gradual correction via a computer-assisted hexapod – Ortho-SUV Frame. Module transformation (removing of struts and internal half rings) provided opportunity to have patient stand with both legs together. This was helpful for evaluating clinical alignment and appearance.

1 Brief Clinical History

This female 31 y.o. came to Vreden Russian Research Institute of Traumatology and Orthopedics on April 08, 2012, having complaint of bow legs. She has been troubled by her alignment since she was a teenager.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

The patient was unhappy with her lower limb shape: gap between knee joints, concave lower leg internal contour, and curved external contour.

Pathological changes of hip, knee, and ankle joints using physical and ultrasound examination and MRI were not revealed.

Bilateral bow legs without pain.

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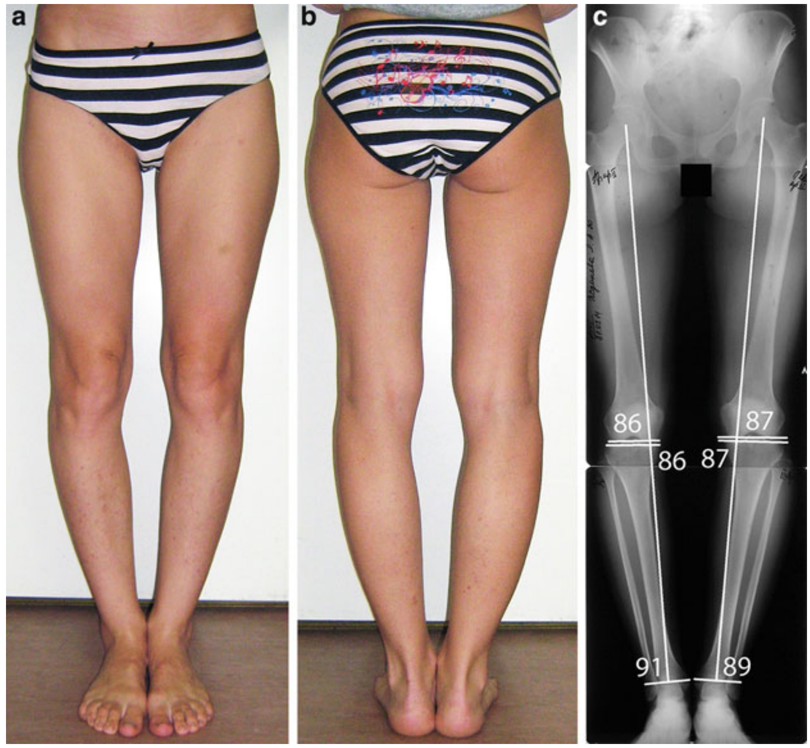

Fig. 1 (**a**) Front view showing bow leg alignment. There is a 5 cm gap between the legs on the level of the knee joints and 8 cm gap between the legs on the level of the proximal third of the shank. (**b**) Behind view showing bow leg alignment. (**c**) Standing X-ray showing bilateral medial mechanical axis deviation

4 Treatment Strategy

The strategy was chosen according to the complexity of correction planned: valgization and medialization of the distal part of the tibia and tibia lengthening to pull the fibula distally. We planned to carry out three types of bone fragment moving. To simplify this procedure, software-based Ortho-SUV Frame (http://ortho-suv.org) was chosen. After deformity correction, the modular transformation of the external fixation device can be done.

5 Basic Principles

1. The use of external fixation provides possibility of low-traumatic surgery, avoiding large incision and opening the bone fragments.
2. The use of computer-assisted Ortho-SUV Frame provides precise, one-step gradual deformity correction.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

The assembly of the external frames provided stable fixation of the bone fragments and possibility of modular transformation. The assemblies used according to Method of Unified Designation of External Fixation (MUDEF: http://ortho-suv.org/index.php?option=com_content%26view=article%26id=127%26Itemid=93%26lang=en) are the following (identical for both lower legs):

$$\frac{\text{I}, 9, 90;\ \text{I}, \mathbf{3} - 9;\ \text{II}, 1, 90}{140} - \text{Ortho} - \text{SUV}$$
$$- \frac{\text{IV}, 2, 90;\ \text{VI}, 12, 70}{140} - \frac{(\text{VII}, \mathbf{8} - 2)\text{VII}, 8 - 2}{140}$$

- Use of module transformation of the circular external frame decreases the bulkiness of the frames:

$$\frac{\text{I}, 9, 90;\ \text{II}, 1, 90}{1/2 \quad 140} - \frac{\text{IV}, 2, 90;\ \text{VI}, 12, 70}{1/2 \quad 140}$$

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

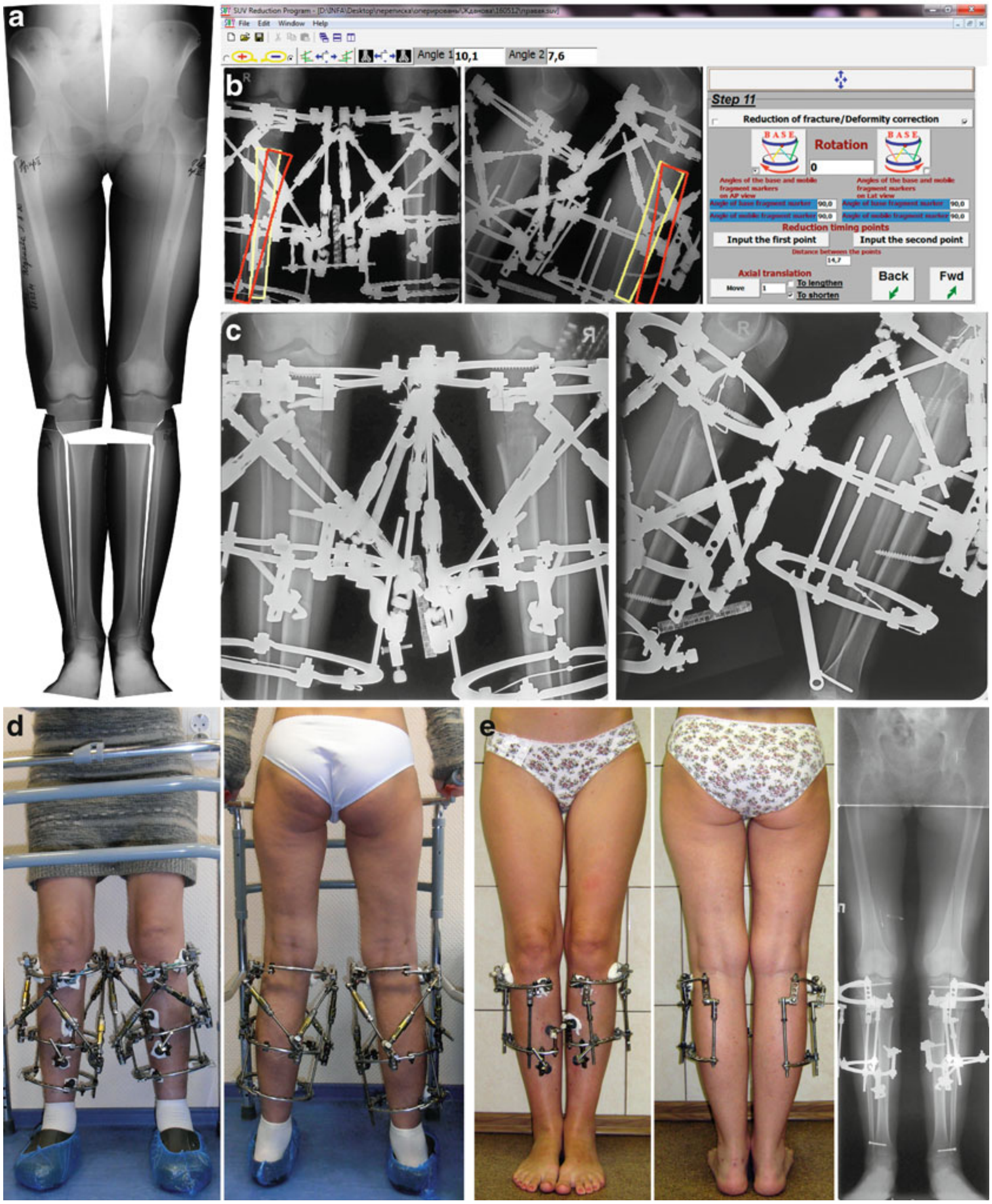

Fig. 2 (**a**) Preoperative planning. To achieve the desired result, we planned to carry out lengthening of the tibia of 2 cm, medialization of the distal part of the tibia of 10 mm, and valgization of 7°. (**b**) The Ortho-SUV software window at step 11: the deformities correction planning. The *yellow* bone contour indicated the initial mobile (corresponding) fragment position. The *red* bone contour created by the software indicates the final position of the mobile bone fragment. The same calculation was done for the *left* lower leg. (**c**) Radiographs after correction by Ortho-SUV. (**d**) Photos after correction. (**e**) Photos and radiographs after the modular transformation. Removing of internal half rings and struts provided the opportunity for the patient to stand with legs together which is a more accurate indication of final appearance

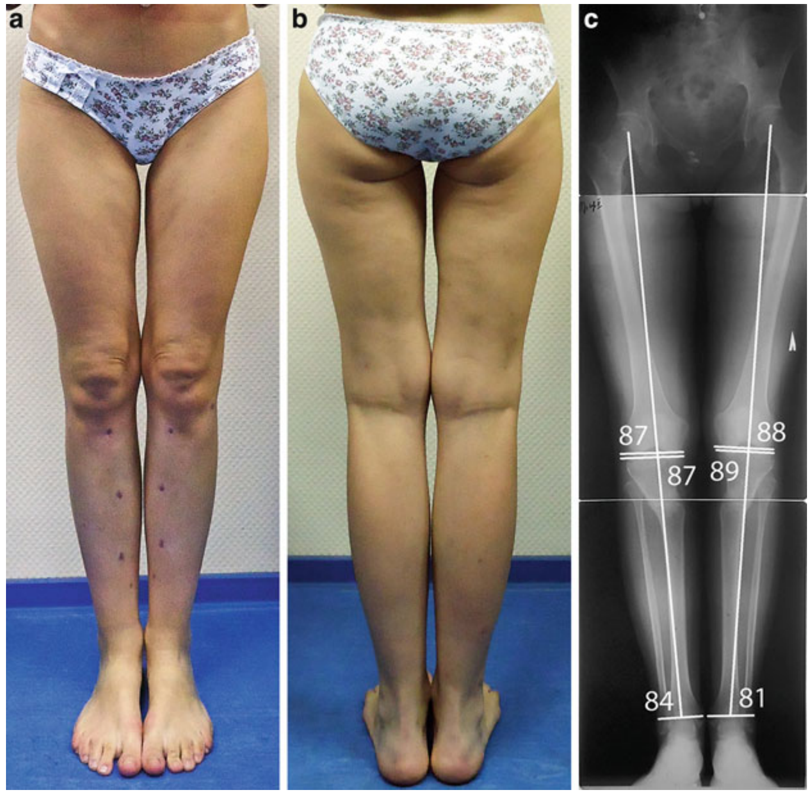

Fig. 3 (**a–c**) Photos and radiographs 1 month after removal of the external fixation frames showing normal alignment. There is no mechanical axis deviation noted

9 Avoiding and Managing Problems

The correction of the deformities was done gradually. Use of a structure at risk point helped determine optimal speed of correction, prevented nerve or vascular disorders, and helped with optimal callus formation.

Active antibiotic therapy and close method of pin-site management were used to prevent infectious complications.

Distal tibiofibular syndesmosis was fixed by screws to prevent gap after frame module transformation and removal of the tibiofibular wire.

10 See Also in Vols. 1 and 2

Case 95: Spondyloepiphyseal Dysplasia Treated by Bi-lateral Proximal Tibial Osteotomy Followed by Gradual Deformity Correction (Vol. 1)

Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity (Vol. 2)

Case 5: Computer Assisted External Fixation at Femur Two-Level Posttraumatic Complex Deformity (Vol. 2)

Case 21: Computer Assisted External Fixation and then Nailing at Both Lower Legs Non-unions Accompanied with Complex Deformities (Vol. 2)

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Case 18: Gradual Correction of Distal Tibial Varus Deformity

Megan M. Riedel and Janet D. Conway

Contents

Abstract

A 57 year old man presented with a distal tibial fracture of the left limb that had been treated with a plate. He had progressive deformity due to hardware failure and had developed significant varus angulation of 25° and nonunion. He underwent repair of the tibial nonunion and osteotomy with application of a Taylor spatial frame (TSF) (Smith & Nephew, Memphis, TN) for gradual deformity correction.

1 Brief Clinical History

A 57 year old man presented with a significant varus deformity of the distal tibia. He previously underwent plating on the lateral side of the distal tibia to treat a hypertrophic tibial nonunion. After hardware failure, the deformity progressed creating a varus angulation and nonunion. Patient also has diabetes and is a current smoker.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

– Hypertrophic nonunion
– Significant varus angulation

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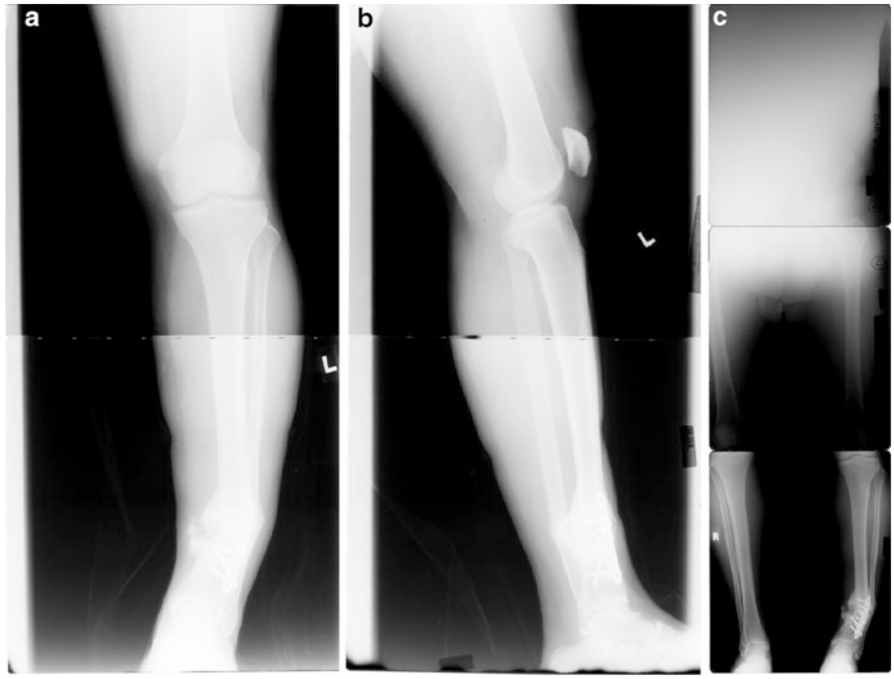

Fig. 1 Anteroposterior (**a**), lateral (**b**), and anteroposterior erect leg (**c**) preoperative radiographs showing varus deformity with plate (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

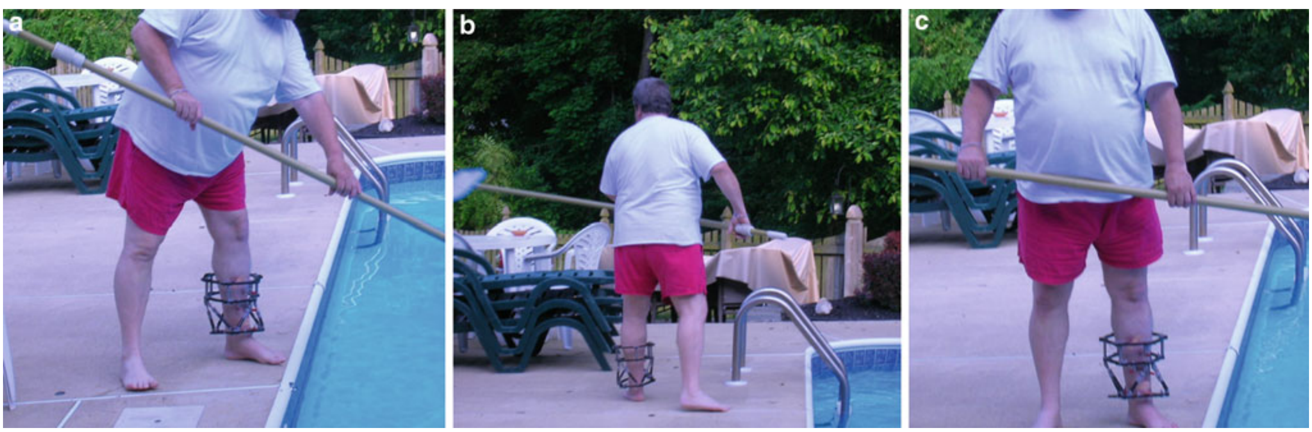

Fig. 2 Clinical photographs obtained during consolidation phase. (**a**) Medial view of Taylor spatial frame. (**b**) Posterior view of Taylor spatial frame. (**c**) Anterior view of Taylor spatial frame to show performance of daily activities (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

4 Treatment Strategy

To treat this significant varus deformity, we performed a distal tibial osteotomy at the apex of the deformity and then applied a Taylor spatial frame for gradual correction of the deformity. Removal of hardware was needed. The patient was allowed 50% weight bearing, was given oral antibiotics, and attended regular physical therapy sessions. After correction was achieved, the frame was dynamized to promote bone healing. After discharge from the hospital, he was allowed 50% weight bearing and was given prophylactic oral antibiotics and pain medication.

5 Basic Principles

We added wires and half-pins through the bones to increase stability. The ring should be positioned two-to-three finger's breadths from the skin to allow for edema. The wires should be tensioned to 130 kg to maintain stability. Hypertrophic nonunion contains fibrocartilaginous tissue that has

Fig. 3 Long-standing radiograph obtained during consolidation to show correction of deformity and LLD (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

osteogenic potential. Deformity correction and stable fixation are critical for success.

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

Use a distal reference for the TSF. Perform the osteotomy of the fibula first. Then judge the mobility of the tibial nonunion after removing the hardware. If there is some limited mobility (5–10°), then correction can proceed through the nonunion without additional osteotomy. If there is very limited mobility, then an osteotomy is required either through the nonunion or adjacent to the nonunion depending on the CORA location and the soft tissue and bone quality.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

Fig. 4 Anteroposterior (**a**) and lateral (**b**) view radiographs obtained 2 months after frame removal (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

9 Avoiding and Managing Problems

Pin sites need to be looked after and taken care of to avoid pin site infections. If they become infected or start draining, an acute infection could harm the healing process. Premature consolidation can occur if the patient does not follow the distraction schedule. The nonunion healing can be impaired due to poor patient health including low vitamin D and protein levels. These should be normalized with supplementation.

10 See Also in Vols. 1 and 2

Case 43: Tibial Hemimelia (Vol. 1)
Case 37: Hypertrophic nonunion distal periarticular tibia. Treatment with callus distraction using a Spatial Frame (Vol. 2)
Case 54: Gradual Correction of Distal Tibia Malunion (Varus with Shortening) (Vol. 2)

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Case 19: Bilateral Genu Varum and LLD Corrected with an Internal Lengthening IMN and Contralateral HTO

Austin T. Fragomen

Contents

Abstract

Genu varum is typically a tibial deformity that affects many people. When symptomatic, surgical realignment through a proximal tibial osteotomy is a powerful technique for reducing pain, improving function, and, perhaps, preventing osteoarthritis. The following case is unique in that the patient presented with a right-sided femoral deformity with shortening and a left-sided tibial deformity. This asymmetric pattern of genu varum is rare and highlights the need for accurate radiographic analysis and customized treatment plans. In addition the case highlights the utility of the PRECICE IMN (Ellipse Technologies Inc., Irvine, CA, USA) for acute correction and lengthening of femur deformities.

1 Brief Clinical History

A 53 year old male, who was a black belt in Tae Kwon Do (martial arts), presented to the office complaining of medial knee pain bilaterally. He noted that his pain was worse with activity and felt it stemmed from the varus deformity of both knees. He wanted to correct the deformities in order to continue to practice martial arts at a high level. Physical exam revealed a thin and very fit man with full knee and ankle range of motion, bilateral genu varum, and a leg length discrepancy (LLDleg length discrepancy (LLD)) corrected with a 2 cm block under the right foot. The rotational profile was symmetric for femur and tibia.

Radiographs showed an LLD of 2.2 cm right side shorter. The femoral discrepancy was 16 mm and the tibial discrepancy was 6 mm. The right MAD was 34 mm medial with an LDFA of 98° and an MPTA of 87°. The left side showed a MAD of 29 mm medial with an LDFA of 91° and an MPTA of 81°. There were mild medial joint space changes on the left side and no joint space narrowing of either knee joint.

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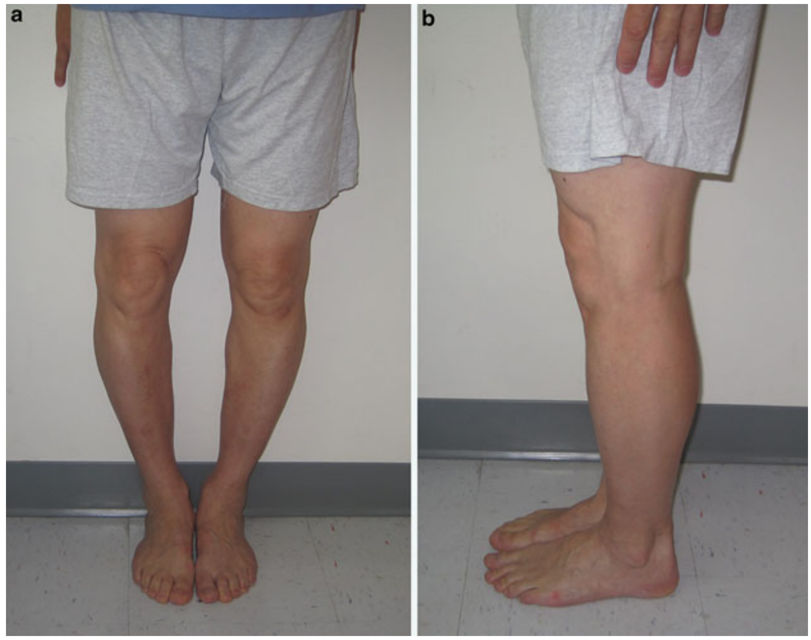

Fig. 1 The patient is seen standing from the front (**a**) and side (**b**) showing bilateral genu varum and full knee extension

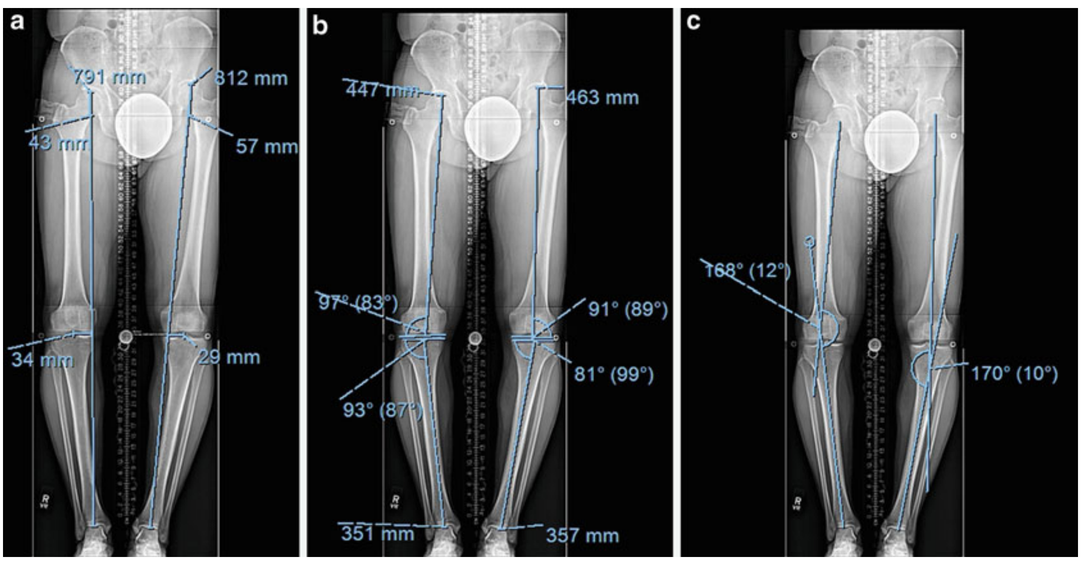

Fig. 2 Bipedal, 51″, standing radiographs demonstrate the MAD and leg lengths (**a**), joint orientation angles and segment lengths (**b**), and CORA planning and total angular deformity (**c**)

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. (LLD) 2.2 cm right side short: Δ Femur 16 mm and Δ Tibia 6 mm
2. Right femur varus of 12°
3. Left tibia varus of 10°
4. Minimal osteoarthritis of the knees

4 Treatment Strategy

1. Correction of the left tibial deformity with simple external fixation and early weight bearing. Slight overcorrection was desirable.

Fig. 3 The left side was corrected first. The partial osteotomy is seen with half-pins placed. The mild medial compartment changes are noted

2. Staged correction of the right femur deformity and LLD with a retrograde, internal lengthening nail.

5 Basic Principles

1. Accurate diagnosis. Through high-quality radiographs the origin of the varus deformity was identified independently for both lower extremities. This was confirmed on serial radiographs to ensure accuracy.
2. Staged bilateral correction. Approaching bilateral lower extremity deformities in a staged fashion has many advantages: improved patient mobility and independence, improved accuracy of radiographs, lower postoperative risk of immobilization-related complications (VTE), and shorter operative times. The left leg was selected first because the frame allowed for early weight bearing and the increased length acquired by the angular correction could be measured and accounted for prior to right-sided lengthening.

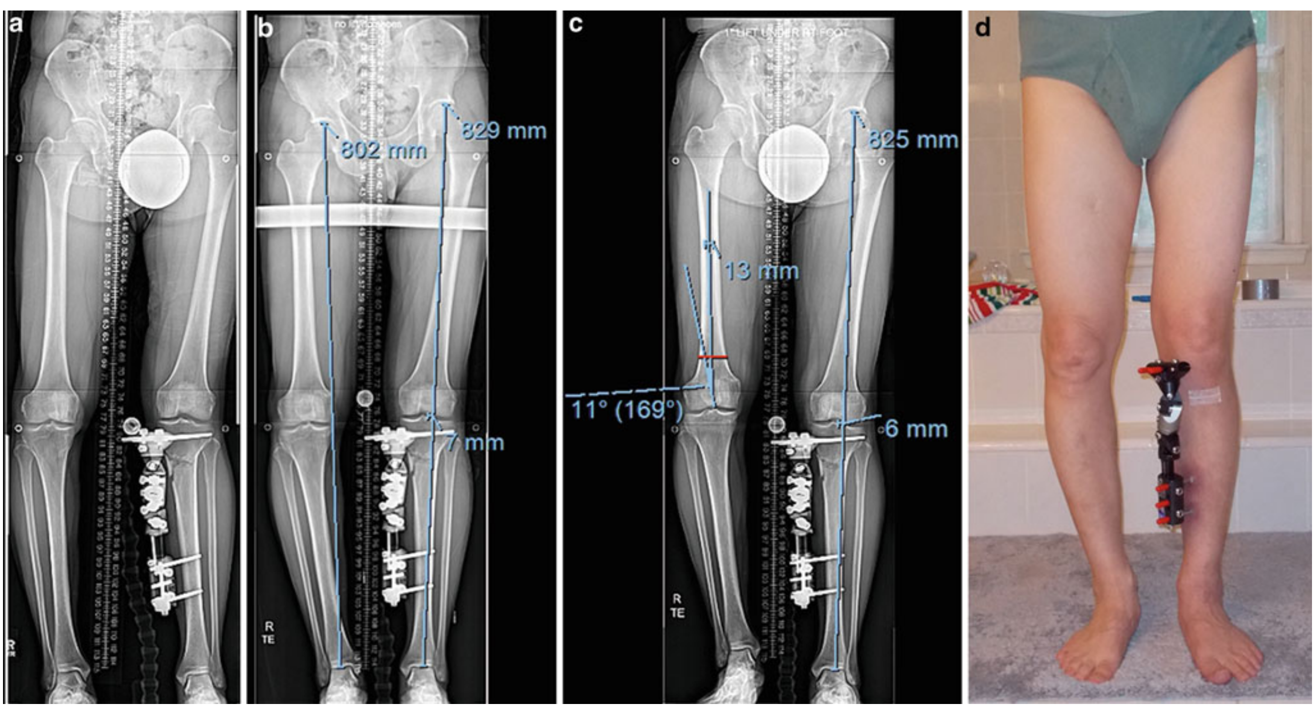

Fig. 4 The patient overcorrected the osteotomy creating a butterfly fragment, valgus deformity, and fracturing through the lateral cortex. (**a**) An acute correction in the office was well tolerated. He was encouraged to walk on the leg for 1 week when new X-rays were obtained to measure the left side alignment. (**b**) The MAD was seven lateral, and the new (LLD) was measured at 27 mm. Retrograde deformity planning was implemented and a 1 in. block was seen to level his pelvis. The transverse line indicates the osteotomy site and the necessary translation. (**c**) The patient took a clinical photo from his bathroom and e-mailed to me during treatment. (**d**) Keeping an open dialogue with the patients is important for moral and good care. E-mail has been revolutionary in improving communication with patients

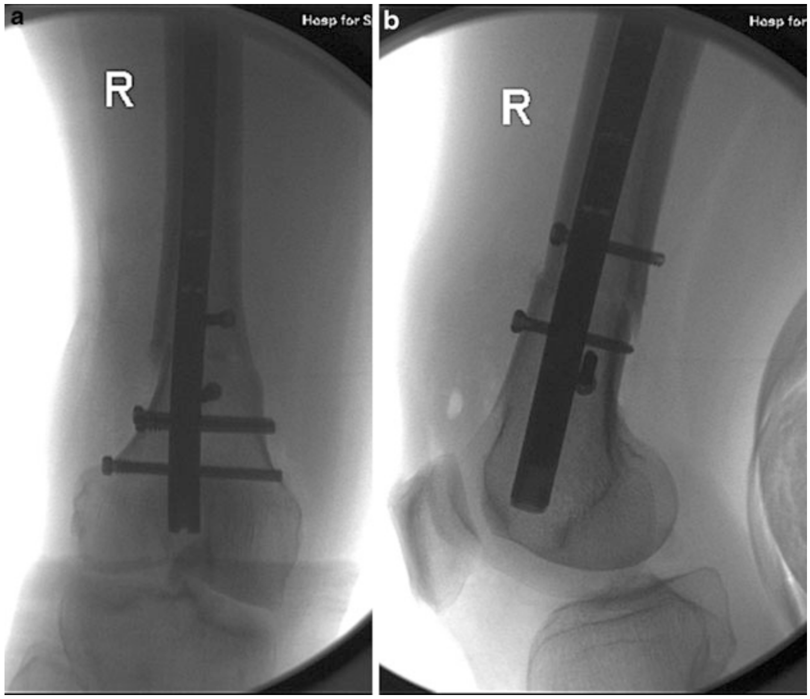

Fig. 5 AP (**a**) and lateral (**b**) radiographs demonstrate the osteotomy with medial translation and the use of blocking screws to prevent deformity. The distal fragment is protected from valgus deformity by the lateral cortex resting against the nail and from varus deformity by the medial blocking screw. The proximal fragment is protected similarly. (**a**) The distal fragment is protected from flexion by the posterior blocking screw, and the proximal fragment cannot flex unless the nail bends or fractures. (**b**) One must be careful with blocking screws used in the proximal fragment: if the screw impinges the nail, it may become incarcerated and not lengthen

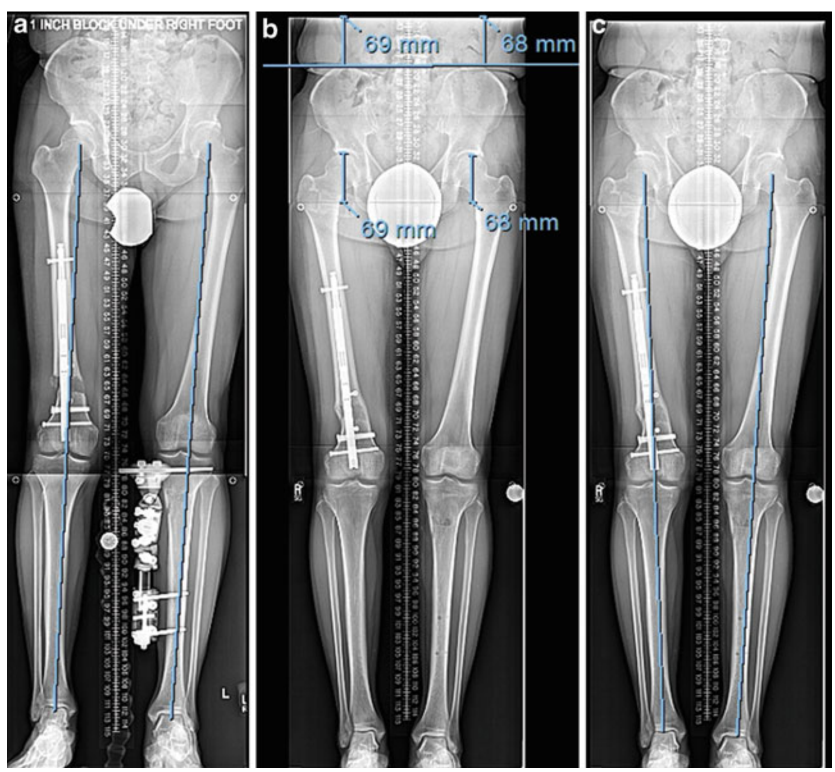

Fig. 6 This long radiograph was taken immediately after the patient performed 2.5 cm of lengthening. (**a**) The distraction space measured 2.5 cm, but the LLD still measured 1 in. This illustrates the dependence of the X-ray on patient positioning. If he were bending the knee or hip, the length calculation would be errant. The distraction gap measurement is more reliable in these scenarios. To continue lengthening would be a mistake. The subsequent radiograph taken 2 months later showed LLD within 1 mm without any additional lengthening. (**b**) MAD was 0 mm on the right and 7 mm lateral on the left which was felt to be ideal. (**c**)

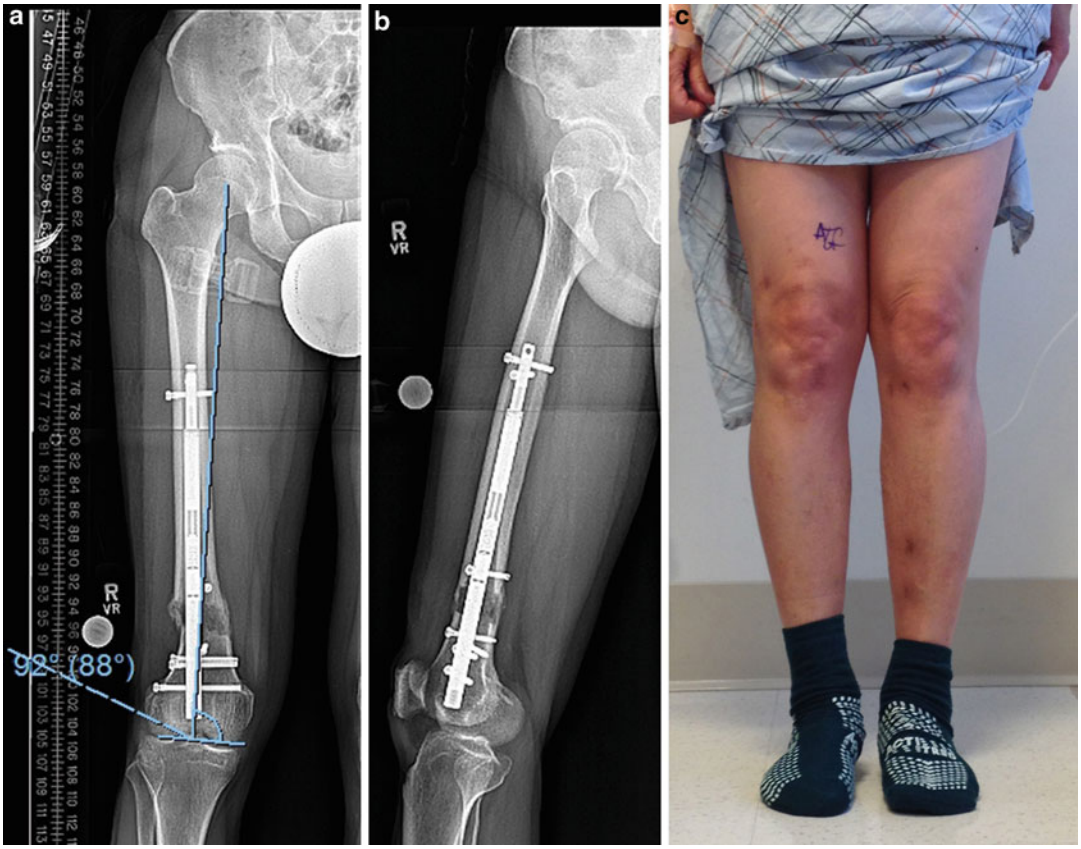

Fig. 7 The final AP (**a**) and lateral (**b**) radiographs show the desired coronal translation and no lengthening-related secondary deformity. A final clinical photo before IM nail removal shows complete resolution of the varus deformity (**c**)

3. Mixed fixation. We have a selection of superb implants available for use to correct limb deformity. Surgeons should be familiar with all available techniques and fixation tools to provide optimal care to patients.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

1. Communication. An active dialogue with the patient is important throughout the treatment process. This patient overcorrected the left tibia and contacted me when he realized that his alignment was valgus. A simple acute correction in the office remedied this mistake.
2. PRECICE IMN. Blocking screws are important to prevent flexion and varus/valgus deformity during femoral lengthening with an internal implant. The retrograde nail comes in a straight and a curved distal implant version. If the patient has a distal recurvatum deformity, the apex anterior curved IMN may be helpful in correcting this problem. Additionally, a flexion deformity can be allowed to occur during lengthening by not using a posterior blocking screw. In this case a straight nail and a blocking screw were used to ensure no loss of knee extension. Over-reaming is critical to ensure atraumatic nail insertion and smooth distraction in the canal.
3. Deformity planning. Planning a femoral deformity correction with an intramedullary implant requires careful anatomic alignment assessment. Proper translation needs to be accounted for. Rotational markers are recommended to prevent incidental rotational deformity after the osteotomy and before locking the IMN. These pins are placed posterior to the IMN using the LON-style (lengthening over nail) technique. I prefer to ream the distal segment up to the proposed osteotomy site first to ensure proper nail orientation. Then I perform the osteotomy, reduction, and proximal reaming. Blocking screws are placed after the nail is positioned and locked, but they could be placed during reaming to ensure a proper trajectory.

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

9 Avoiding and Managing Problems

Overcorrection with an external fixator is easily remedied with reverse adjustments. Pin infections are common. Prevention with pin care is suggested. Early treatment with oral antibiotics is important to halt progression of the infection.

Overlengthening of the femur with a PRECICE is similarly resolved with reversing the direction of the magnet as this is a compression-distraction nail. Blocking screws help to avoid lengthening-related deformity.

10 Cross-References

- ▶ Case 4: Both Femur and Tibial Shortening Caused from Hemi-hyperthropia Treated Simultaneously with Two Antegrade Precice Nails
- ▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate
- ▶ Case 8: Femoral Lengthening (12 cm) with Two Precice Nail Lengthenings. Management of a Broken Precice Nail During the First Lengthening
- ▶ Case 16: Correction of Bilateral Genu Varum for a High Level Athlete
- ▶ Case 27: Correction of Varus Deformity of the Femur and Tibia in Patient with LCL Laxity

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Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique

Dong Hoon Lee

Contents

Abstract

Correction of bilateral tibial deformity (varus and external rotation) was accomplished with a fixator-assisted acute correction of deformity. Varus was corrected through a proximal tibial osteotomy and rotation was corrected through a supramalleolar osteotomy. The fixator-assisted technique and the percutaneous plating were both accurate and required minimal incision.

1 Brief Clinical History

A 24 year old female complained of bowlegs and out-toeing gait. Other pathologic findings were not found and she was diagnosed as idiopathic tibia vara and torsional deformity of the tibia; rotation of the hip joint was in normal range and thigh-foot angle was increased.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4

3 Preoperative Problem List

- Proximal tibia vara (MPTA 79°/80°), both
- External tibial torsion (39°/39°), both

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Fig. 1 A foot-forward position photograph shows internal rotation of the patella (A), and a patella-forward position photograph shows a considerable outward rotation of the foot, indicating rotational deformity

Fig. 2 A long bone coronal radiograph shows varus malalignment of the lower extremities (femorotibial angle, varus 9°/8°)

Fig. 3 Thigh-foot angle shows external torsion of the tibia (TFA 35°/35°)

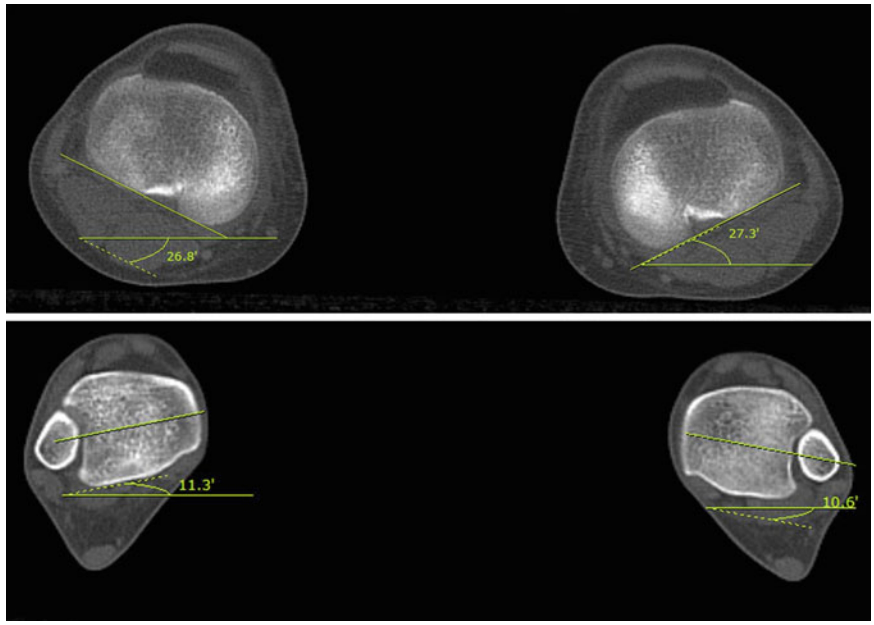

Fig. 4 Axial view of her proximal (*upper*) and distal (*lower*) portion of the tibia from the computed tomography showed external tibial torsion (39°/39°)

4 Treatment Strategy

Acute correction of both deformities was determined for the treatment of such combined deformities because the patient did not want to wear a bulky fixator. Proximal tibia vara was corrected using the fixator-assisted high tibial osteotomy, and derotation was made at the distal tibia using the fixator-assisted plating technique.

5 Basic Principles

Correction of both varus and torsional deformities can be done gradually by single level osteotomy at the proximal tibia. If derotation is intended by an acute manner, the internal derotation of the tibia should be done at the distal tibia to avoid peroneal nerve injury. The fixator-assisted technique is useful for correcting and maintaining the alignment until the final definitive fixation is inserted.

6 Images During Treatment

See Figs. 5, 6, 7, 8, and 9

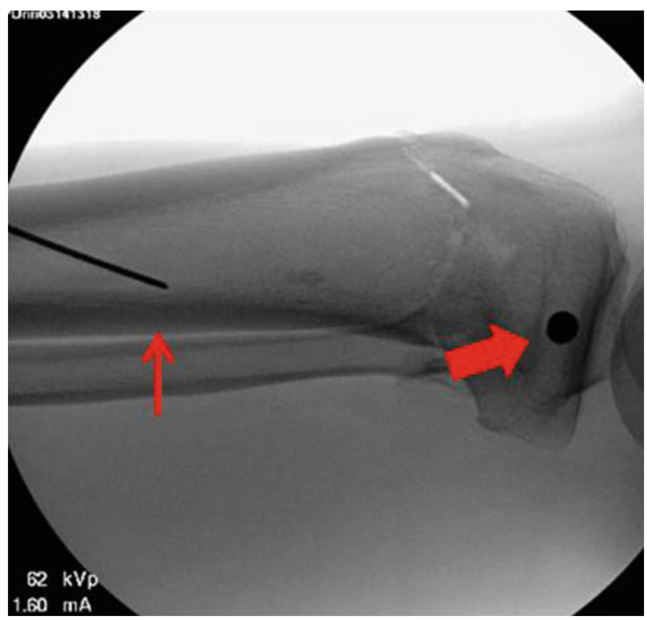

Fig. 5 After osteotomy at the proximal tibia sparing the lateral cortical hinge, a Schantz pin is inserted at the proximal tibia along the level of the posterior cortex of the shaft (*arrow*), and a guide distal Schantz pin is located just anterior to the posterior cortex to avoid the plate pathway (*narrow arrow*)

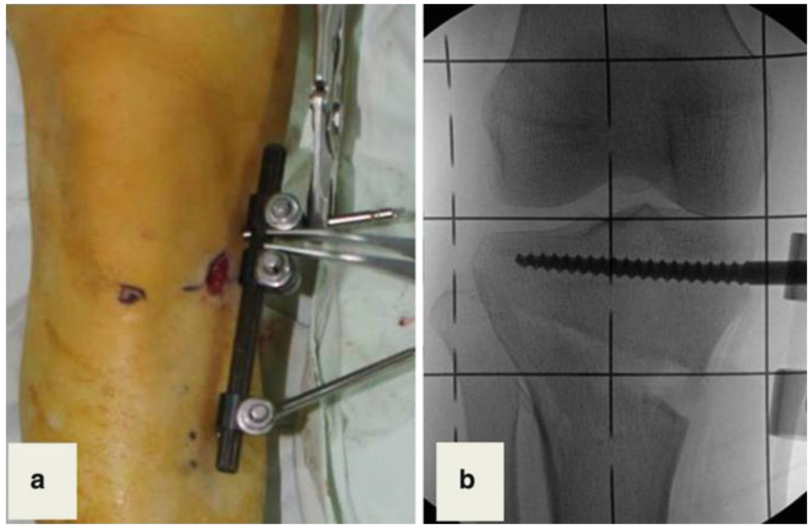

Fig. 6 A pin-to-bar-type fixator is applied for correction of the varus with an opening wedge correction and temporary external fixation is applied. Position is checked with the c-arm X-ray

Fig. 7 A locking plate (TomoFix Medial High Tibial Plate, Synthes) is applied with minimally invasive plate osteosynthesis technique

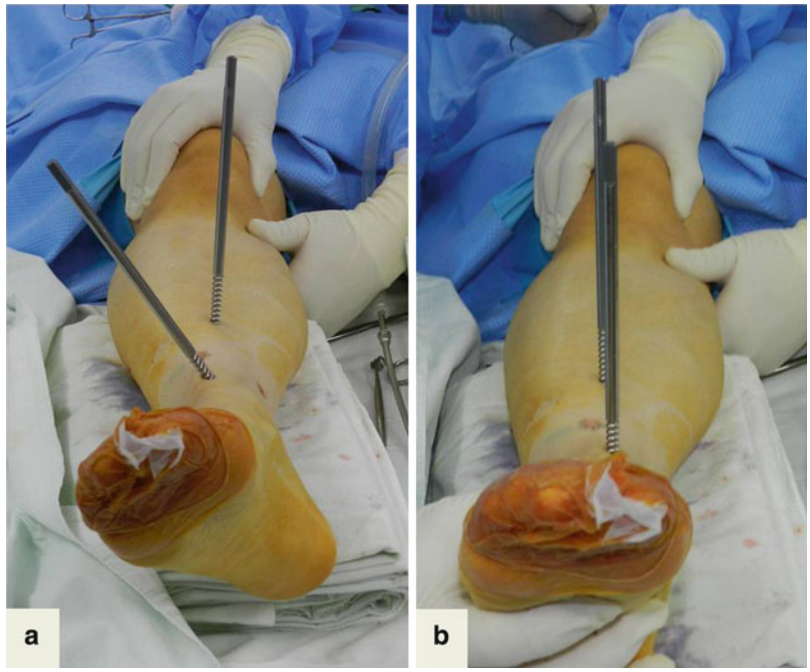

Fig. 8 Derotation at the distal tibia is confirmed using two Schantz pins (A → B)

Fig. 9 After derotation, two Schantz pins and a frame are used for temporary fixation. A locking plate is applied with minimally invasive plate osteosynthesis technique from the medial side

7 Technical Pearls

To avoid the pathway of the plate, two Schantz pins at the proximal tibia should go through near the posterior cortex for high tibial osteotomy, and another two Schantz pins at the distal tibia should go through just medial to the anterior crest for derotation.

8 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, 12, and 13

9 Avoiding and Managing Problems

Posterior location of the Schantz pins in high tibial osteotomy allows the plate to pass through without any obstacle and helps prevent an increase in the posterior slope of the tibia from the opening wedge osteotomy.

Fig. 10 A postoperative long bone radiograph (postoperative 21 months) both in coronal and sagittal planes shows proper limb alignments

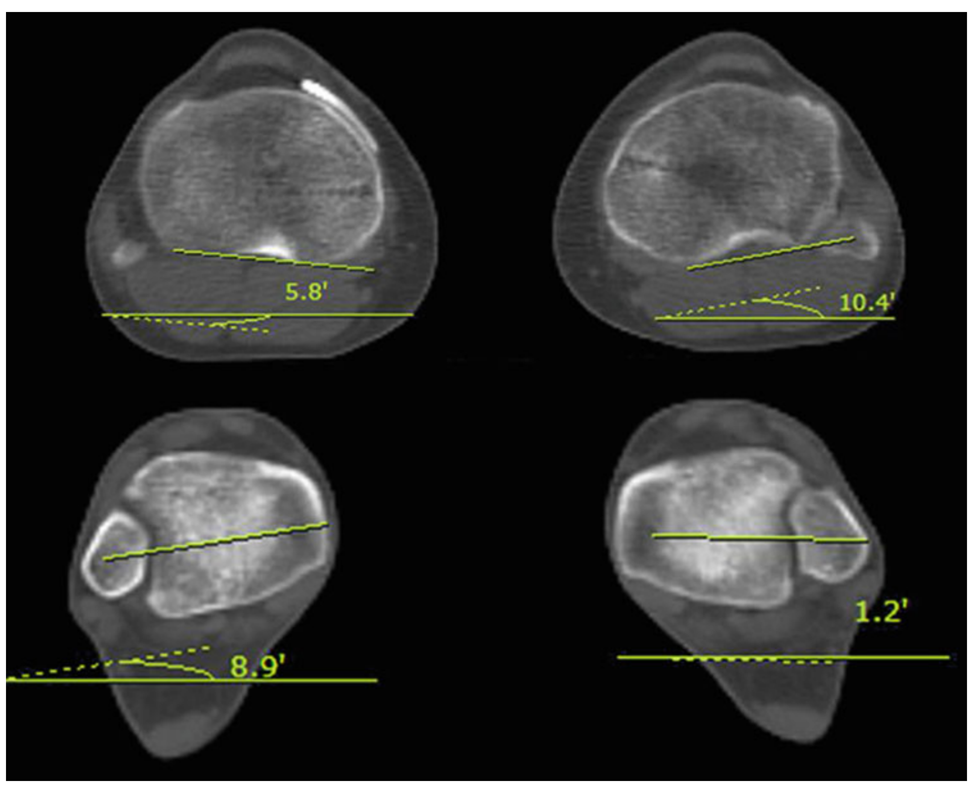

Fig. 11 A postoperative computed tomography of both tibiae shows derotation of both tibiae, having a normal tibial external rotation (14°/11°)

Fig. 12 Patella faces forward in the foot-forward standing position

Fig. 13 Thigh-foot angle shows normal tibial rotation

10 Cross-References

- ▶ Case 16: Correction of Bilateral Genu Varum for a High Level Athlete
- ▶ Case 18: Gradual Correction of Distal Tibial Varus Deformity
- ▶ Case 21: Complex Tibial Deformity: Acute Correction and IM Nail Fixation

11 See also in Vol. 1

Case 68: Correction of Adolescent Tibia Vara without Fibular Osteotomy and without Fixation of the Fibula using the Taylor Spatial Frame (TSF)

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Case 21: Complex Tibial Deformity: Acute Correction and IM Nail Fixation

Mahmoud A. El-Rosasy

Contents

Abstract

Complex diaphyseal deformities of long bone may need more than one osteotomy to restore the normal mechanical axis. Difficulties with multiple tibial osteotomies arise when intramedullary fixation is chosen due to short bone segments rendering the fixation unstable. A corrected complex tibial deformity due to congenital tibial dysplasia is better fixed by intramedullary nail due to poor healing capacity of this dysplastic bone and the expected delayed bone-healing time. A major difficulty of correction and fixation of such deformity is the presence of secondary compensatory deformities and the adjustment of leg length to avoid residual leg length discrepancy (LLD). Resolution of the deformities into one CORA (center of rotation of angulation) to achieve correction through one osteotomy is an attractive idea which leaves long enough bone segments for stable fixation. Careful preoperative planning and paper tracing is essential for determination of both the osteotomy level and nail insertion point.

1 Brief Clinical History

The patient is a 16 year old female patient known to have neurofibromatosis type 1 (NF-1) and congenital tibial dysplasia with apex anterolateral deformity of the right leg. Examination revealed LLD of 1 cm, normal neurovascular status of the limb, and fully mobile knee and ankle joints.

When planning deformity correction, it is helpful to use the full-length standing X-ray in addition to radiographs of the operative bone. The surgical planning is done within the context of the lower extremity mechanical axis. In this case, a long-standing X-ray would reveal the source of the valgus alignment outcome which may be from the femur and/or the proximal tibia. Further realignment surgery may be indicated in this case (SRR).

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Fig. 1 (**a**, **b**) Preoperative radiographs show a dysplastic middle third of the tibia (indicated by increased bone density and cortical thickening) with a varus-procurvatum deformity. A compensatory proximal tibial valgus deformity is seen. (**c–e**) Clinical photos show *right* leg deformity with anterolateral apex

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Congenitally dysplastic bones have low healing potential which render gradual deformity correction, using external skeletal fixation, unsuitable due to protracted bone-healing time.
- The actual length of the deformed tibia is longer than the normal side (361.4 mm vs. 360 mm), making it necessary to perform a wedge resection osteotomy to avoid over-lengthening.
- Multiplanar and multilevel tibial deformity and the possibility of having a hidden residual deformity.
- Dysplastic tibia with narrow and partially blocked medullary canal. Medullary reaming and insertion of a suitable intramedullary nail (IMN) may be difficult.

4 Treatment Strategy

- Acute correction of the tibial deformity through a closing wedge osteotomy based anterolateral
- Reaming of the medullary cavity of the tibia to the largest possible diameter and insertion of a statically locked intramedullary nail to ensure a stable mechanical environment
- Insertion of autogenous iliac crest bone graft (ICBG) after decortication of the bone at the level of the osteotomy to improve the healing capacity of the bone

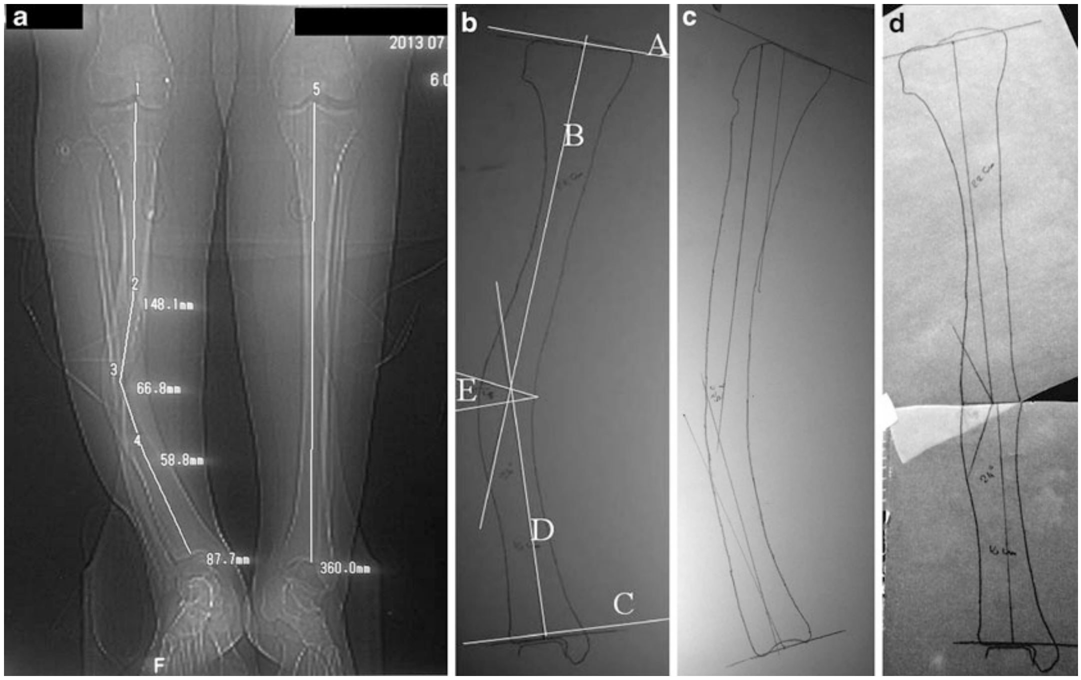

Fig. 2 (**a**) Preoperative scanogram for measurement of tibial length. Measurement of each segment of the deformed *right* tibia shows a total length of 361.4 mm compared to 360 mm length of the normal *left* tibia. (**b–d**) Preoperative tracing of the radiographs of the tibia on transparent papers for deformity analysis, planning the osteotomy and location of nail insertion point. The knee joint orientation line is drawn (*A*) and the mechanical axis of the proximal tibia is drawn (*B*); similarly, the joint orientation line of the ankle (*C*) and mechanical axis of the distal tibia (*D*) are drawn. Intersection of lines *B* and *D* represents the resolution CORA, and the angle subtended represents the magnitude of the deformity. A laterally based triangle is drawn (*E*) where the angle of its apex equals the magnitude of the deformity, and its sides are perpendicular to the lines *B* and *D*. Triangle *E* represents the closing wedge osteotomy to be resected for deformity correction. The mechanical axis of both segments (lines *B* and *D*) represents the path of the intramedullary nail to be inserted. From the tracing, it is clear that the insertion point of the nail has to be medial to the tibial tuberosity in the anteroposterior view and anterosuperiorly in the lateral view so that the nail could be inserted without breaching the lateral and posterior cortices of the tibia

5 Basic Principles

In treating congenital tibial dysplasia, the critical concepts are correction of angular deformity, stable mechanical environment, the routine use of autogenous ICBG, and retention of the IMN as a permanent splint to avoid refracture.

6 Images During Treatment

See Fig. 3.

7 Technical Pearls

Of paramount importance is to preoperatively plan the correction on paper tracings including the osteotomy cuts and nail insertion point. Attention is directed to avoid breaching the bone cortex and to ensure secure intramedullary insertion of the nail to span the maximal length of tibia. An osteotomy of a congenitally dysplastic tibia should be approached as if it were a nonunion with decortication of the bone, insertion of autogenous ICBG, and the use of stable IMN fixation.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

Acute deformity correction results in stretch of the neurovascular structures according to the direction and level of correction. In case the deformity correction would result in sudden stretch of the neurovascular structures, then decompression is necessary (tarsal tunnel decompression for distal tibia and common peroneal nerve in proximal tibia deformities). In certain cases of large deformity correction, prophylactic nerve decompression is advisable.

Fig. 3 (**a**, **b**) Immediate postoperative radiographs show good bone contact after a closing wedge osteotomy, insertion of the IMN as planned preoperatively, and insertion of autogenous ICBG. Note the MPTA is 90°

10 Cross-References

- ▶ Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique
- ▶ Case 32: Acute Correction of Tibial Deformity and Plate Fixation, with Subsequent Lengthening Over Plate
- ▶ Case 35: Acute Correction with Marrow (Intramedullary Canal) Narrowing Technique and Subsequent Lengthening Over Nail for the Femoral Shortening Combined with a Deformity

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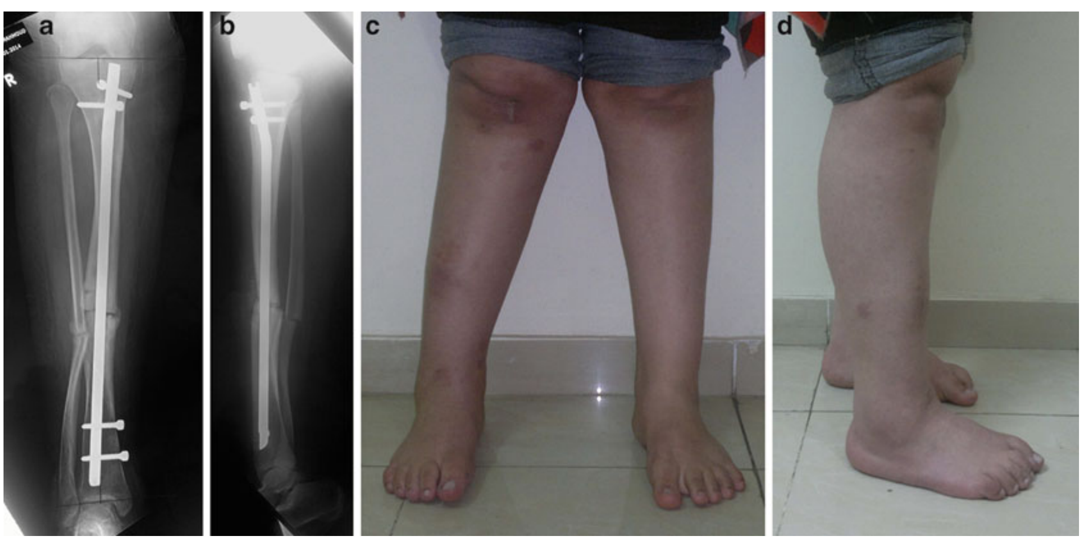

Fig. 4 (**a**, **b**) Follow-up radiographs show healing of the osteotomy and graft incorporation. The mechanical axis of the tibia is within normal limits. (**c**, **d**) Clinical photos show full weight bearing and good functional outcome; however, a knock-knee deformity is apparent

Case 22: Treatment of Posterior Tibial Nerve Impingement After Tibial Lengthening

Dong Hoon Lee

Contents

Abstract

Acute correction of severe equinus deformity can cause a compression and stretch of the branches of the posterior tibial nerve at the tarsal tunnel. If neuropraxia is suspected, early release of the tarsal tunnel is necessary to relieve the symptoms. This is an example of a patient who recovered completely after relatively delayed (4 months) release of the tarsal tunnel impingement syndrome that developed after lengthening of the tibia.

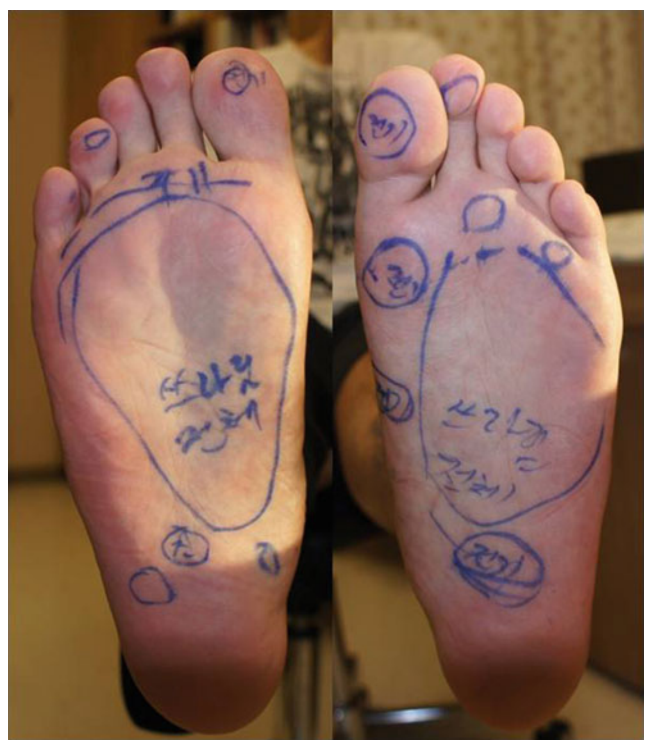

Fig. 1 The patient suffered from severe uncomfortable tingling and burning sensation after acute correction of equinus deformity. Based on the distribution marked by the patient, the medial and lateral plantar branches of the posterior tibial nerve were thought to be involved

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Fig. 2 Orthoradiography showed valgus alignment of ankle joint due to proximal migration of distal fibula and distal migration of fibular head on the right side

1 Brief Clinical History

A 25 year old male underwent bilateral tibial lengthening at an outside clinic, 8 months before visiting our institute. Severe equinus deformity developed after 8 cm of lengthening, and the doctor performed an acute correction of the equinus contracture using a percutaneous triple-cut Achilles tenotomy. After that, severe dysesthesia developed on his soles (Fig. 1). He came complaining of persisting symptoms lasting for 4 months.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

Compression neuropathy of the medial and lateral plantar branches of the posterior tibial nerve at the tarsal tunnel (bilateral).

4 Treatment Strategy

Distribution of the painful area marked by the patient indicated the involvements of both the medial and lateral plantar branches of the posterior tibial nerve. Electromyography and nerve conduction velocity tests revealed "axonal neuropathy of the posterior tibial nerve." Though there was a possibility that the posterior tibial nerve was damaged directly from triple-cut tenotomy, we decided to try to decompress the tarsal tunnel.

5 Basic Principles

The posterior tibial nerve can be impinged from acute correction of the ankle. Acute correction of plantar flexion to dorsiflexion and varus to valgus causes stretch of the nerve which is positioned in the concavity of the deformity. Therapeutic decompression is indicated if there is motor or sensory compromise. If an impingement is suspected, timely therapeutic decompression is recommended for the faster and most predictable recovery.

Gradual correction of deformity is less likely to lead to nerve injury. In this case, the nerve injury was likely related to a "double-crush" phenomenon. The lengthening of the tibia likely caused a subclinical nerve abnormality. Then the acute correction of equinus was the second assault that led to full-blown clinical symptoms of neuropraxia.

Fig. 3 Linear incision 6 cm in length is made along the course of the posterior tibial nerve between the medial malleoli and Achilles tendon

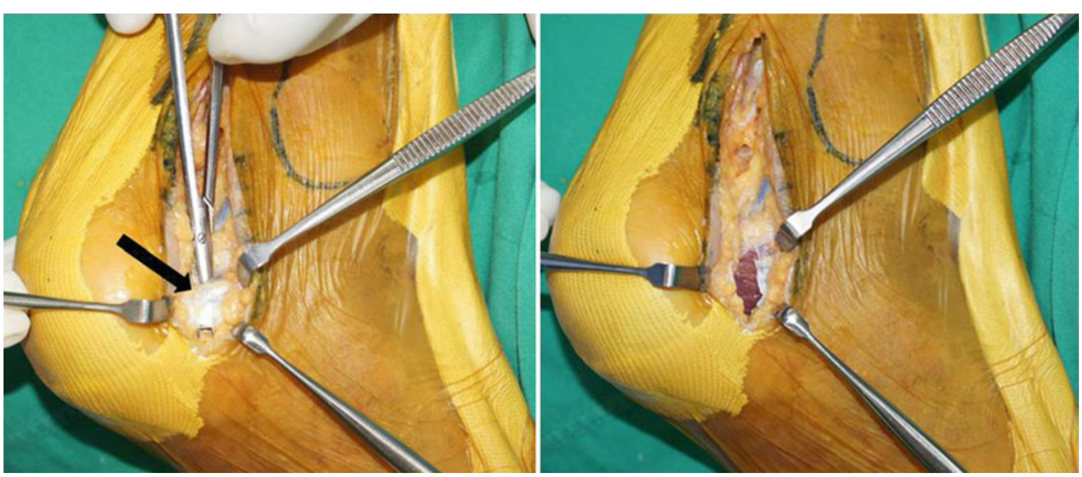

Fig. 4 Superficial fascia of the abductor hallucis muscle (*arrow*) is identified and released being careful not to damage the muscle

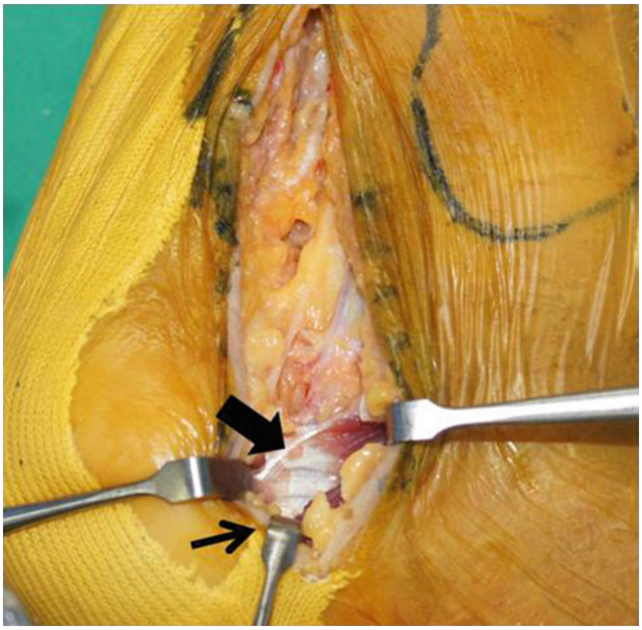

Fig. 5 While retracting the abductor hallucis muscle distally (*thin arrow*), the deep fascia (*thick arrow*) is identified and released being careful not to damage the nerve deep to the fascia

Fig. 6 Anchoring fascia (*arrow*) located between the medial and lateral branches of the posterior tibial nerve is released

Fig. 7 Complete decompression is confirmed

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, and 8.

7 Technical Pearls

The use of loupe magnification is helpful not to injure the small branches of the nerve during decompression.

8 Outcome Clinical Photos and Radiographs

See Fig. 9.

9 Avoiding and Managing Problems

Equinus is inevitable to a certain degree during lengthening of the tibia, but acute correction of severe equinus deformity should be avoided. If an impingement is

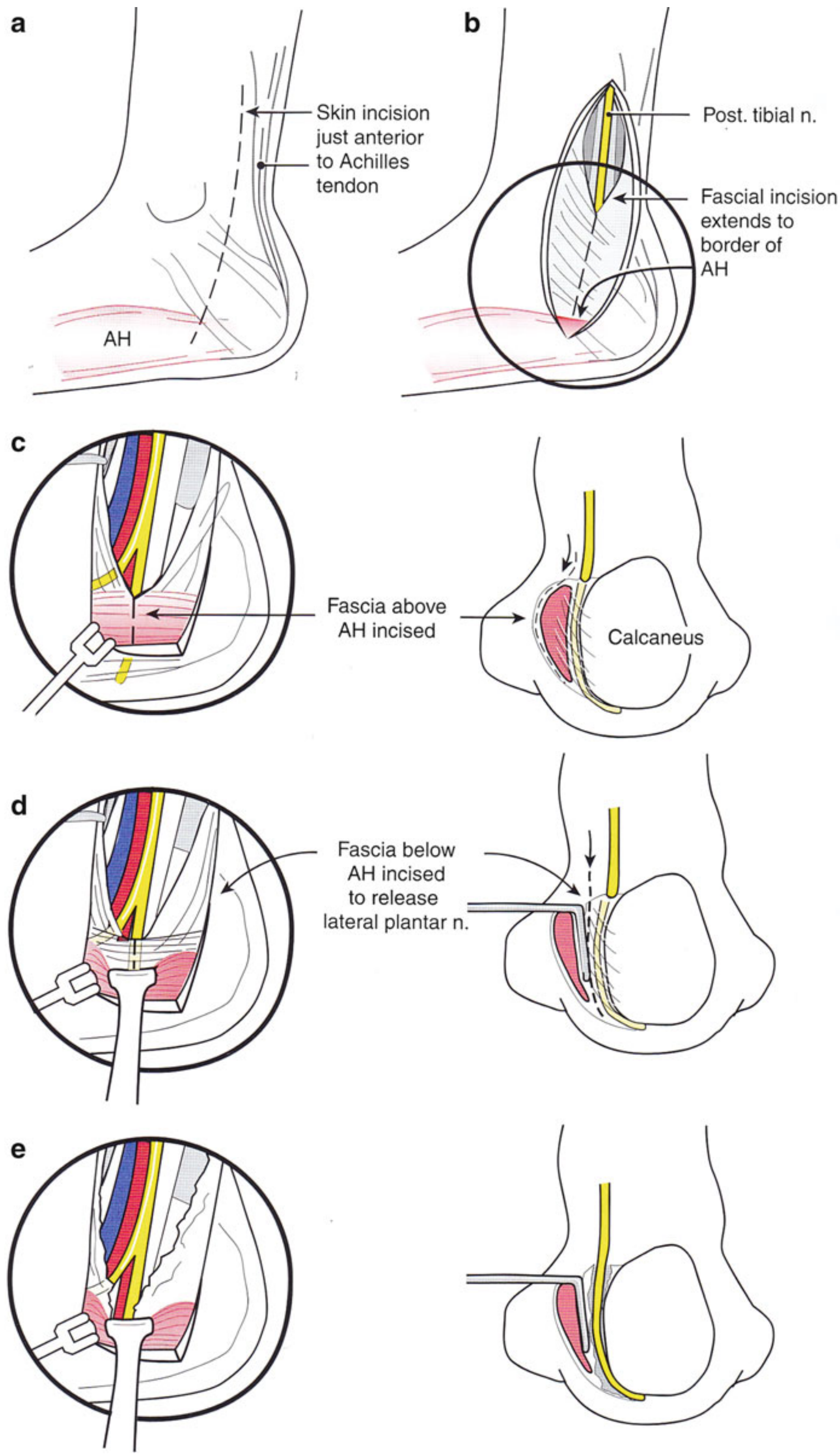

Fig. 8 Schematic diagram reviewing surgical steps of posterior tibial nerve decompression and relevant anatomy (Paley 2002, Figs. 10–18)

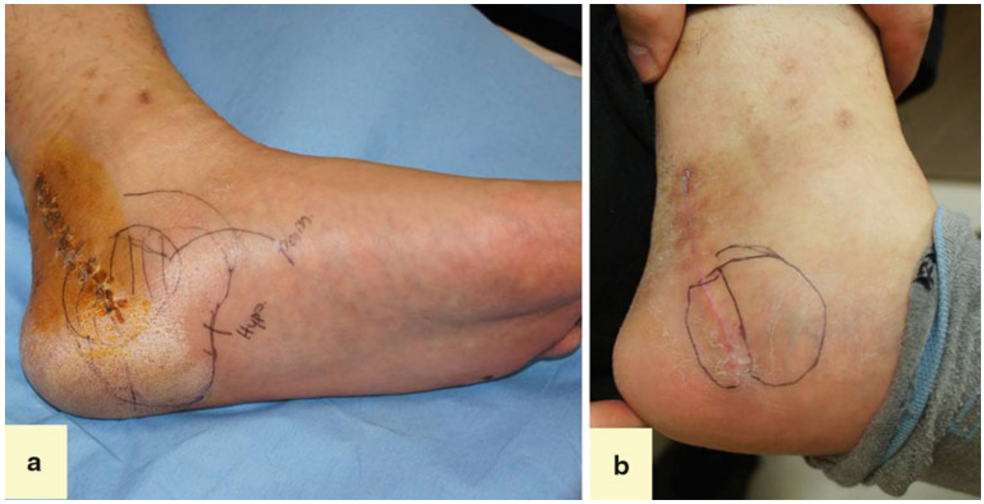

Fig. 9 Most of sensory symptoms at the sole of the foot resolved 1 month after nerve release (**a**). Hypoesthesia around the incision (**b**) remained for 6 months after surgery and then resolved

suspected, earlier therapeutic decompression is recommended for the faster recovery.

10 See Also in Vol. 1

Case 111: Severe Equino-Varus Foot and Ankle Deformity from Compartment Syndrome. TSF to Correct Deformities followed by Tendon Transfer
Case 112: Severe Equinus Secondary to Linear Scleroderma Treated by Gradual Deformity Correction via Circular External Fixation Without Osteotomies

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Part IV

Adult Deformity: Multiple Segment Deformity

Case 23: Complex Deformity After PFFD Treatment – Multifocal, Gradual Correction on Femur and Tibia with Monolateral External Fixation

Peter Helmut Thaller and Sami Sokucu

Contents

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Abstract

Many complications may be encountered during or following deformity correction and limb lengthening surgeries. Integrated techniques were used to decrease the patient's time wearing the external fixator. Preoperative analysis and planning is necessary to determine the osteotomy level, to simulate the deformity correction and simultaneous lengthening, and to choose the type of implant for stabilization. This chapter presents a complex, gradual, multi-level deformity correction, and limb lengthening for a 23 year old female having complex deformity and LLD after previous proximal femoral focal deficiency (PFFD) treatment.

1 Brief Clinical History

A 23 year old female was admitted with deformity complaints of her left lower extremity with a previous diagnosis of left proximal femoral focal deficiency (PFFD). This had been classified according to Aitken classification as type A (Aitken 1969). Initially, with a 12 cm lower limb length discrepancy (LLD) of the left side, she achieved 4 cm of femoral lengthening in 1996 and 8 cm of tibia lengthening in 2006 with an external fixator. Clinical examination at this time indicated severe valgus deformity, 2 cm of left LLD, rotational deformity of the femur (rotational profile was 60° internal and 30° external rotation in left hip joint), restricted flexion of the left knee joint (range of motion was 100° flexion and 0° extension), and moderate knee instability. Her joint lines of both knees were not symmetrical. Additionally, she was unable to walk long distances without a long leg brace support (Fig. 1a, b).

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Fig. 1 (**a**, **b**) Clinical photographs with and without brace

LLD was measured on a long-standing radiograph (LSR) according to our standard (Thaller et al. 2005), and deformity analysis of the patient was performed by the method defined by (Kucukkaya et al. 2013). The left femur was 36 mm shorter and the left tibia was 17 mm longer compared to the right side. Her actual LLD was 19 mm. She also had 67 mm lateral mechanical axis deviation on LSR. Joint orientation angles of the left lower limb were aMPFA: 84, mLPFA: 99, aLDFA: 104, mLDFA: 101, MPTA: 119, and LDTA: 79 (Fig. 2).

Preoperative planning was performed by using CorelDRAW Graphic Suite X4 software (Fig. 3).

2 Preoperative Clinical Photos and Radiographs

See Figs. 1a, b, 2, and 3.

3 Preoperative Problem List

- Femoral deformity – varus deformity and rotational deformity
- Tibial multi-apical valgus deformity (2 CORAs)
- Risk of peroneal nerve injury with correction of valgus
- Need for correction of left LLD
- Unstable left knee joint and need for brace support

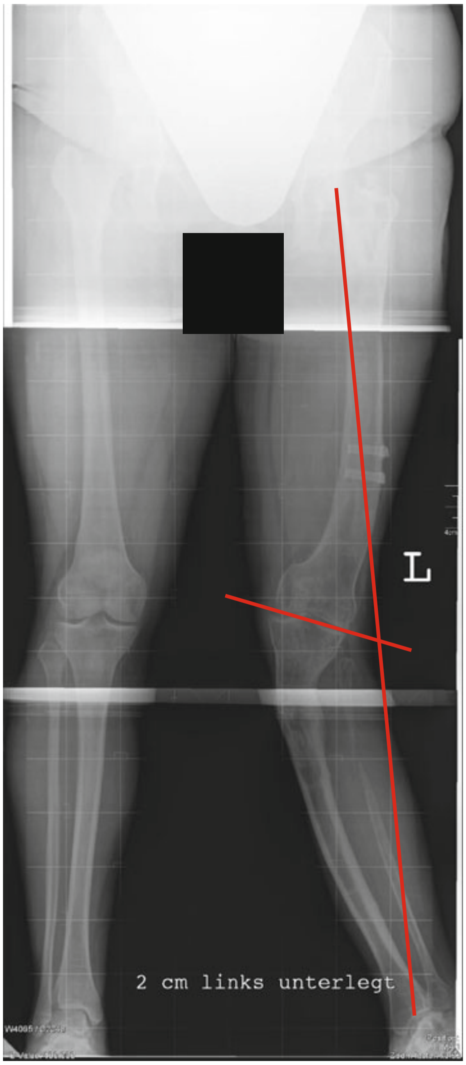
4 Treatment Strategy

- For the femur:
  Valgus osteotomy of distal femur
  Torsional correction at the osteotomy site
  Rigid reaming
  Retrograde nailing
  Treatment of the shortening with lengthening over nail (LON) technique
  Interlocking of the nail and external fixator removal when the distraction is completed

- For the tibia:
  Fibular osteotomy
  Closing wedge osteotomy at distal CORA of the tibia for correction of valgus deformity followed by acute correction and plate fixation
  Closing wedge osteotomy at proximal CORA of the tibia for correction of valgus deformity followed by gradual correction by anterior T-clamp LRS (acute correction would be dangerous to the peroneal nerve)
  Insertion of plate and external fixator removal after the gradual correction of valgus is complete (done at same time as the insertion of locking screws into the femoral rod)

5 Basic Principles

PFFD is a rare congenital anomaly which may be encountered bilaterally in 50 % of the cases. The main problem is developmental defect or atrophy of the primary ossification center. Fibular hemimelia, ACL deficiency, coxa vara, and joint contractures of the knee may be the accompanying orthopedic problems of PFFD. Lower limb



Analyse der LAIS

LAIS mit ...... mm □ rechts □ links	rechtes Bein	linkes Bein
Oberschenkel [mm]	457	421
Unterschenkel [mm]	361	378
Gesamtlänge [mm]	822	792
Mech.Achsdeviation in Höhe KG (mm, M=med, L=lat)	6 L	67 L
Caput-Collum-Diaphysenwinkel CCD (124° - 136°)	127	126
med, prox Femur-Tangenten-Winkel aMPFW (80°-89°)	80	84
lat, prox Femur-Tangenten-Winkel mLPFW (85°-95°)	93	99
anat, lat, dist Femur-Gelenk-Winkel aLDFW (79°-83°)	84	104
mech, lat, dist Femur-Gelenk-Winkel mLDFW (85°-90°)	90	101
med, prox,Tibia-Gelenk-Winkel MPTW (85°-90°)	93	119
lat, dist Tibia-Gelenk-Winkel LDTW (86°-92°)	94	79
anat, post, dist Femur-Gelenk-Winkel aPDFW (79°-87°)		
anat, post, prox Tibia-Gelenk-Winkel aPPTW (77°-87°)		
anat, ant, dist Tibia-Gelenk-Winkel aADTW (78°-82°)		

Beinlängendifferenz

Differenz Oberschenkel (mm)	-36 L
Differenz Unterschenkel (mm)	+17
Gesamtdifferenz (mm)	-30 L

Fig. 2 Preoperative long-standing radiograph (LSR)

lengthening operations are commonly performed on Aitken A and B group PFFD patients with marked LLD. LON is a method in lower limb extremity lengthening where lengthening and deformity correction can be synchronously accomplished. The use of blocking screws helps maintain stability and accuracy during LON when used for deformity correction and lengthening in the distal femur (Kucukkaya et al. 2013). Detailed imaging, analysis, and planning are essential prior to meticulous surgery. The end point first (EPF) planning method is useful for analysis of the deformity, to determine the osteotomy level, and to simulate lengthening on the accompanying template (Fig. 3).

6 Images During Treatment

See Figs. 4a, b, and 5a, b.

Fig. 3 Meticulous preoperative deformity and lengthening planning with end point first (EPF) method. There is one CORA in the femur and two CORAs in the tibia

7 Technical Pearls

- The operation was performed with the patient in supine position on a radiolucent operating table by the aid of X-ray grid.
- Femoral deformity was corrected with drill bit osteotomy via stab incision and LON method.
- Prior to femoral retrograde nail application, intramedullary reaming was performed approximately 0.5–1 mm larger than the diameter of nail by the aid of femoral canal rigid reamers. Blocking screws were used to improve the distal metaphyseal stability of the nail in both fragments.
- Adequate correction of the femoral deformity was controlled by using the X-ray grid.
- Medial closing wedge osteotomy via medial incision was performed to correct the valgus deformity of tibia deformity which has two individual CORAs. Following acute correction of the distal deformity, lateral plating was accomplished with a minimal incision plating osteosynthesis (MIPO) technique. The proximal tibia deformity was gradually corrected with an anteriorly placed T-clamp to avoid peroneal nerve injury.

8 Outcome Clinical Photos and Radiographs

See Fig. 6a–c.

9 Avoiding and Managing Problems

- To avoid problems during surgery, meticulous preoperative analysis and planning is essential for all deformity correction and lengthening procedures, especially in complex deformities cases.
- To achieve proper alignment after gradual lengthening and deformity correction, the procedure should be simulated preoperatively (EPF method).
- To avoid under- or overcorrection of deformity, an X-ray grid should be used during the procedure.
- To avoid problems of impingement between the IM nail and the bone, including a jammed nail and/or inadequate correction of deformity, we suggest reaming with rigid straight millers.
- To provide better stability of the nail, blocking screws should be used to narrow the medullary canal. This is especially important for simultaneous correction of deformity and lengthening in the distal femoral and proximal tibia metaphyseal regions.

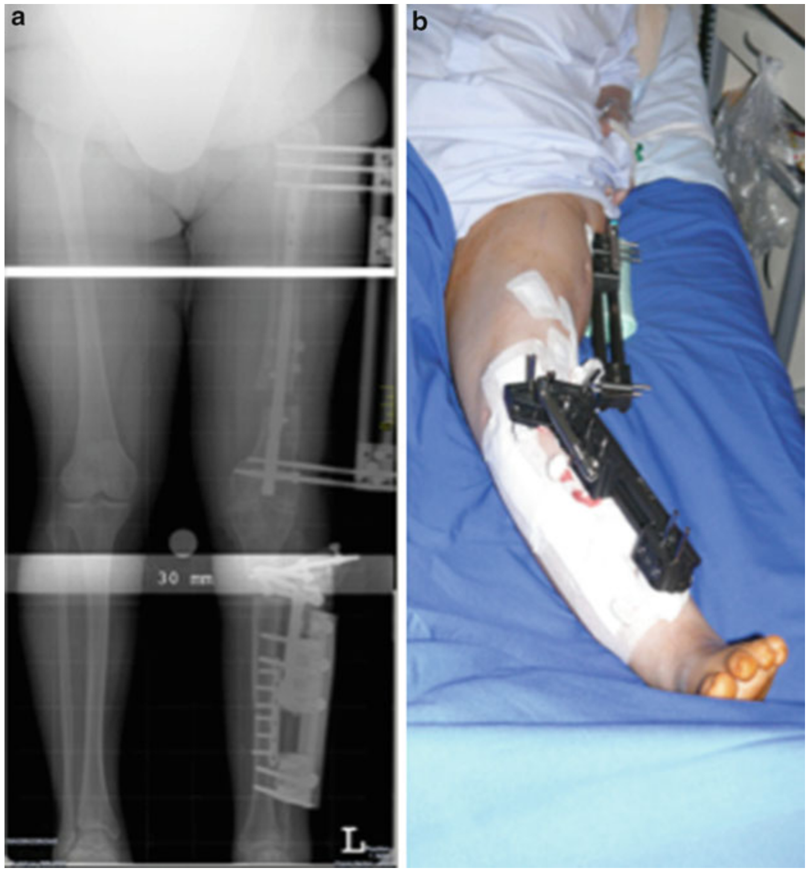


Fig. 4 (**a**, **b**) Clinical photos during lengthening and deformity correction. Note the femoral external fixator is being used for distraction and lengthening over the femoral IM nail. The tibial external fixator is being used to gradually correct valgus at the proximal osteotomy. The mid-diaphyseal osteotomy of the tibia was acutely stabilized with a lateral plate

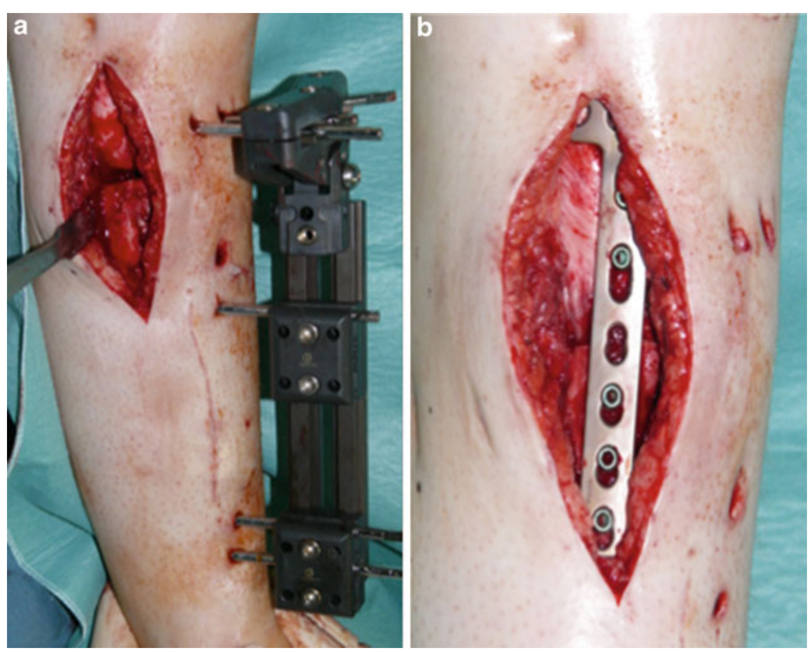


Fig. 5 (**a**, **b**) Deformity correction in the proximal tibia followed by plating and external fixator removal. After deformity correction, the plate was inserted through a medial approach

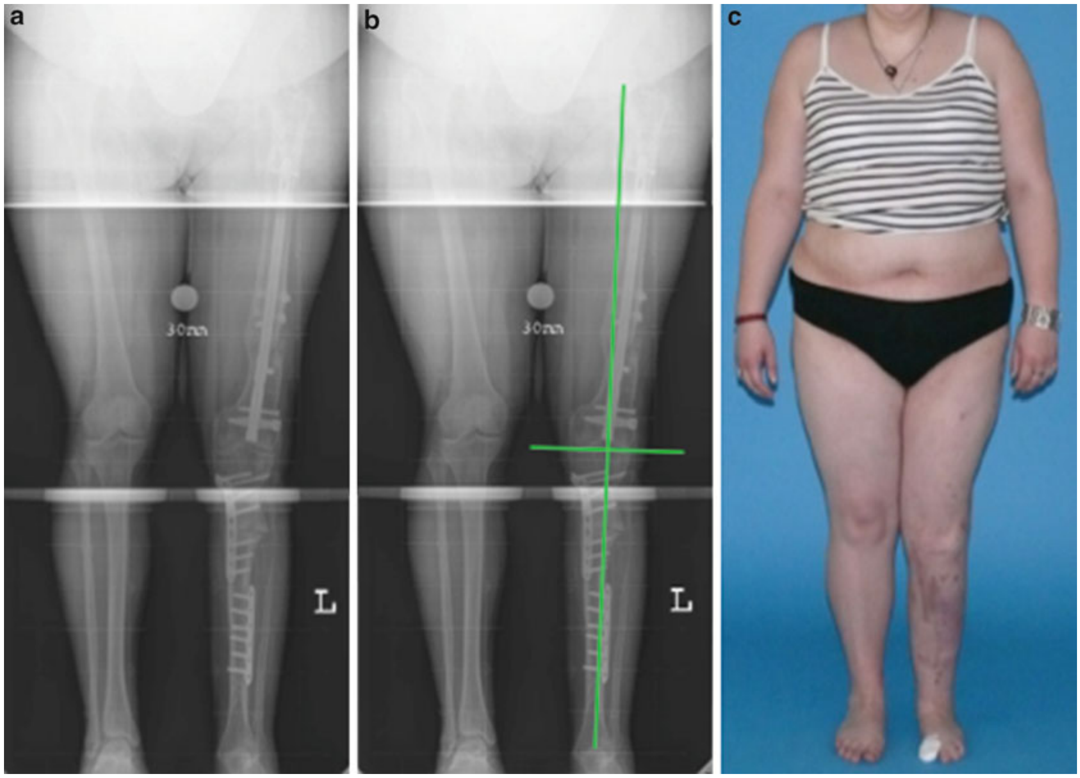


Fig. 6 (**a**, **b**) LSR after consolidation showing correction of deformity and LLD. (**c**) Clinical view

10 Cross-References

- ▶ Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique
- ▶ Case 35: Acute Correction with Marrow (Intramedullary Canal) Narrowing Technique and Subsequent Lengthening Over Nail for the Femoral Shortening Combined with a Deformity

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Case 24: Complex Four Segment Multiapical Lower Extremity Deformities in Rickets Treated with Fixator Assisted Intramedullary Nailing

Mehmet Kocaoglu and F. Erkal Bilen

Contents

Abstract

This is a case of severe multiapical deformity in all four segments (the bilateral femur and tibia) caused by rickets. Furthermore, the deformities were oblique plane (frontal and sagittal) as well as rotational in the axial plane. In this patient with metabolic bone disease where there was a risk of recurrence, acute deformity corrections and stabilization with IM nails were used. The case required meticulous preoperative planning, the use of intraoperative external fixators (fixator-assisted nailing (FAN)), multiple osteotomies, and prophylactic peroneal nerve release and leg fasciotomies.

1 Brief Clinical History

A 33 year old female patient presented to our clinic with multiple lower extremity deformities, limb length discrepancy, and gait abnormality. She suffered from an impairment in her ability to engage in activities of daily living, knee pain, and poor aesthetic appearance (Fig. 1a–c).

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

(a) Multiple-level bone deformities (multiplanar including three planes: frontal, sagittal, and axial) (Fig. 2a–d).
(b) Severe genu valgum on the right and genu varum on the left side (windswept deformity).

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Fig. 1 (**a**) Clinical picture (*frontal* view) showing the windswept deformity. (**b**) Clinical picture (*rear* view) showing the windswept deformity. (**c**) Clinical picture (*side* view) showing the windswept deformity

(c) Limb length discrepancy of 4 cm (measured by the pelvic tilt on a standing X-ray of the pelvis).
(d) Severe deformities prevented both lower extremities to fit into a single orthoroentgenogram; thus, we obtained separate X-rays of all four bone segments of the lower extremities.
(e) The deformities were most profound in the sagittal plane (Fig. 2c).
(f) Flexion and adduction contracture of the left hip joint.

4 Treatment Strategy

Although we normally prefer to correct the deformities of all four segments during the same surgical session, in this complex case, we decided on a staged approach. The plan was to address the right side first (Fig. 3).

(a) Right lower extremity:
  (i) Prophylactic peroneal nerve release prior to correction of the excessive genu valgum deformity
  (ii) Deformity correction of the femur with retrograde IM nailing (fixator-assisted nailing, FAN)
  (iii) Deformity correction of the tibia with antegrade IM nailing (fixator-assisted nailing, FAN)
(b) Left lower extremity:
  (i) Deformity correction of the femur with retrograde IM nailing (fixator-assisted nailing, FAN)
  (ii) Deformity correction of the tibia with antegrade IM nailing (fixator-assisted nailing, FAN)
  (iii) Adductor and flexor muscle release of the hip

5 Basic Principles

(a) Two pairs of Schanz pins are inserted proximally and distally in the femur (perpendicular to the anatomic axis). The pins should be in the posterior aspect of the femur on the sagittal plane to leave enough space for the nail.
(b) Angular correction is performed after achieving the desired amount of translation either manually or with the use of the monolateral fixator (the authors prefer the

Fig. 2 (**a**) AP X-ray showing the excessive right genu valgum deformity. (**b**) AP X-ray of the right femur showing the long bowing varus deformity. (**c**) Lateral view X-ray of the right femur showing the excessive apex anterior deformity. (**d**) Lateral view X-ray of the left femur showing apex anterior and rotational deformity (Note that the distal femoral part is in AP position due to excessive rotational deformity)

EBI/Biomet (Parsippany, NJ) monorail system with swivel clamp).

(c) Osteotomies in the long bones can be executed through limited incisions percutaneously either by the Gigli saw technique or by the multiple drill hole technique.

(d) The placement of the intramedullary nail also can be performed through a 2-cm transverse incision over the patellar ligament. The reason behind the choice for a transverse incision is that it leads to less scarring, improving aesthetics (Fig. 4). The paratenon and the patellar ligament, however, are split longitudinally. The same incision can be used for both retrograde femoral and for antegrade tibial nailing procedures.

(e) Before the acute correction of valgus deformities of the knee of $>20°$, prophylactic peroneal nerve release must be performed.

(f) The patient is placed supine on a radiolucent table and checked with fluoroscopy from the hip to the ankle in both planes before sterile preparation (Fig. 5).

(g) With the use of paper tracings, the procedure can be simulated preoperatively, which will enhance the preoperative plan (Fig. 6). Preoperative planning also includes an estimation of the diameter and length of the intramedullary nail to be used as well as the location of the interference screws (“poller,” “blocking”) for each case (Fig. 7).

Fig. 3 Clinical picture following the deformity correction on the *right* side (Note the large increase in limb length with deformity correction)

Fig. 4 Transverse incision over the patellar ligament

(h) The accuracy of correction is checked with intraoperative X-rays (Fig. 8).

(i) Extra custom-made holes for locking screws may be placed in the nails, if necessary.

(j) Interference screws are inserted before reaming, to guide the intramedullary drill as well as to prevent loss of the correction.

(k) Retrograde reaming over a guidewire is performed through a mini incision. The reamings produce an internal grafting effect.

(l) The nail is inserted and locked statically, proximally, and distally.

(m) The external fixator is removed at the end of the surgery, and the nail maintains the correction (Fig. 9a–d).

(n) Prior to tibial correction, the fibula is osteotomized percutaneously.

(o) During tibial correction, two pairs of Schanz pins are inserted proximally (parallel to the joint line) and distally (perpendicular to the anatomic axis) in the tibia (Fig. 10). The pins should be at the posterior aspect of the tibia on the sagittal plane to leave enough space for the nail.

(p) The IM nails also prevent the recurrence of deformity which would otherwise be a significant risk in metabolic bone deformities (Fig. 11a–e).

(q) Disorders of calcium, phosphorus, and magnesium metabolism result in deficient strength and structure of bone tissue. One of the clinical manifestations of this pathology is long bone deformity associated with short stature and abnormal gait. Although there are several types of rickets, the basic pathogenesis is a relative decline in calcium and/or phosphorus, so that it interferes with physeal growth and mineralization of bone matrix. Rickets and renal osteodystrophy are the most common types of metabolic bone diseases. In renal osteodystrophy, glomerular damage in kidneys leads to phosphate retention, and tubular damage causes decreased production of the active form of vitamin D due to the absence of 1-hydroxylase activity.

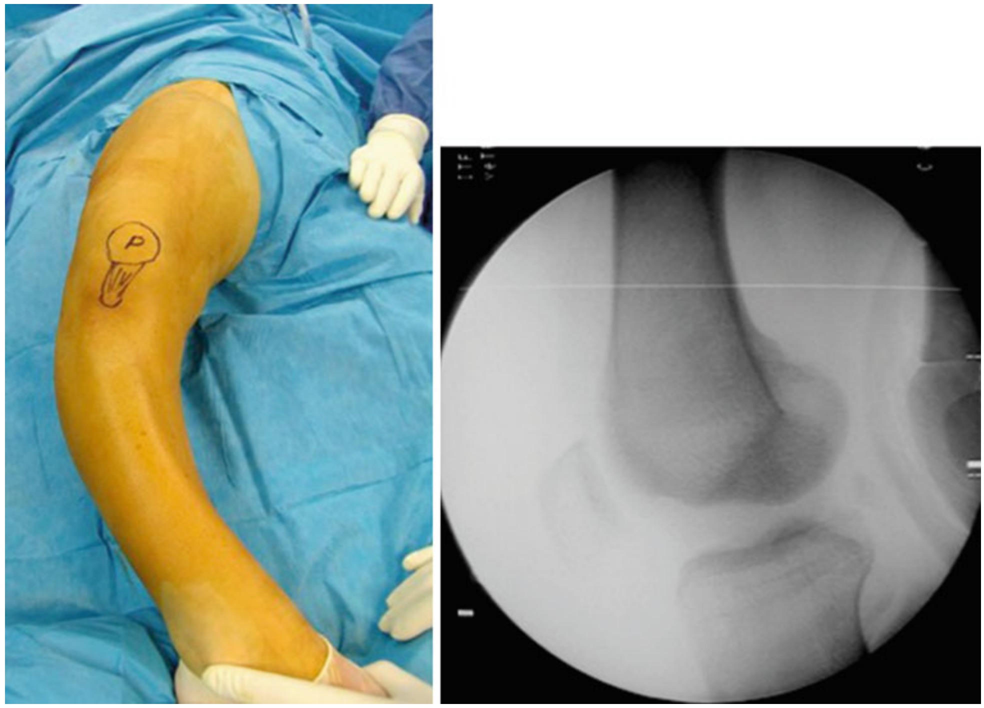

Fig. 5 Preparation and positioning for surgical procedure

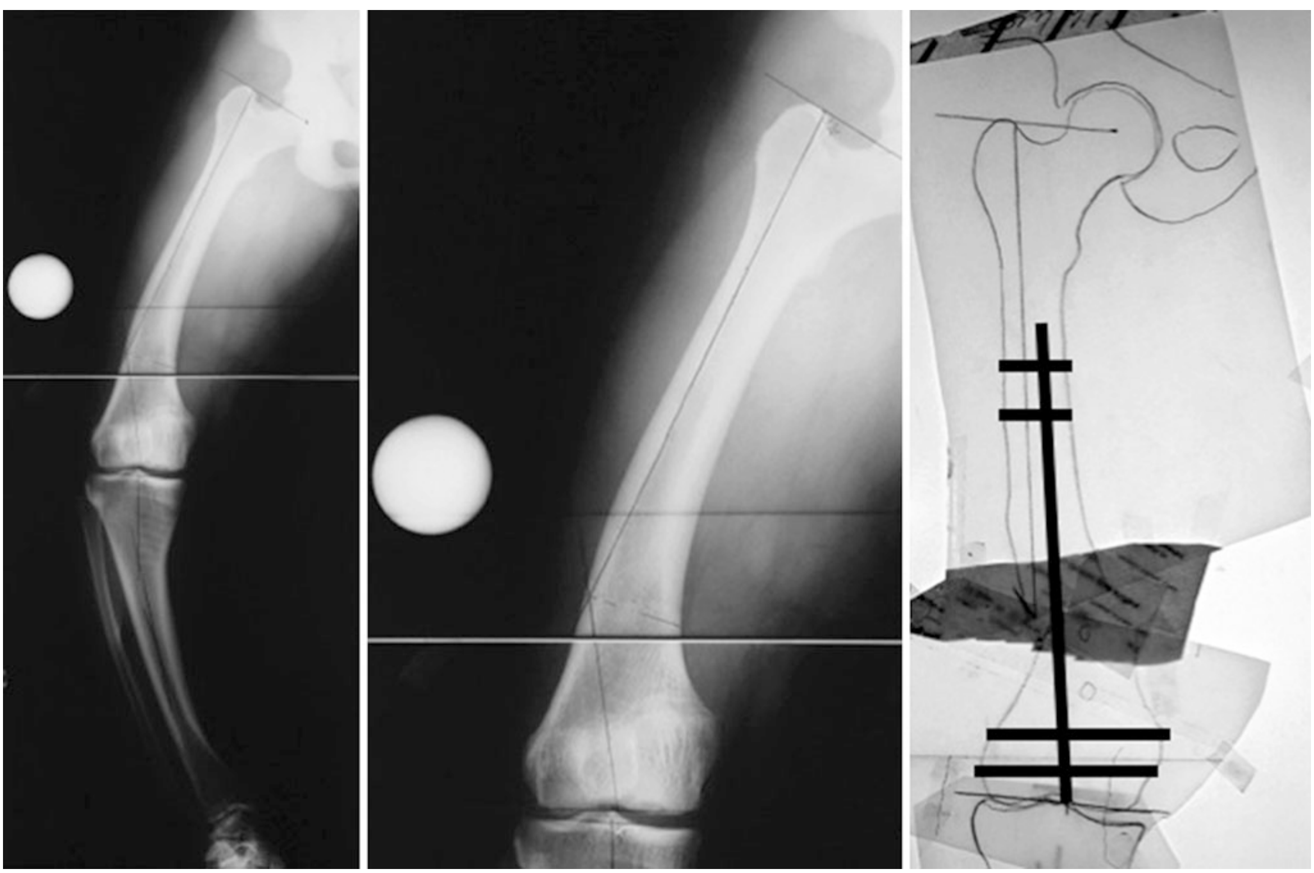

Fig. 6 Preoperative X-rays and paper tracing planning for the right femur

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, 8, 9, and 10.

7 Technical Pearls

(a) Kirschner wires are placed perpendicular to the IM nail (anatomical axis) on both planes (frontal and sagittal).
(b) Minimally invasive percutaneous corticotomy technique should be performed to obtain new bone formation of good quality.
(c) We prefer using regular tibial nails for retrograde femoral nailing because their curve helps correct any sagittal deformity present (Fig. 9a).
(d) Alternatively, the translation may be created by manipulating the Schanz pins as a joystick.

8 Outcome Clinical Photos and Radiographs

See Fig. 11.

9 Avoiding and Managing Problems

- Peroneal nerve palsy is a common complication in cases with severe genu valgum deformity (>15°). Prophylactic peroneal nerve release is required to prevent this complication.
- Excessive reaming and acute varus correction of the tibia may lead to development of compartment syndrome. Thus, postoperative epidural analgesia is not recommended as this may mask the symptoms of compartment syndrome. Prophylactic compartment release with fasciotomy is recommended in cases with severe tibia valga deformities.

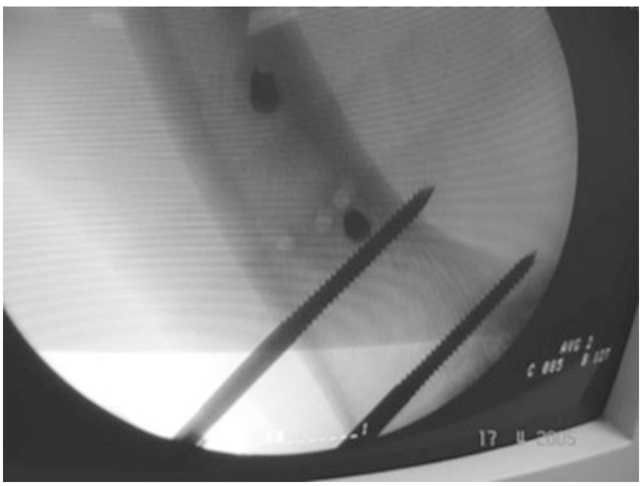

Fig. 7 C-arm view showing the predrilling before the osteotomy and the interference screws

Fig. 8 Manual correction of the deformity is checked with an intraoperative X-ray and stabilized with a temporary intraoperative external fixator

Fig. 9 (**a**) Lateral view X-ray after the right femoral deformity correction and IM nailing. Note the need for second osteotomy in the proximal femur. (**b**) AP view X-ray after the right femoral deformity correction and IM nailing. (**c**) Lateral view X-ray after the right tibial deformity correction and IM nailing. (**d**) AP view X-ray after the right tibial deformity correction and IM nailing

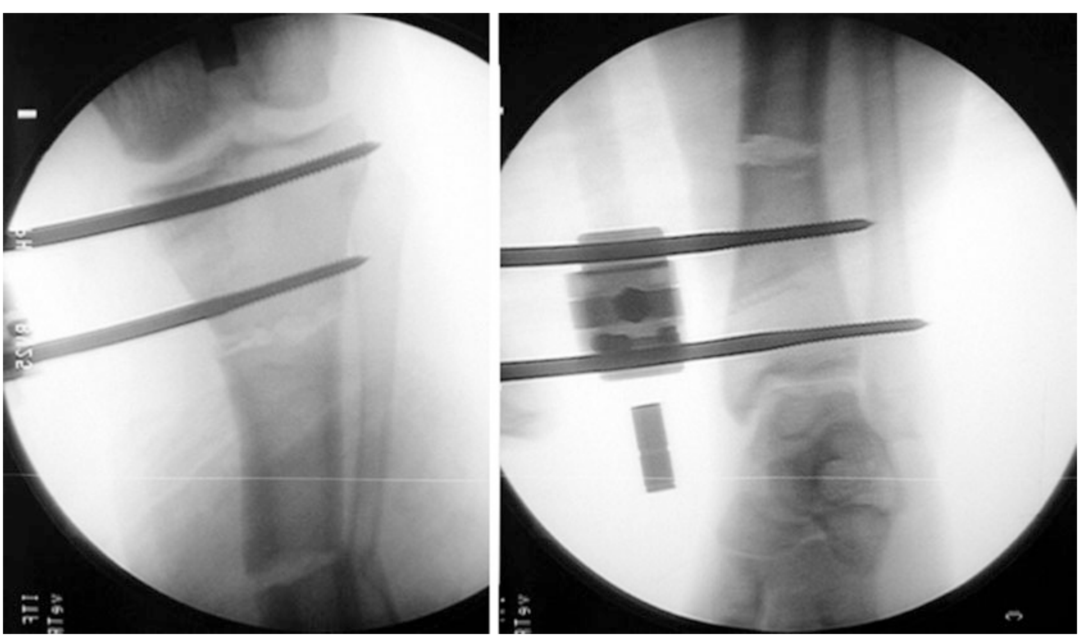

Fig. 10 Intraoperative C-arm views showing the parallel placement of the Schanz screws to the adjacent joint line proximally and distally

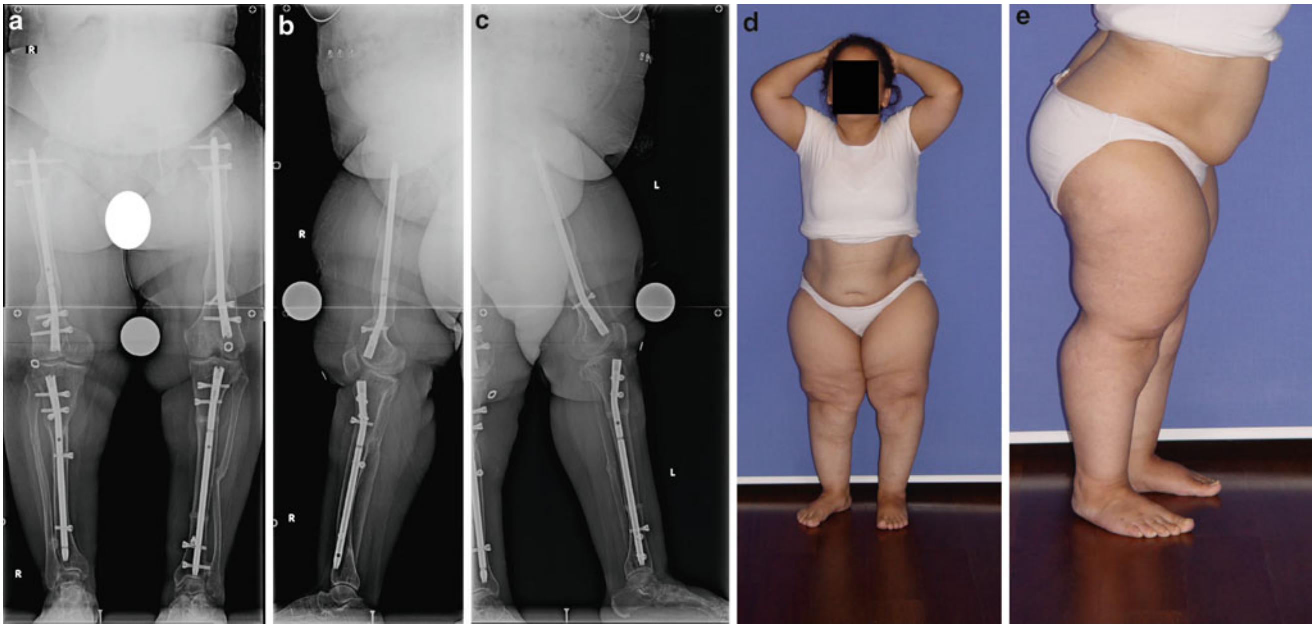

Fig. 11 (**a**) AP orthoroentgenogram at the end of the treatment. (**b**) Side view orthoroentgenogram of the right lower limb. (**c**) Side view orthoroentgenogram of the left lower limb. (**d**) Front view clinical picture at the end of the treatment showing dramatic improvement in lower limb alignment and aesthetic appearance. (**e**) Side view clinical picture at the end of the treatment

10 Cross-References

▶ Case 33: Multiapical Deformity Correction in Bilateral Femur and Tibia in Rickets. LATP Technique to Decrease the Time of External Fixator

11 See Also in Vol. 1

Case 100: Hypophosphatemic Rickets with Bilateral Severe Genu Varum. Retrograde Fixator Assisted Nailing for Femurs and Double Level Tibial Osteotomies with TSF
Case 101: Vitamin D-Resistant Hypophosphatemic Rickets Treated by Double-Level Femoral Osteotomy with Internal Fixation and Proximal Tibial Osteotomy with Gradual Deformity Correction

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Case 25: Correction of Windswept Rotational Deformity with Fixator Assisted Plating Technique

Mitchell Bernstein and S. Robert Rozbruch

Contents

Abstract

This case outlines a stepwise approach to a patient with a complex infrapelvic rotational deformity status post multiple revised total hip arthroplasties. In such patients the physical exam is critical to assess the axial plane deformity. Fixator-assisted plating below well-fixed femoral stems is an excellent option to correct both rotational and coronal plane malalignment. Residual limb length discrepancy can be corrected through classic or integrated fixation methods in the tibia.

1 Brief Clinical History

This is a 54 year old female who presented to our clinic with decreased ability to ambulate, chronic pain, and a limb length discrepancy. The patient was in a high-speed motor vehicle accident at age 17. She suffered proximal femur and pelvic fractures that subsequently required bilateral total hip replacements 1 year post injury. Since her index hip replacements, she has had 11 revision surgeries. Clinical examination revealed difficulty ambulating with abnormal gait pattern, stiff hips, and rotational and angular malalignment of her lower limbs. Her lower extremities point in a direction that is approximately 45° rotated from the direction to that of her pelvis.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, and 5.

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Fig. 1 During physical examination, it was evident that the patient had a complex infrapelvic rotational deformity. In order to ambulate with her patellas facing forward, she rotated her pelvis in the opposite direction

Fig. 2 Patient with a 5 cm block under the right foot, equalizing her pelvic heights, maintenance of her patellas forward (*black circles*), elucidates counterclockwise rotational deformity (*black arrow*) of pelvis

3 Preoperative Problem List

1. Chronic pain
2. Status post bilateral revision component well-fixed total hip arthroplasties
3. Limb length discrepancy, right short 6.2 cm
4. Right lower extremity valgus, femur origin, 11°
5. Left lower extremity valgus, femur origin, 10°
6. Right femur 40° external rotation deformity
7. Left femur 40° internal rotation deformity
8. Right tibia 15° external rotation deformity

4 Treatment Strategy

The femoral valgus and rotational deformities are approached first by staged bilateral distal femur osteotomies. Locking plates are utilized and augmented with cables where screw fixation is comprised because of the long femoral stem on the left side. Once the coronal and axial planes are corrected, a new 51″ hip to ankle X-ray is used to assess limb length discrepancy. Tibial lengthening and residual axial malalignment is then performed. In this case, due to the long femoral stem, lengthening was chosen in the tibia. We accept between 2 and 5 cm in knee height differences. We have not found this to be problematic for ambulation and other activities of daily living. This needs further investigation.

5 Basic Principles

1. The magnitude of the coronal plane deformity can change as the rotational alignment is corrected. Be cognizant of this.
2. Distal femur osteotomy with fixator-assisted plating is a safe and accurate method to achieve coronal and rotational correction.

Fig. 3 Asking the patient to stand with her torso and pelvis facing forward (*black double arrow*) and a 5 cm block under the right foot, the complex rotational deformity is more apparent. External rotation deformity and shortening of the right lower extremity and internal rotation deformity of her left lower extremity

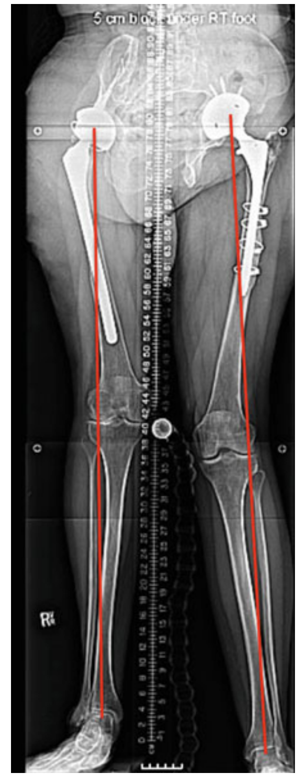

Fig. 4 Preoperative 51″ erect leg hip to ankle X-ray. Patient has 5 cm block under the right foot. *Left*, mechanical axis deviation (*MAD*) = 28 mm lateral; LDFA = 83°; MPTA = 91°; joint line convergence (*JLCA*) = 0°; valgus. *Right*, MAD = 25 mm lateral; LDFA = 84°; MPTA = 90°; JLCA = 2°; valgus. LLD = 62 mm, right side short

3. Osteotomy below well-fixed total hip femoral stems can be utilized rather than femoral stem revision, to correct rotational malalignment.
4. Since her hips are stiff, there is little ability for her to adjust the rotational deformity.

6 Images During Treatment

See Figs. 6, 7, 8, 9, and 10.

7 Technical Pearls

1. The use of a distal femoral locking plate allows for translation to occur, which is mandatory when the osteotomy is not at the CORA (center of rotation of angulation). Locking screws will ensure stability of the osteotomy when the plate is not adherent to the bone.
2. The external fixator application should not obstruct lateral locking plate application; place half-pins anteriorly and medially.
3. The external fixator should match the deformity prior to the osteotomy; this will allow accurate coronal and axial deformity correction.
4. Mark the patella and maintain its position during the case.
5. The TSF allowed gradual lengthening and correction of rotational deformity in the tibia, while the LATN technique allowed for earlier frame removal.

8 Outcome Clinical Photos and Radiographs

See Figs. 11, 12, 13, 14, 15, and 16.

9 Avoiding and Managing Problems

1. In complex rotational deformities, the physical exam is critical to accurately assess the deformity. Asking patients to ambulate, disrobed from the waist down, will elucidate rotational and dynamic deformities that cannot be otherwise assessed with static imaging.

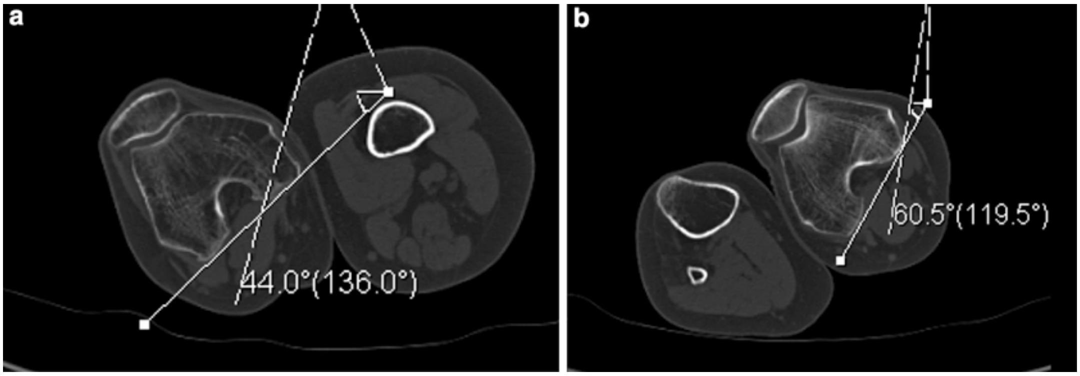

Fig. 5 (**a**, **b**) CT rotational profile of bilateral lower extremities was obtained preoperatively. Calculations demonstrated 40° of external rotation and 40° of internal rotation of the right and left femurs, respectively. In addition, right tibia 15° external rotation

Fig. 6 External fixator half-pins applied anteriorly and medially. Proximal half-pin (*yellow arrow*) placed in neutral rotation

Fig. 7 Maintaining the limb in neutral rotation (patella centered), the distal segment is internally rotated the magnitude of the deformity (*yellow arrow*). External fixator was secured once correction was achieved, prior to plate placement

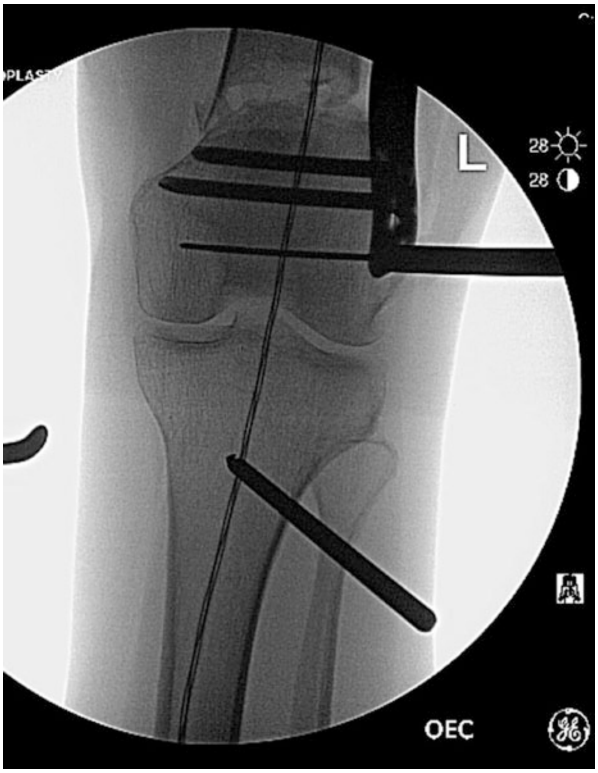

Fig. 8 Bovie cord from center of the femoral head to center of ankle can accurately assess intraoperative mechanical axis alignment

Fig. 9 Clinical photograph post-bilateral distal femoral osteotomy to correct rotation and valgus alignment

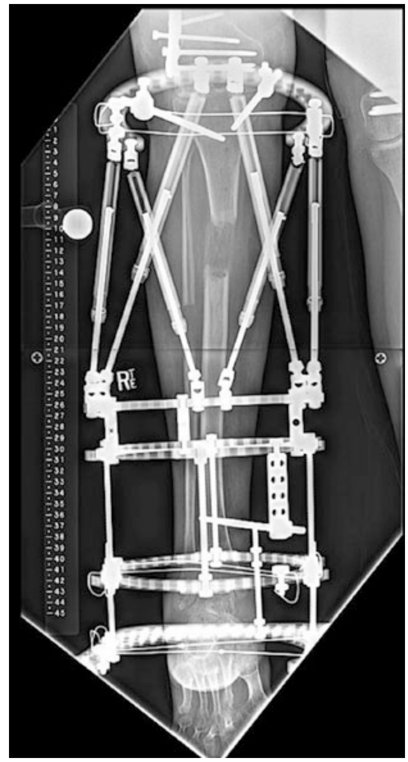

Fig. 10 Patient returned to the operating room for lengthening of tibia and correction of external rotation deformity with Taylor Spatial Frame using the lengthening and then nailing (*LATN*) technique

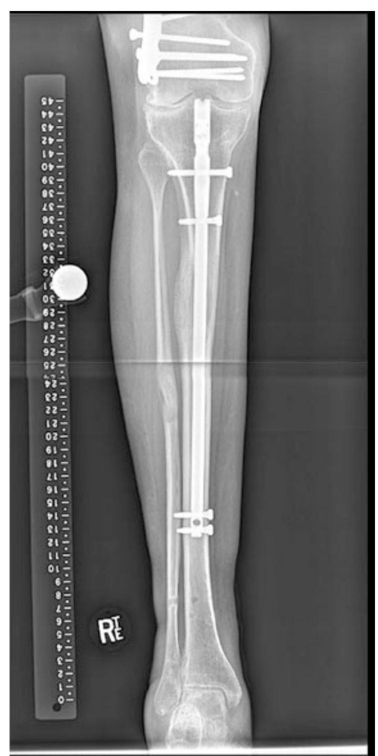

Fig. 11 AP X-ray of right tibia. Patient had lengthening with the Taylor Spatial Frame and then insertion of IM nail (*LATN*)

Fig. 12 AP X-ray of right distal femur rotational and valgus-correcting osteotomy

Fig. 13 AP X-ray of left distal femur rotational and valgus-correcting osteotomy

Fig. 14 Final standing clinical photo. Note the restoration of mechanical axis alignment and limb length discrepancy

Fig. 15 Final standing clinical photo. Patient ambulation much improved

Fig. 16 Final standing sagittal alignment

2. A staged approach is best with combined limb length discrepancies and rotational deformities. A new 51″ hip to ankle X-ray after stage one allows for modification, if necessary, of original planned procedures.

10 Cross-References

► Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique

References and Suggested Reading

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Case 26: Correction of Valgus-Torsion Deformity of the Femur and Varustorsion Deformity of the Lower Leg Accompanied with LLD

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Contents

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Abstract

This is a case of operative treatment of complex multiplanar femur and tibia deformities done in a staged fashion. We performed gradual correction via multiple computer-assisted hexapod – Ortho-SUV frames. Knee joint stiffness that developed during the correction of the femur, was treated with an additional Ortho-SUV Frame.

1 Brief Clinical History

This is a 20 year old female who complains of the right lower limb deformity and knee pain. The etiology was congenital. Eight years earlier she underwent femoral and tibial osteotomies around the knee.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

(a) Right femur valgus, procurvatum (apex anterior) and torsional deformity (internal rotation) accompanied by shortening of 2–3 cm
(b) Right lower leg varus and torsional deformity (external rotation) accompanied with shortening 1 cm. Distal tibial procurvatum deformity.
(c) Gonarthrosis II

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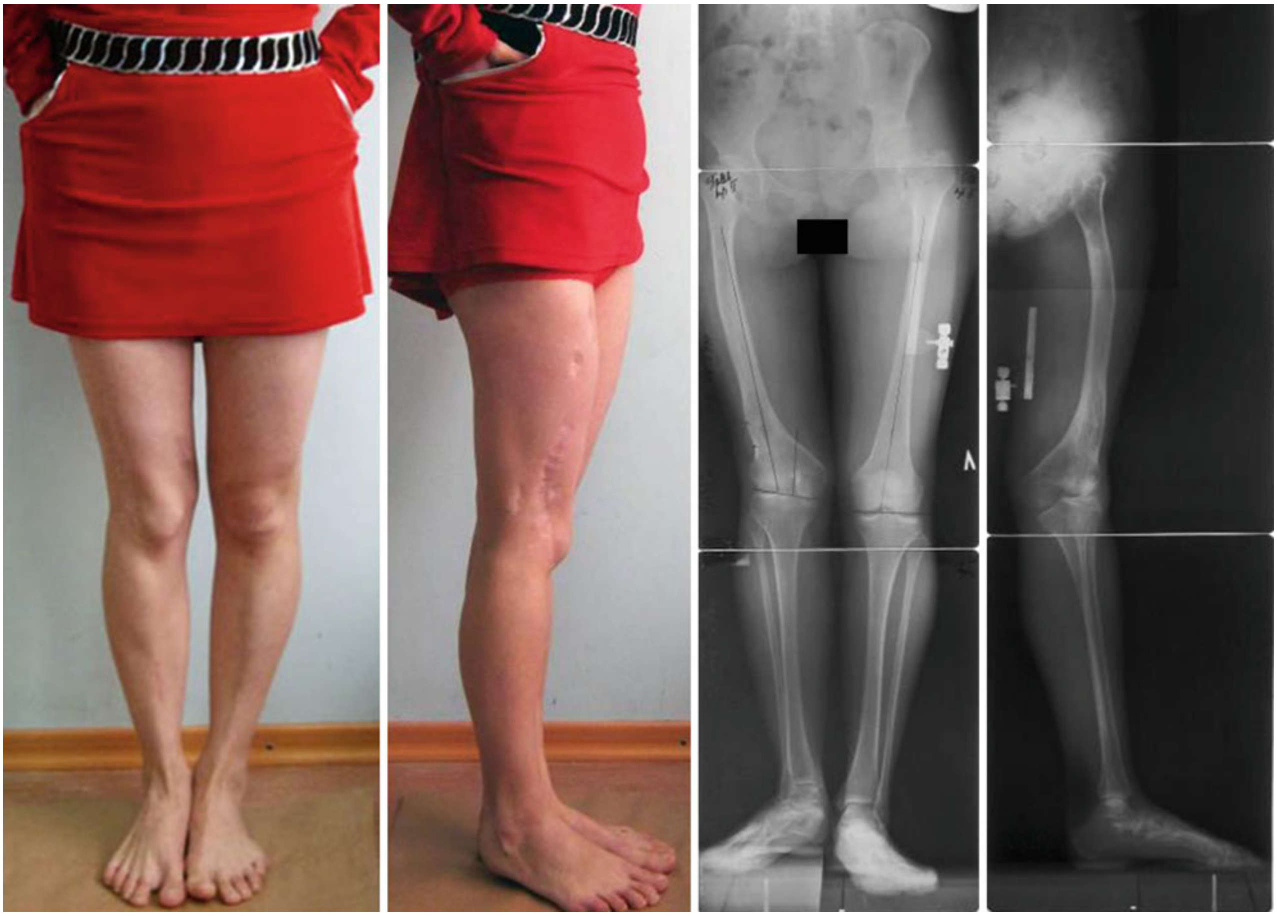


Fig. 1 Right MAD = 19 mm lateral, mLDFA = 71°., MPTA = 81°., JLCA = 4°. varus, LDTA = 95°., femur: upper third varus deformity 17°. & flexion deformity 17°., distal third valgus deformity 18°. & medial translation 14 mm, AVd = 64°., RVd = 51°. Left MAD = 6 mm medial, mLDFA = 89°., MPTA = 87°., JLCA = 1°. varus, LDTA = 88°., AVs = 31°., RVs = 30°. LLD = 3 cm. ***AVd** = **anteversion dextra** (**right side**), **anteversion of femoral neck. RVd** = **retroversion dextra** (**right side**), **external rotation of the ankle relative to the knee. AVs** = **anteversion sinistra** (**left side**), **anteversion of femoral neck. RVs** = **retroversion sinistra** (**left side**), **external rotation of the ankle relative to the knee***

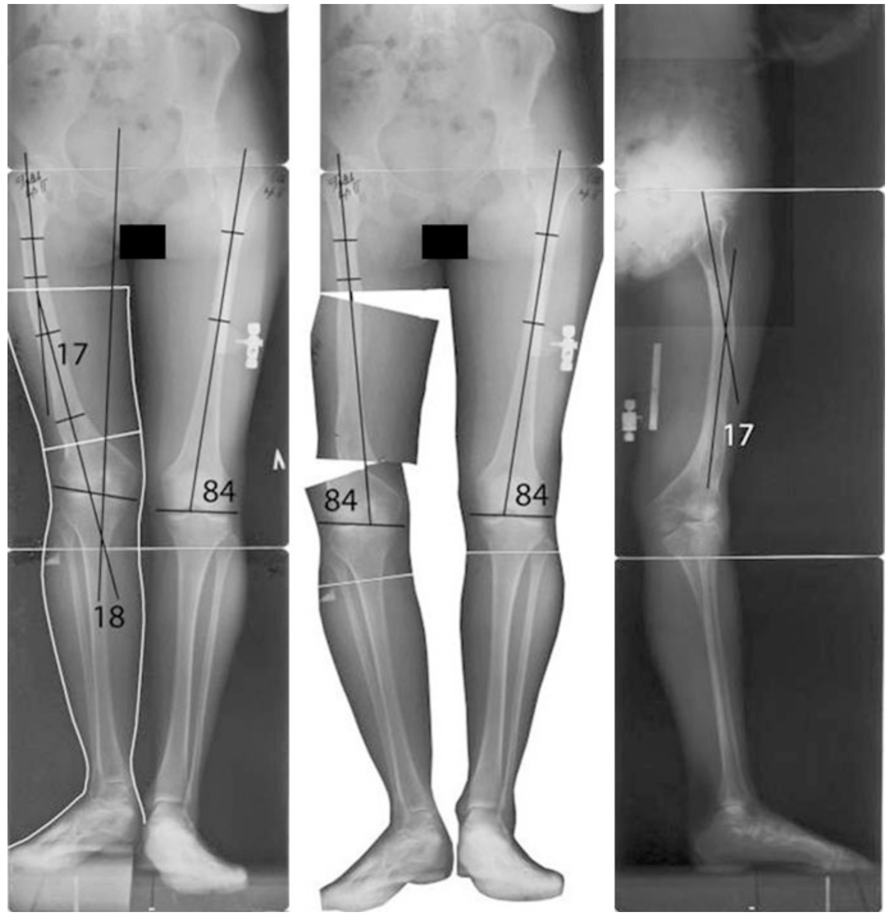
4 Treatment Strategy

(a) Two-level femur osteotomy with gradual deformity correction. Proximal osteotomy will correct varus, procurvatum, and internal rotation; distal osteotomy will correct valgus.
(b) Two-level tibia and fibula osteotomy with gradual deformity correction. Proximal osteotomy will correct varus and recurvatum; distal osteotomy will correct procurvatum and varus. External rotation is corrected through both osteotomies.
(c) Lengthen small amounts through each osteotomy to correct LLD.

5 Basic Principles

(a) As both the femur and the lower leg have deformity, staged correction should be made of both segments: first the femur and then the lower leg. Presence of two CORAs on each segment leads us to the use of two osteotomies.
(b) As one of component of the deformity is shortening, it is best to accomplish this gradually with external fixation.
(c) Application of the software-based hexapod allows us to address all components of deformity with high accuracy.
(d) Full lower limb alignment will improve the biomechanics of the knee joint and will delay the development of gonarthrosis.

Fig. 2 Preoperative planning of the femur deformity correction. Two-level osteotomy: proximal osteotomy will correct varus, procurvatum, and internal rotation; distal osteotomy will correct valgus



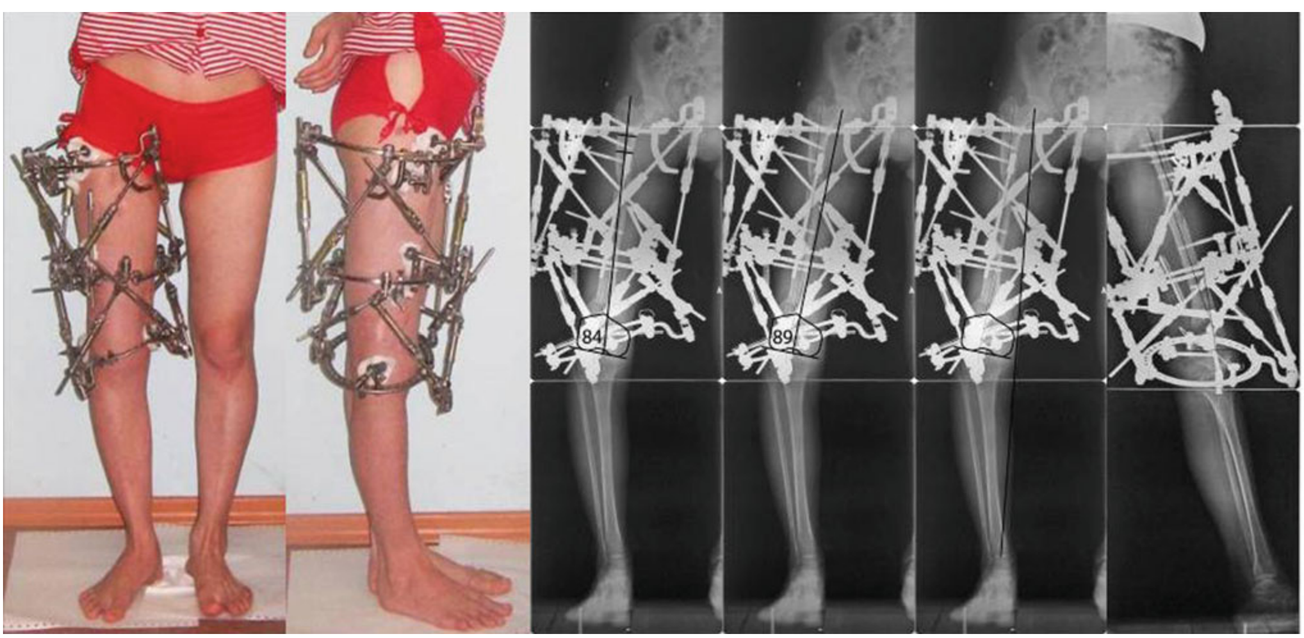


Fig. 3 Photos and long films after the femur deformity correction by means of two computer-assisted Ortho-SUV Frames

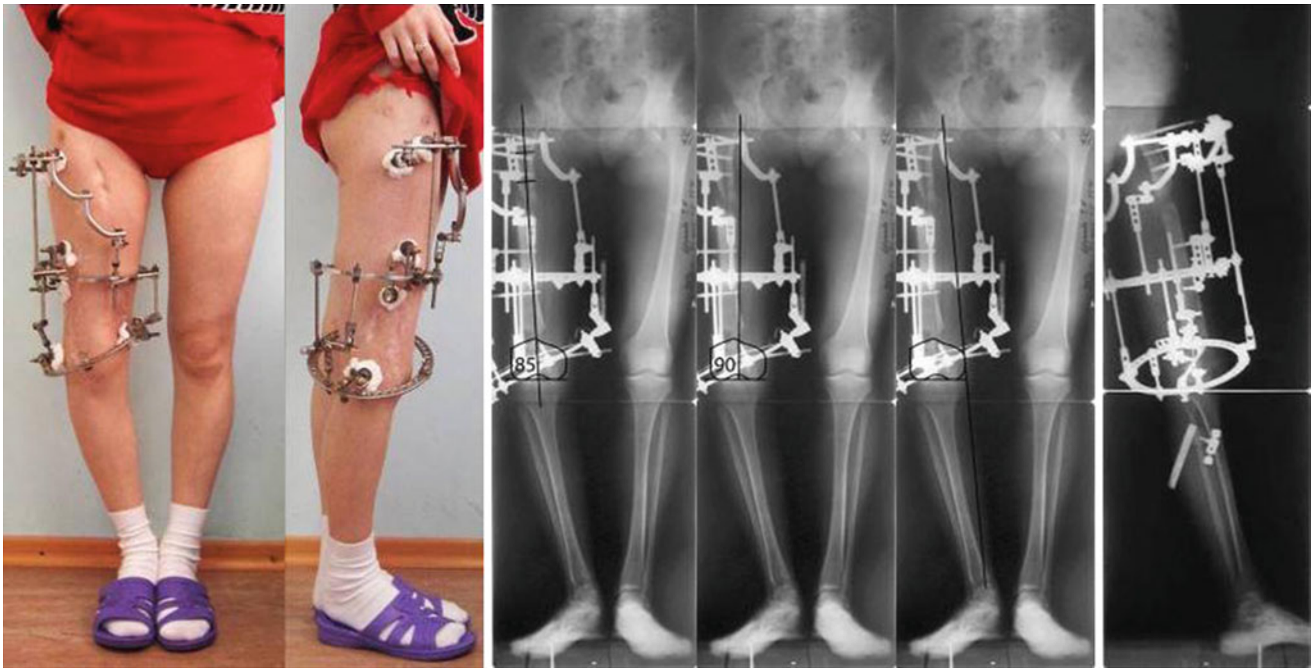


Fig. 4 Photos and long films after frame modification done to improve patient comfort

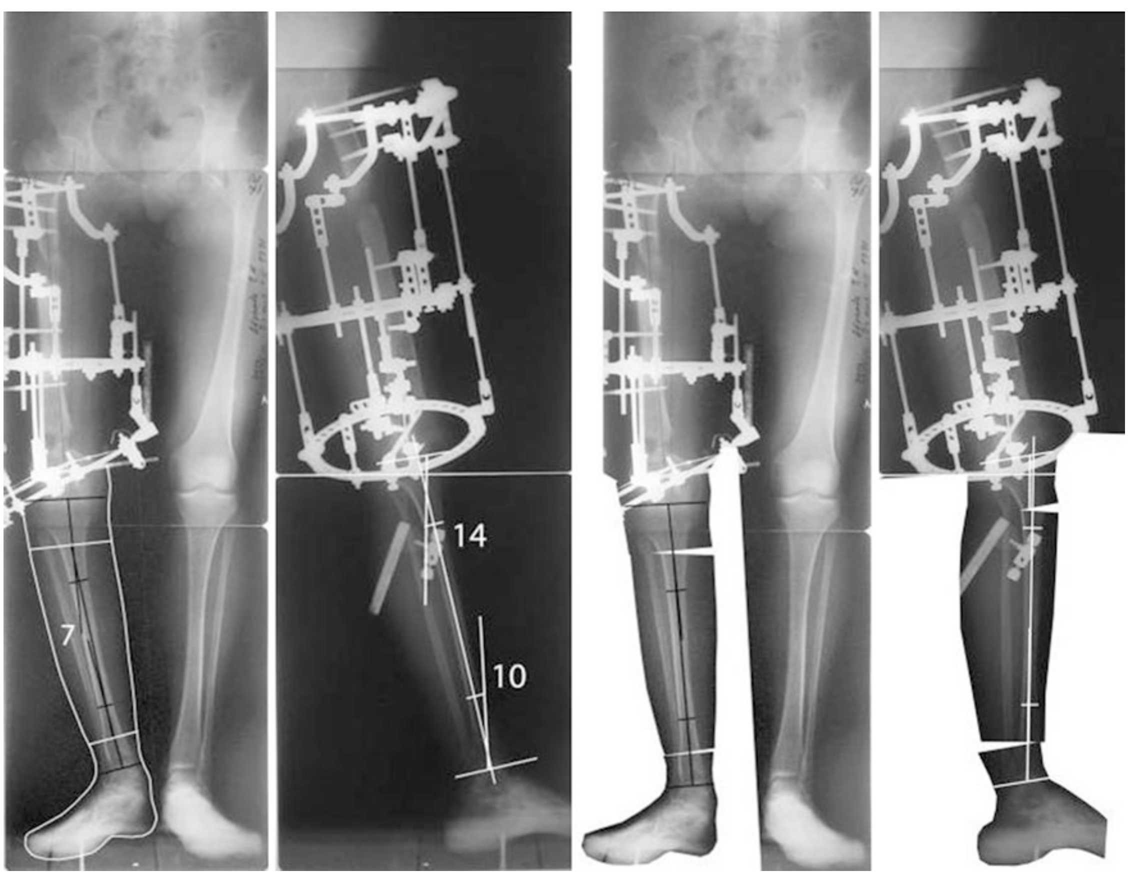


Fig. 5 Preoperative planning of the lower leg deformity correction. Right MAD = 36 mm medial, mLDFA = 90°, MPTA = 81°, Joint line convergence (JLCA) = 6°. varus, LDTA = 95°, PPTA = 93°, ADTA = 90°, tibia: upper third varus deformity 7°, extension deformity 14° & distal third flexion deformity 10°, AVd = 33°, RVd = 51°

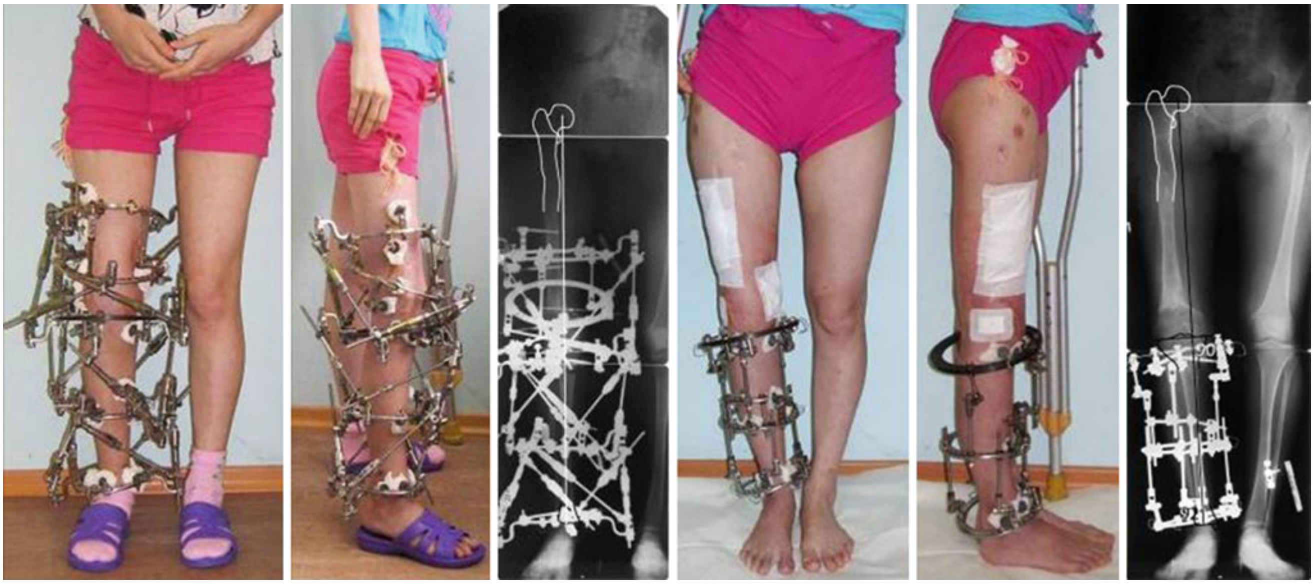


Fig. 6 Photos and long films after lower leg deformity correction using two hexapods and secondary frame modification. Knee joint stiffness, developed at correction of the femur, is eliminated by means of an additional Ortho-SUV Frame

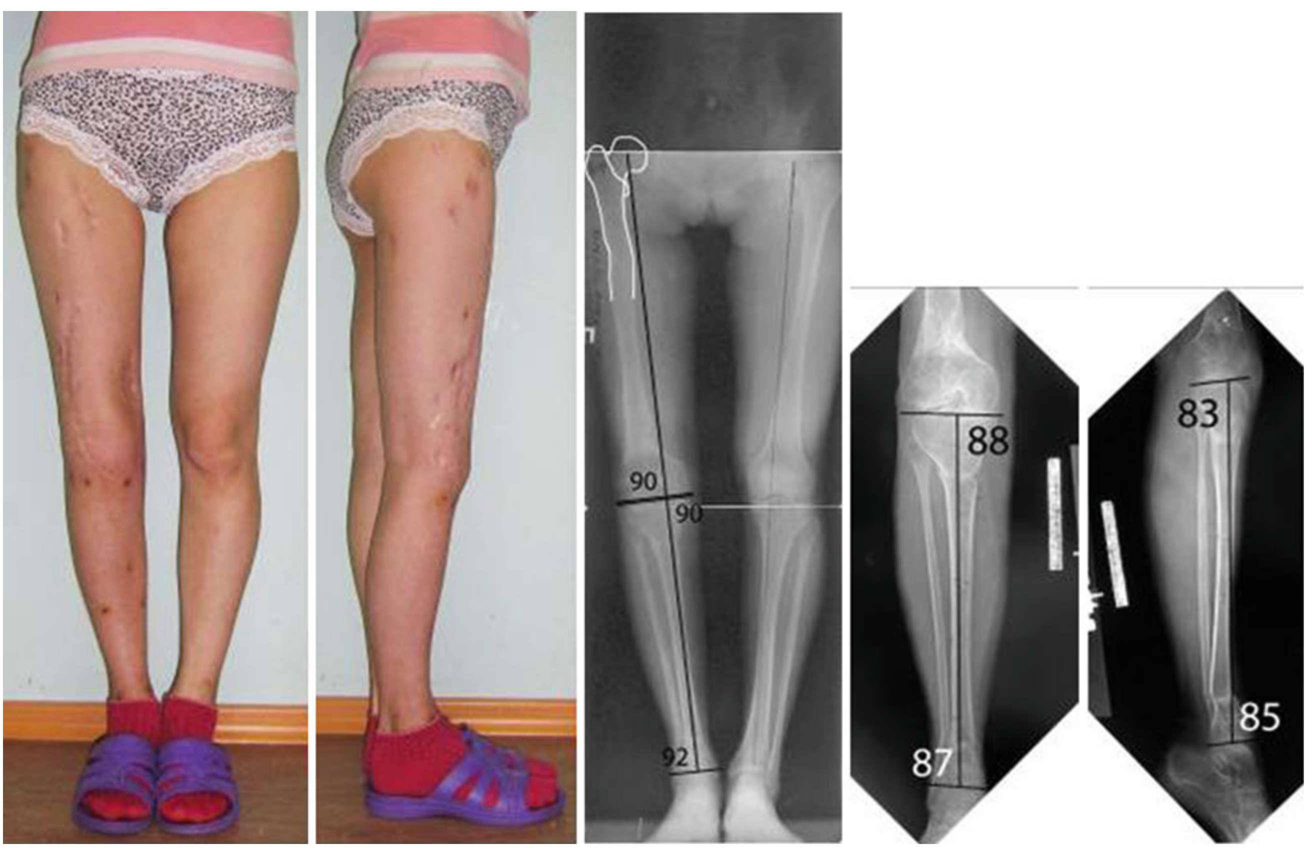


Fig. 7 Photo and long films 1 month after frame removal. Reference lines and angles are normalized: Right MAD = 13 mm medial, mLDFA = 90°, MPTA = 88°, Joint line convergence (JLCA) = 0°, LDTA = 87°, PPTA = 83°, ADTA = 85°, AVd = 33°, RVd = 33°

6 Images During Treatment

See Figs. 2, 3, 4, and 5.

Two-level osteotomy: proximal osteotomy will correct varus and recurvatum; distal osteotomy will correct procurvatum and varus. External rotation is corrected through both osteotomies (Fig. 6).

7 Technical Pearls

(a) Double level osteotomy helps to avoid excessive translation of the bone fragments during the deformity correction.
(b) Correction of complex multiplanar femur and tibia deformities can be done effectively with hexapod frames. A multiple drill hole osteotomy is used.

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

9 Avoiding and Managing Problems

(a) Development of knee joint stiffness can be addressed by means of additional hinge frame.
(b) Try to make osteotomy through new bone. The osteotomies were made distal to the previous osteotomy to avoid delayed bone healing.
(c) Use of structure at risk (SAR) points helped optimize the rate of correction and prevented any nerve or vascular disorders and provided a satisfactory environment for callus formation.

10 Cross-References

- ▶ Case 17: Computer Assisted External Fixation for Aesthetic Changing Lower Limb Shape
- ▶ Case 23: Complex Deformity After PFFD Treatment – Multifocal, Gradual Correction on Femur and Tibia with Monolateral External Fixation
- ▶ Case 28: Femoral and Tibial Rotational Deformity Treated with Fixator Assisted Nailing and Gradual Correction with the Taylor Spatial Frame
- ▶ Case 57: An Initially Successful Lengthening of a Traumatic Below Knee Amputation Stump by Ilizarov Technique with Subsequent Failure due to Soft Tissue Conditions
- ▶ Case 83: Adolescent with 15 cm Humeral Shortening from Osteomyelitis Treated by Humeral Lengthening via Circular External Fixation
- ▶ Case 98: Bilateral Metacarpal Lengthening for Congenital Brachymetcarpia

11 See Also in Vols. 1 and 2

Case 114: Fourteen year old female with residual clubfoot deformity treated with Taylor Spatial Frame (Vol. 1)
Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity (Vol. 2)
Case 5: Computer Assisted External Fixation at Femur Two-Level Posttraumatic Complex Deformity (Vol. 2)
Case 21: Computer Assisted External Fixation and then Nailing at Both Lower Legs Non-unions Accompanied with Complex Deformities (Vol. 2)
Case 44: Complex Ankle Fusion and Tibial Lengthening Using the LATN Technique (Vol. 2)
Case 45: Ankle Fusion and Tibial Lengthening (LATN Technique) for Failed Ankle Replacement (Vol. 2)
Case 59: Charcot Reconstruction with External Fixation (Vol. 2)
Case 65: Closed Correction of Club Foot with Ilizarov (Vol. 2)
Case 67: Clubfoot sequela treated with a multilevel, hexapod, external fixator (Vol. 2)
Case 68: CMT Foot Deformity Treated with TSF Butt Frame (Vol. 2)

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Case 27: Correction of Varus Deformity of the Femur and Tibia in Patient with LCL Laxity

S. Robert Rozbruch

Contents

Abstract

This case illustrates an approach to a young patient with a large varus deformity and LCL laxity. After analyzing the deformity, it became clear that the varus was coming from the distal femur, proximal tibia, and joint line obliquity. Also present was a procurvatum deformity of the proximal tibia. We performed an acute deformity correction of the femur with a plate and a gradual correction of the tibia varus and procurvatum with a TSF. With correction of the deformity, the LCL laxity improved dramatically.

1 Brief Clinical History

A 32 year old male complains of bilateral knee pain, where the left knee is worse than the right and is unstable. Two years earlier, he underwent a high tibial osteotomy and MCL and PCL reconstructions. He feels persistent pain and instability.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, and 5.

3 Preoperative Problem List

(a) Left femur varus
(b) Left tibia varus and procurvatum deformity
(c) Left LCL laxity with JLCA 13 °
(d) Right leg varus deformity (moderate)

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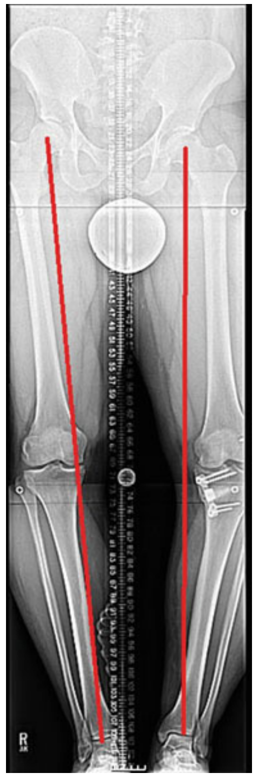

Fig. 1 *Left*: MAD = 71 mm medial; LDFA = 92 °; MPTA = 84 °; joint line convergence (JLCA) = 13 ° varus. LLD = 1 in. left side short. *Righ*t: MAD = 30 mm medial; LDFA = 91° ; MPTA = 85° ; JLCA = 3 varus.

Fig. 3 LCL laxity and varus deformity (*left*)

Fig. 2 Note the left knee LCL laxity and the joint line obliquity contributing to the varus alignment.

Fig. 4 PPTA = 58 ° (*left* tibia flexion deformity)

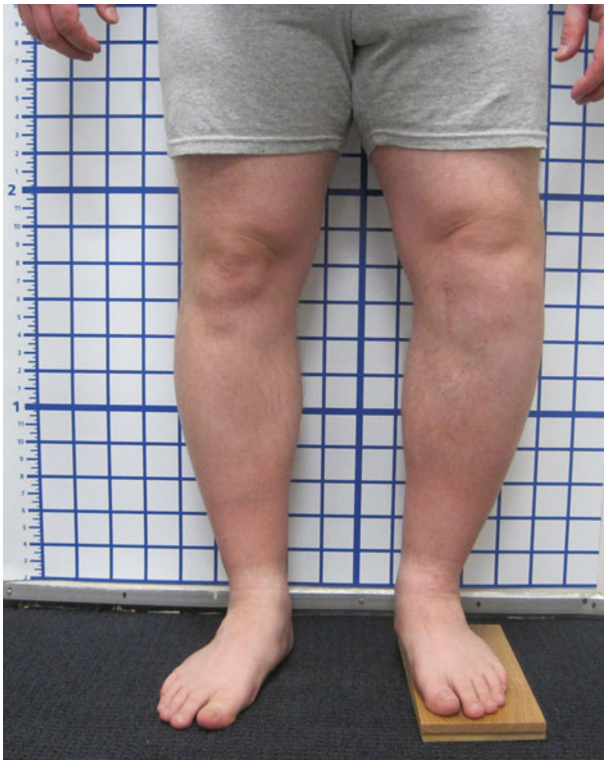

Fig. 5 Front view showing varus and LLD

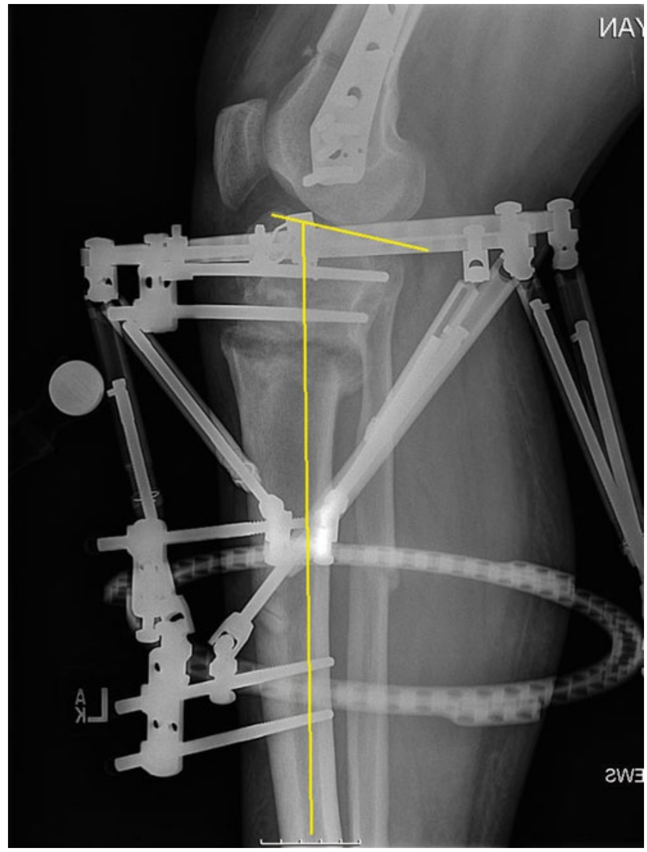

Fig. 7 Correction of apex anterior deformity

Fig. 6 Correction of MAD

4 Treatment Strategy

(a) Left sided deformity is a composite of 17 ° varus from the femur, tibia, and joint line obliquity. Plan is to correct femur varus by 7 ° with closing wedge osteotomy and plate fixation. Correct tibia gradually with hexapod frame. Correct varus by 6 ° to start and dial in correction to achieve a MAD of 0 or some overcorrection laterally. Correct tibia apex anterior deformity by 15 ° and add length.

(b) Staged treatment of the right tibia varus. The deformity is predominantly coming from the tibia although the femur and joint line obliquity also contribute.

5 Basic Principles

(a) Correction of femur with acute correction and internal fixation is safe and simpler than external fixation.

(b) Gradual correction of tibia allows one to address varus, apex anterior deformity, and shortening simultaneously in a safe manner.

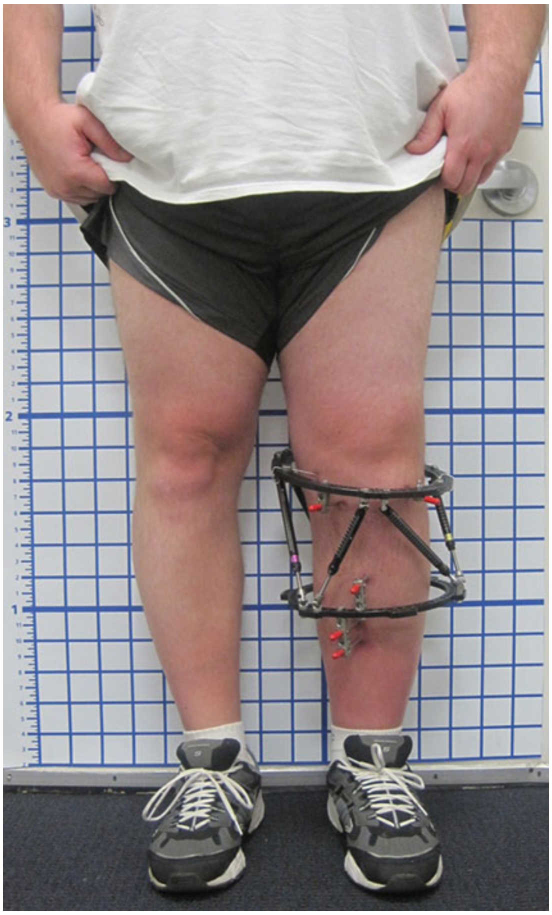

Fig. 8 Front view showing left realignment with hexapod frame

Fig. 9 Staged correction of the right tibia

(c) Gradual correction with the hexapod frame allows one to dial in the MAD correction. The joint line obliquity will change as the MAD is lateralized and the LCL laxity will decrease.
(d) LCL reconstruction may not be necessary after realignment.

6 Images During Treatment

See Figs. 6, 7, 8, 9, and 10.

7 Technical Pearls

(a) Left femur closing wedge osteotomy is best done by leaving medial cortex intact and using a locked plate. The plate may sit off the bone without compromise to stability. A micro-sagittal saw cooled with saline is used to perform the osteotomy.
(b) Correction of left tibia varus and flexion and shortening can be done effectively with hexapod frame. A multiple drill hole osteotomy is used.

8 Outcome Clinical Photos and Radiographs

See Figs. 11, 12, 13, 14, 15, 16, 17, and 18.

9 Avoiding and Managing Problems

(a) Try to make osteotomy through new bone. The left proximal osteotomy was made distal to the previous osteotomy to avoid delayed bone healing.
(b) Avoid over- or under-correction of the MAD on left side by gradually correcting the tibia and dialing in the correction. The correction of the joint line obliquity is somewhat unpredictable. This is the “seesaw effect.”

Fig. 10 Staged correction of the right tibia

Fig. 11 Slight overcorrection of MAD achieved. Note the correction of the joint line obliquity and LLD

Fig. 12 Femur plate sits off the bone for best fit. Joint line obliquity improved

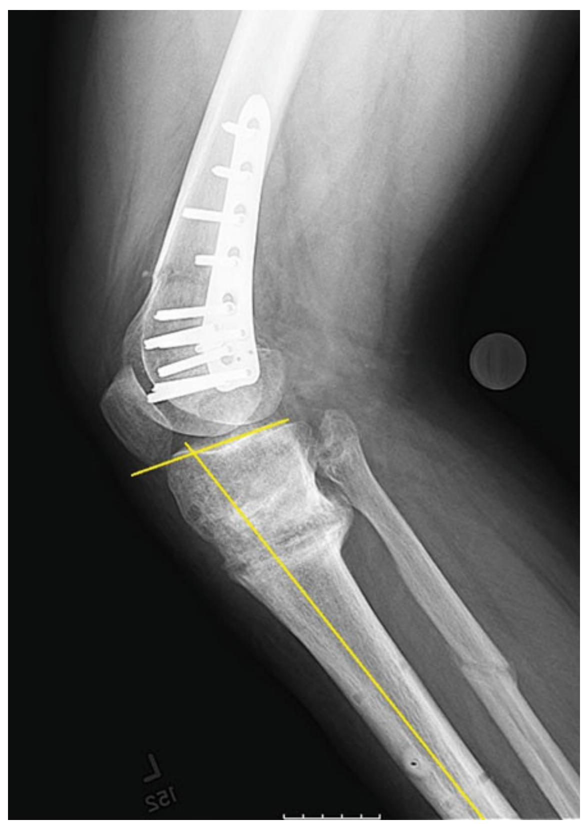

Fig. 13 PPTA is normalized

Fig. 14 Right side is healed in excellent position

Fig. 15 Right side is healed in excellent position

Fig. 16 Front view showing excellent realignment

Fig. 17 Side view showing full knee extension on *left*

Fig. 18 Back view showing excellent correction of deformity and LLD

10 Cross-References

- ▶ Case 16: Correction of Bilateral Genu Varum for a High Level Athlete
- ▶ Case 17: Computer Assisted External Fixation for Aesthetic Changing Lower Limb Shape
- ▶ Case 19: Bilateral Genu Varum and LLD Corrected with an Internal Lengthening IMN and Contralateral HTO

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Case 28: Femoral and Tibial Rotational Deformity Treated with Fixator Assisted Nailing and Gradual Correction with the Taylor Spatial Frame

Vikrant Landge and Janet D. Conway

Contents

Abstract

A teenage boy presented with Blount disease and progressive varus deformity of the left proximal tibia with internal rotation deformity of 35°. He also had severe femoral retroversion and no internal rotation of his left femur. The femoral deformity was corrected with fixator-assisted nailing (FAN). The tibial deformity was gradually corrected using the Taylor spatial frame (Smith & Nephew, Memphis, TN). Deformity correction was achieved, and the patient experienced dramatic improvement in his clinical gait.

1 Brief Clinical History

A 13 year old boy presented with Blount disease and progressive varus deformity of the left proximal tibia with internal rotation deformity of 35°. He also had severe femoral retroversion and no internal rotation of his left femur. His internal foot progression angle was 15°, and his thigh-foot axis was 35° internal. The external varus moment of his knee was three times more than normal. Pedobarographs showed that he was putting significantly more weight on the lateral border of the foot. He had no previous surgery. The femoral deformity was corrected with fixator-assisted nailing (FAN). The tibial deformity was gradually corrected using the Taylor spatial frame (Smith & Nephew, Memphis, TN). The patient attended physical therapy sessions regularly for gait training and to maintain range of motion. The tibial correction was achieved, and the frame was dynamized 1 month prior to removal. The frame was removed 6 months after frame application.

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_219

Fig. 1 Preoperative anteroposterior (**a**) and lateral (**b**) view radiographs show patient was skeletally immature and had varus tibial deformity with a medial proximal tibial angle of 67° and posterior proximal tibial angle of 80° (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Significant femoral retroversion (25° of external rotation deformity of knee)
- Tibia vara with internal rotation (35° of internal rotation deformity of the foot/ankle)

4 Treatment Strategy

Acute femoral correction was chosen to prevent pin-tract infection in the large soft-tissue envelope of the thigh. A subtrochanteric osteotomy level was chosen for good healing potential and to minimize the effect on the extensor mechanism of the knee. Gradual tibial correction was chosen because of the combination of varus and rotational deformity. The tibial deformity was too large to correct acutely.

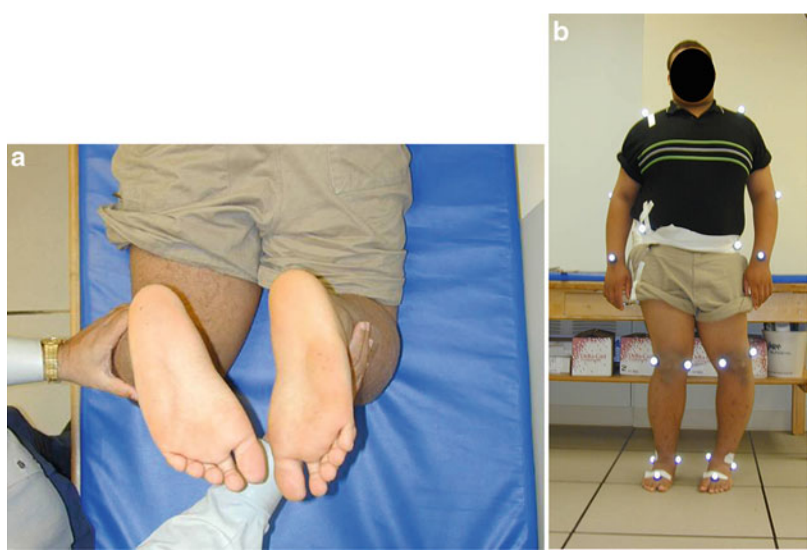

Fig. 2 (**a**) *Left* thigh-foot axis demonstrating 35° internal rotation. (**b**) Clinical anteroposterior view photograph obtained during gait analysis. Note the severity of the patellar external rotation (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

5 Basic Principles

Wires and pins were placed away from the growth plates. The frame was dynamized 1 month prior to removal to improve regenerate bone formation. In such cases, occupational therapy Orthoplast foot splints should always be used to prevent the ankle from going into equinus during tibial deformity correction. The patient attended physical therapy sessions daily to maintain range of motion.

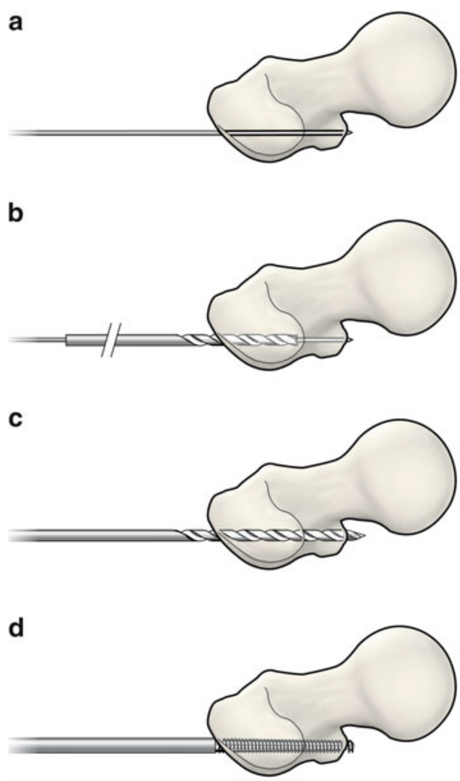

Fig. 3 Cannulated wire technique for pin placement. (**a**) A 1.8-mm diameter wire is placed out of the plane of the nail. (**b**) Cannulated 4.8-mm diameter drill bit is used to drill over the wire. (**c**) Wire and cannulated drill bit are removed. A solid, pointed drill tip is used to drill the second cortex. (**d**) Half-pin is placed with bicortical purchase (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, 8, 9, 10, and 11.

7 Technical Pearls

The cannulated wire technique was used to place the femoral fixator pins out of the tract of the nail (Figs. 3, 4, 5, and 6). A trochanteric start for the rod was chosen secondary to the patient's obesity. An external fixator (Synthes, West Chester, PA) with two distal femoral pins and two proximal femoral pins was applied. The pins were placed out of the tract of the nail. A guide rod was inserted and then a femoral subtrochanteric osteotomy was performed because it has the least effect on the extensor mechanism of the knee. The femur was acutely rotated 25° internally with the FAN technique. A goniometer was used to carefully measure the angle of the two pins of the external fixator to ensure 25° of internal rotation. An antegrade nail was then inserted in the femur. A Taylor spatial frame was applied to the tibia to correct the tibial rotational deformity.

It is important to capture the fibula proximally and distally when correcting tibial rotational deformities. Surgeon preference determines whether multiple drill hole osteotomy or Gigli saw osteotomy is used when performing de-rotational osteotomy. The origin and corresponding point of the Taylor spatial frame program were chosen at the level of the osteotomy to ensure good visualization of this region while the patient was undergoing correction. Watch out for procurvatum deformity during the gradual correction phase.

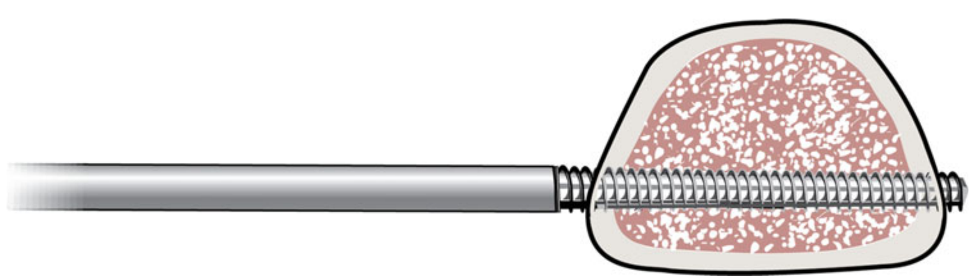

Fig. 4 The half-pin placement procedure is repeated in the distal femur. The half-pin is placed out of the plane of the nail (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

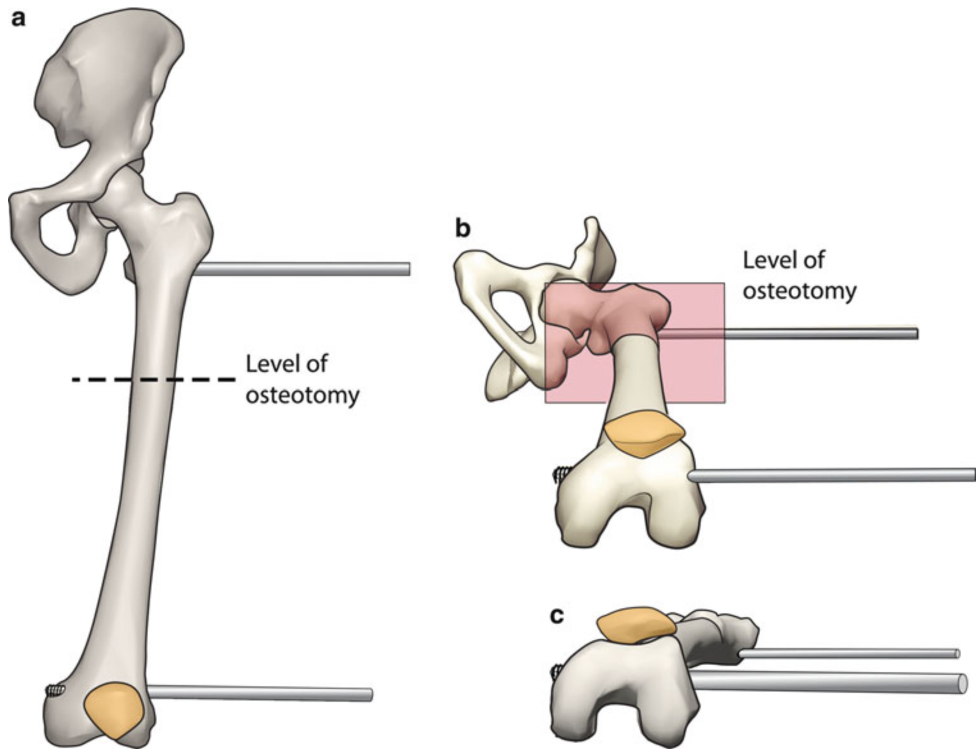

Fig. 5 (**a**) through (**c**), pins are placed parallel to each other and orthogonal to the bone (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

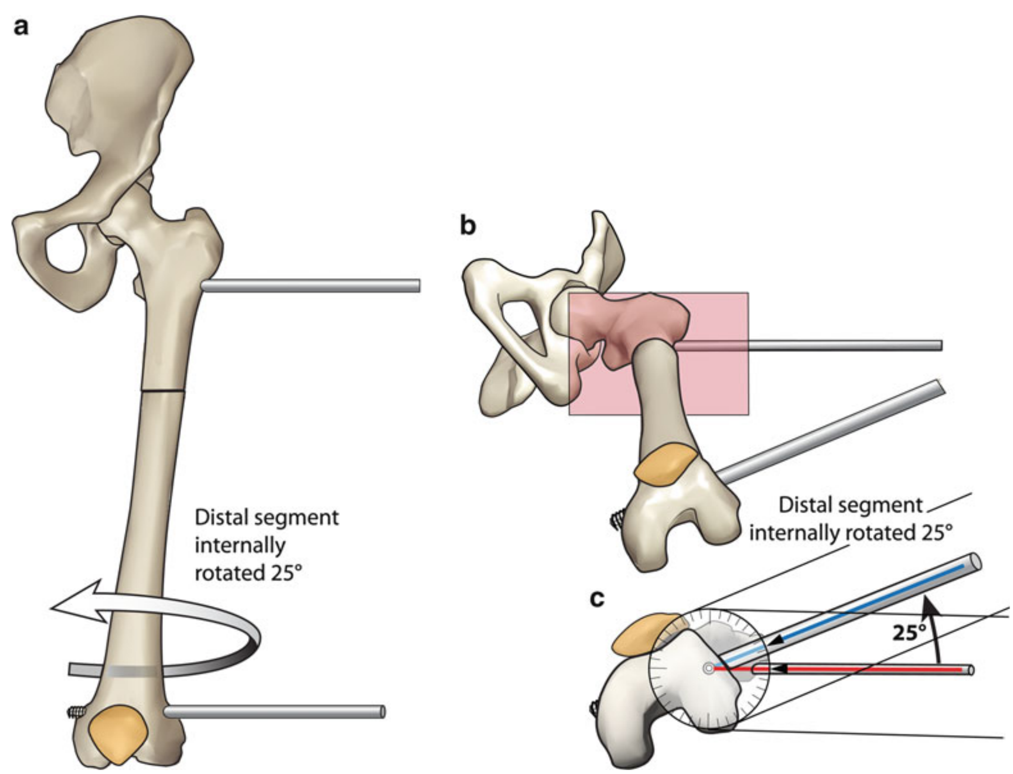

Fig. 6 (**a**, **b**) Bone is cut and de-rotated 25° internally. (**c**) Pins are held in place with the fixator for nailing. Note that a goniometer is used intraoperatively from this perspective to confirm the 25° measurement (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

Fig. 7 Anteroposterior (**a**) and lateral (**b**) view radiographs with the patella forward obtained immediately after surgery (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

Fig. 8 Clinical photograph obtained during treatment before correction was achieved (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

8 Outcome Clinical Photos and Radiographs

See Fig. 12.

9 Avoiding and Managing Problems

The peroneal nerve can become symptomatic during rotational correction. You can elect to address this at the time of surgery prior to frame application or to wait for the patient to become symptomatic and then perform nerve decompression. It is technically easier to perform this procedure prior to frame application. During gradual correction, patients should undergo daily physical therapy to maintain knee and ankle range of motion. You may need to monitor for procurvatum deformity during gradual correction of the tibia. If procurvatum occurs, run a residual program. To prevent procurvatum, you can program in 15° of procurvatum when you initially plan your frame correction using the Taylor spatial frame software.

Fig. 9 Anteroposterior view radiograph obtained with the limb positioned patella forward. The radiograph was obtained during gradual correction with the beam angled down the proximal ring for the best reference shot to assess the deformity correction (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

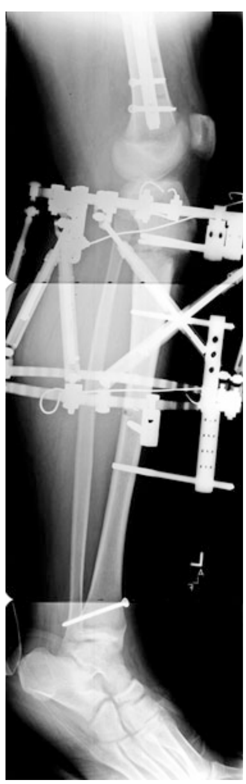

Fig. 10 Lateral view radiograph obtained at completion of gradual correction. The bone diameter mismatch at the osteotomy site was consistent with de-rotation (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

Fig. 11 Full-length standing anteroposterior view radiograph obtained after correction was achieved. The mechanical axis passes through the lateral tibial spine, and the medial proximal tibial angle is intentionally overcorrected to 90° (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

Fig. 12 Anteroposterior (**a**) and lateral (**b**) view radiographs obtained after treatment show that complete correction was achieved. Note that the mechanical axis line passes through the tibial spine on the anteroposterior view radiograph (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

10 Cross-References

► Case 18: Gradual Correction of Distal Tibial Varus Deformity

11 See Also in Vol. 1

Case 71: Morbidly obese teenager with significant Blount's treated with Taylor Spatial Frame
Case 119: Adolescent with Bilateral Femoral and Tibial Rotational Deformity (Miserable Malalignment Syndrome) Combined with Proximal Tibial Varus and Recurvatum

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Case 29: Intraoperative SSEP Monitoring of Circular External Fixation in Achondroplasia

Marina Makarov, Lori Karol, and Mikhail Samchukov

Contents

Abstract

A fifteen year old female with bilateral genu varum and recurvatum associated with achondroplasia underwent sequential (right leg first) staged double level tibial osteotomy for gradual angular deformity correction using circular external fixation. Due to high incidence of neurological complications during external fixation procedures in patients with achondroplasia, intraoperative somatosensory evoked potential (SSEP) monitoring of tibial and peroneal nerves was utilized.

1 Brief Clinical History

The patient is a fifteen year old skeletally mature female with progressive bilateral genu varum, recurvatum, and knee pain secondary to achondroplasia (Figs. 1 and 2) who was previously treated with right high tibial osteotomy and cross-pin fixation along with prophylactic fasciotomy of the anterior and lateral compartments. Over the past number of years, the varus-recurvatum deformity of the treated leg recurred, and she has been experiencing increasing pain bilaterally but most severe at the right knee.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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Fig. 1 Preoperative appearance of the patient illustrating bilateral genu varum and recurvatum

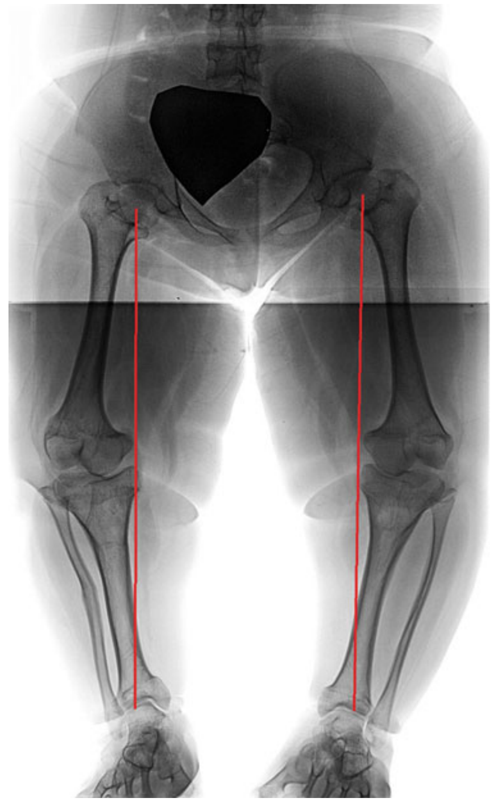

Fig. 2 Preoperative radiograph of the pelvis and lower extremities demonstrating bilateral genu varum with knee laxity, varus deformity of the distal tibiae along with relative fibular overgrowth. Mechanical axis deviation is illustrated (*red lines*)

3 Preoperative Problem List

- Bilateral genu varum with significant laxity and hyperextension of the knees
- Bilateral recurvatum of the proximal tibia due to abnormal orientation of the tibial slope
- Bilateral varus deformity of the distal tibia coupled with relative fibular overgrowth
- Risk of neurological complications during frame application, osteotomies, and multi-planar deformity correction due to achondroplasia

4 Treatment Strategy

Considering the complexity of the deformity, the first stage of treatment included only proximal tibial osteotomy with gradual correction of abnormal orientation of the tibial slope in the sagittal plane simultaneously with translation of the fibula distally to tighten the lateral ligament complex of the knee. This was followed by staged distal tibial osteotomy combined with midshaft fibular osteotomy for gradual correction of varus deformity in the coronal plane. Because of progressive recurrence and its symptomatic nature, the right tibia was elected for initial deformity correction. After completion of deformity correction on the right leg with stabilization of bone segments, an analogous treatment protocol was elected for consecutive correction of deformities of the left leg. To identify potential nerve injury during frame application and tibial and fibular osteotomies, intraoperative SSEP monitoring was performed.

5 Basic Principles

The protocol of intraoperative SSEP monitoring of external fixation on the tibia includes subcutaneous placement of 12-mm needle electrodes over the deep peroneal and posterior tibial nerves at the ankle region followed by stimulation of those nerves using square wave pulses with duration of 0.1 ms, frequency of 4–5 pulses per second, and intensity of 30–40 mA (Makarov et al. 1996, 2003). For recording of evoked potential responses, the identical electrodes are applied in the popliteal fossa, over the lumbar area, and over the cervical spine. The typical recording parameters include channel display gain of 10 μV per

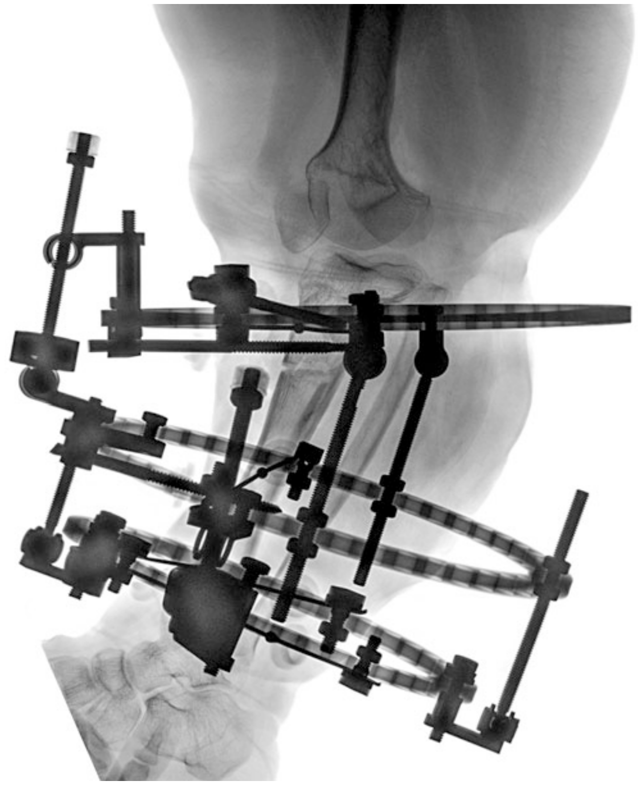

Fig. 3 Lateral radiograph of the tibia after proximal tibial osteotomy and application of TrueLok (Orthofix) circular external fixator. The frame configuration for correction of recurvatum included a proximal ring attached to the proximal tibia with one horizontal olive wire and two half pins. The proximal ring was connected with two posteriorly located hinges and anterior angular distractor to the middle ring. The middle tibial ring was secured to the middle tibia with one medial face olive wire and one half pin. For future distal tibial varus deformity correction, the middle ring was connected via two lateral hinges and medial angular distractor to the distal ring which was secured to the distal tibia with two cross wires. Stable SSEP recordings were documented throughout the surgery. Note that the fibula was attached to the frame only distally for gradual translation simultaneously with correction of tibial recurvatum

Fig. 4 Lateral radiograph of the tibia after correction of proximal tibial recurvatum. Note the proper location of the fibular head

division, filter settings of 10–50 Hz and 30–2,000 Hz, and automatic artifact rejection of 15–2 μV. Evoked potentials are recorded continuously throughout the surgery comparing the resulting signals with those at the baseline. In addition, stimulation of nerves on the opposite extremity serves as control for SSEP changes resulting from anesthesia, physiological factors, and technical problems. SSEP waveform amplitude reduction >50 % or its latency prolongation >10 % relative to baseline values is considered significant and indicative of nerve injury (Makarov et al. 2012).

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.

7 Technical Pearls

Several specific technical details should always be kept in mind when using SSEP monitoring of peripheral nerve function. Because critical changes in SSEP waveforms might develop with some delay after the causative event, it will take some time and experience to correctly identify surgical maneuvers responsible for nerve injury. Therefore, some modifications to surgical protocol should be applied. First, sufficient time should be given to obtain a stable and reliable baseline. Second, potentially hazardous wires and half pins (e.g., proximal fibular-tibial wire or tibial-fibular head half pin) should be inserted first, thereby providing additional time to monitor function of the nerves. If tourniquet is used during the osteotomy, SSEP baseline should be acquired prior to tourniquet inflation, and recovery of the responses should closely be monitored after subsequent tourniquet release. Finally, all surgical steps with the highest likelihood of inducing nerve injury should be performed in sequence with sufficient interval between them to allow enough time to confirm integrity of the nerves.

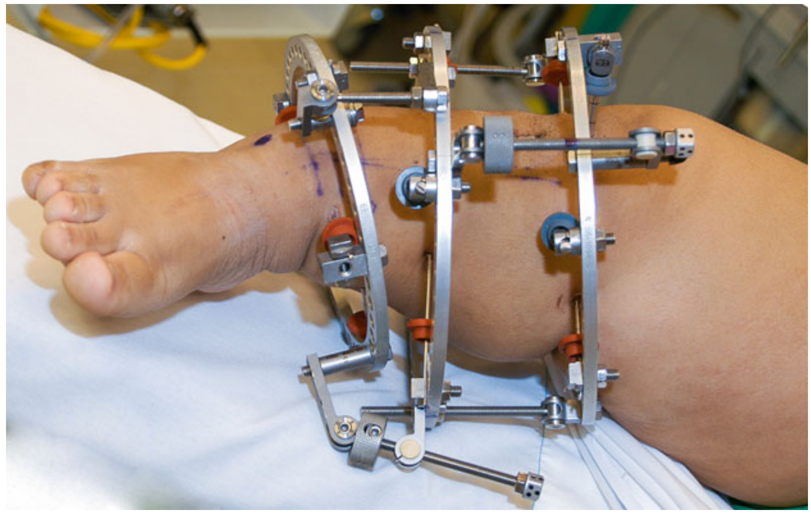

Fig. 5 Preoperative photograph before second stage of surgical treatment, which involved fibular head fixation and enhancement of distal ring stabilization. This was followed by staged distal tibial osteotomy combined with midshaft fibular osteotomy for gradual correction of distal tibial varus

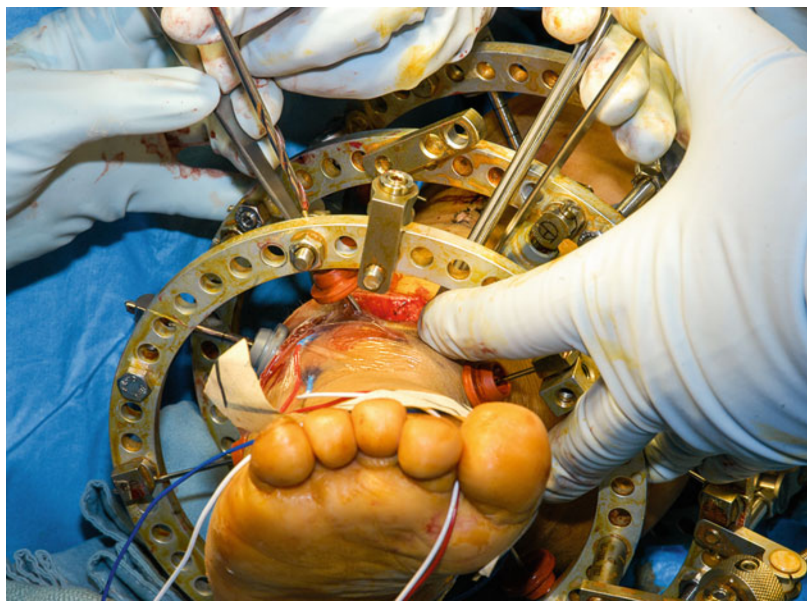

Fig. 6 Intraoperative photograph during the distal tibial osteotomy. Note the additional half pin at the distal ring laterally that produced significant SSEP alterations and was subsequently removed at the end of surgery

8 Outcome Clinical Photos and Radiographs

See Figs. 13 and 14.

9 Avoiding and Managing Problems

Surgical correction of deformities in patients with short stature is associated with high incidence of peroneal nerve compromise, especially when double level tibial osteotomy is required (Correll 1991; Nogueira et al. 2003; Prévot et al. 1994). Intraoperative monitoring of peripheral nerve function for such cases provides a modality for safety. At the same time, these are the most challenging cases for obtaining SSEP responses. Because of excess of soft tissues around the knees, SSEP recordings at popliteal fossa are often weak or unobtainable. In these cases, two lumbar areas (e.g., L1–T8 and L1–IC) are utilized as recording places. One area can provide more reproducible waveforms than the other at a random order (Fig. 8). In addition, significant SSEP alterations may be revealed with a delay requiring special attention in identification of the cause of nerve compromise. In this reported case, the first critical drop-off SSEP waveform was noticed during distal tibial osteotomy with 10–15 min delay after half pin insertion. Considering that osteotomy was carried out at safe zone, the only possible cause of the SSEP drop was identified as insertion of the half pin. Subsequent removal of that pin resulted in prompt improvement of the waveforms.

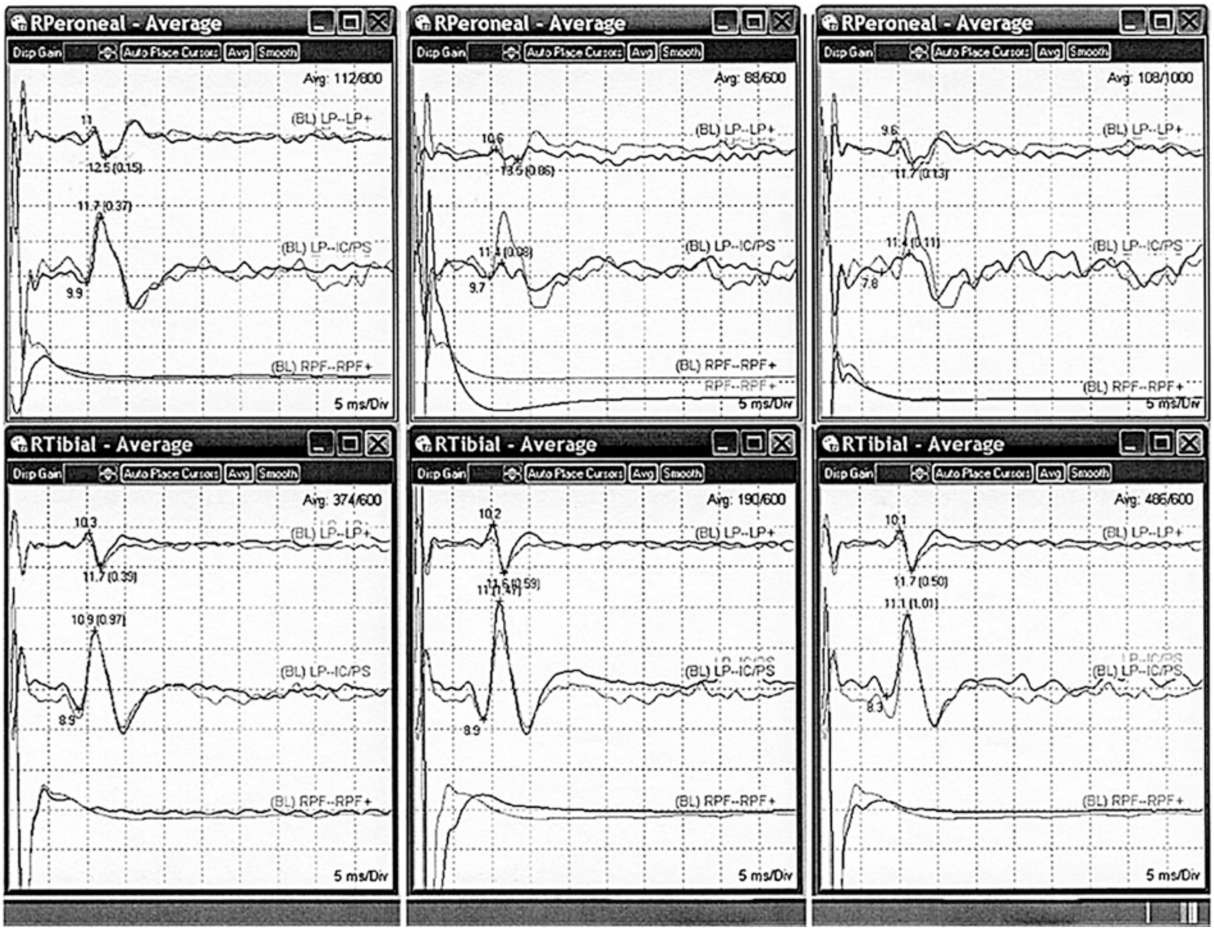

Fig. 7 Intraoperative SSEP monitoring of peroneal and tibial nerves demonstrating stable peroneal and tibial SSEPs during introduction of the fibular head half pin and midshaft fibular osteotomy (*left*), significant attenuation of peroneal response after insertion of the addition distal tibial half pin (*center*). Note the stable tibial nerve recordings at the same time. The new half pin was suspected to stretch superficial peroneal nerve and was subsequently removed. This resulted in partial response restoration with waveform amplitude rising above the critical value (*right*). Postoperatively, the patient experienced decreased sensation on the dorsal surface of the foot and at the first web space, which promptly resolved within a period of 1 month

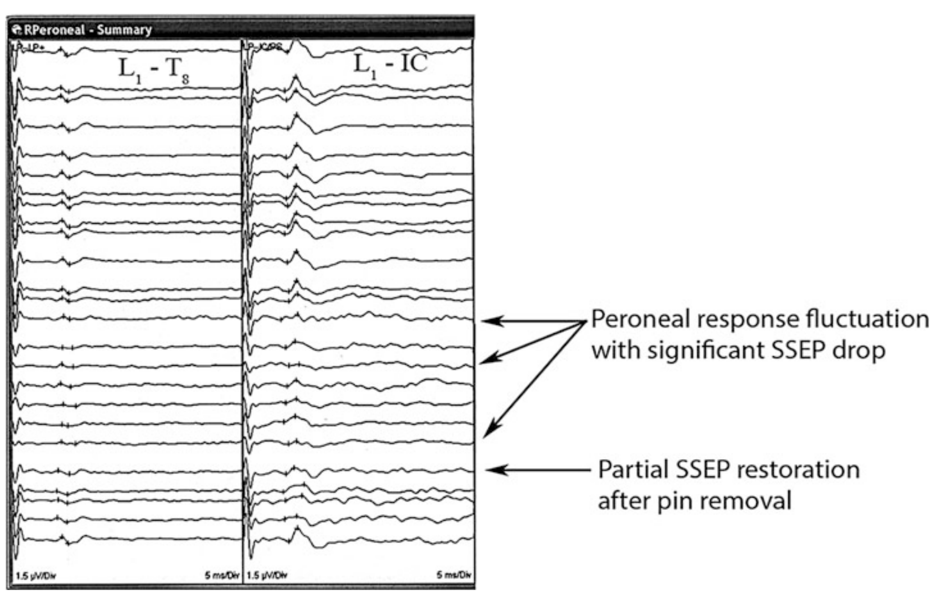

Fig. 8 Sequential peroneal nerve SSEP recordings throughout the entire surgery showing episodes of waveform deterioration and recovery, which were linked to the half pin at the distal tibia. Note that L1–T8 lumbar recording site (*right*) produced more reliable and reproducible responses than the L1–IC site (*left*). *L1* lumbar 1, *T8* thoracic 8, *IC* iliac crest

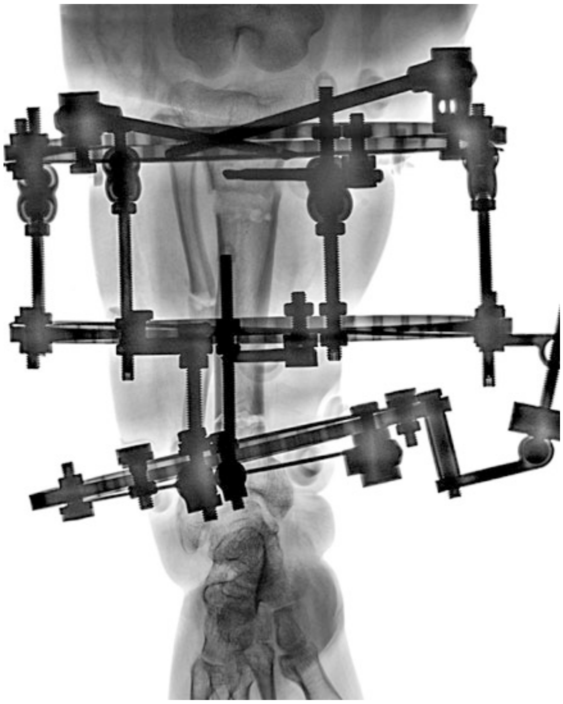

Fig. 9 AP radiographs of the tibia after distal tibial osteotomy and midshaft fibular osteotomy for varus deformity correction. Note that two hinges and angular distractor between the proximal and middle rings were replaced with four lockable universal hinges attached to threaded rods providing compression. Also the proximal tibia and fibula were secured at this time with a half pin

Fig. 11 Photograph of the lower extremities during consolidation period after completion of gradual deformity correction of the left tibia

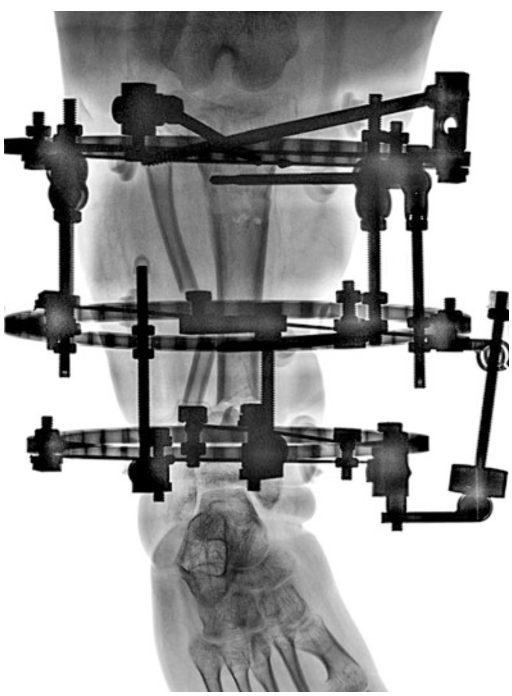

Fig. 10 AP radiograph of the tibia after completion of the distal tibial varus deformity correction. At this time, the bone segments of the right tibia were stabilized, and analogous treatment was initiated for similar deformity correction of the left leg

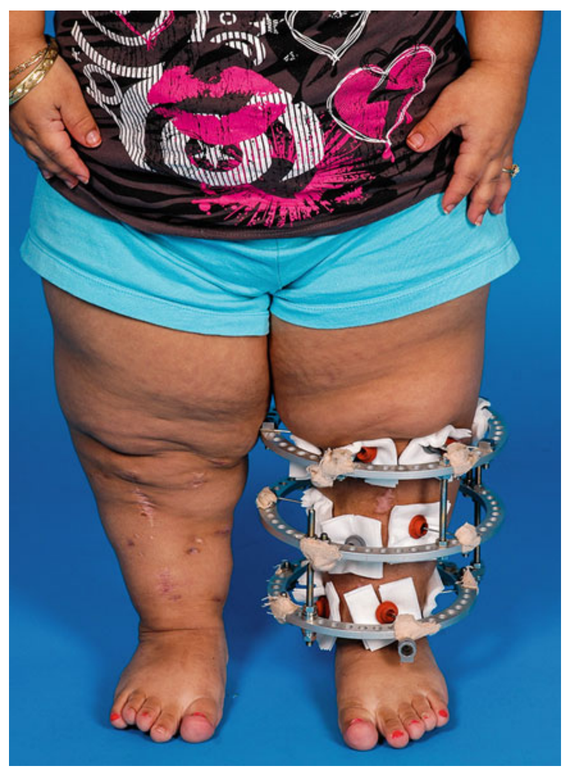

Fig. 12 Photograph of the lower extremities after frame removal from the right tibia and during consolidation of the bone regenerate on the *left*

Fig. 13 Clinical appearance of the patient's lower extremities at 1-year follow-up. Despite slight ligamentous laxity in her knees clinically, the overall alignment of her legs is substantially improved. She is neurologically asymptomatic, satisfied with result of deformity correction, and able to ambulate with full weight bearing without difficulties

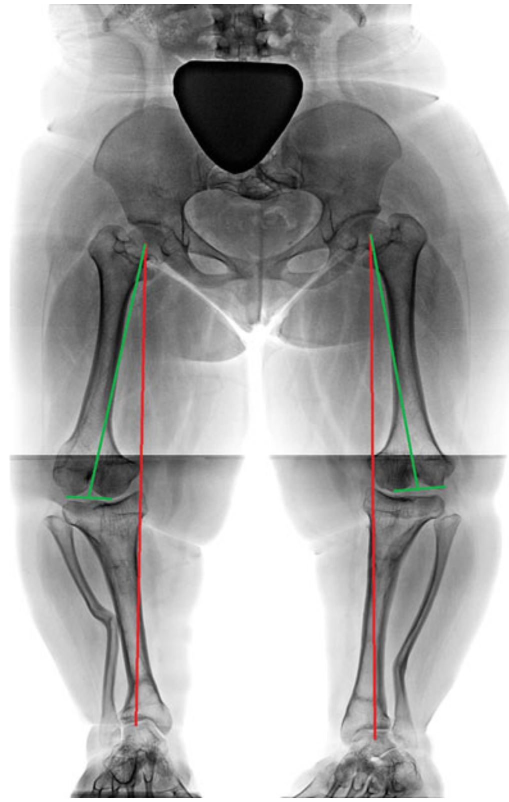

Fig. 14 Radiograph of the pelvis and lower extremities at 1-year follow-up showing large improvement in the varus of the lower extremities. Tibia deformities are well corrected. Residual varus illustrated by medial deviation of the mechanical axis (*red line*) is from the distal femur (*green line* showing LDFA > 90°) and medial subluxation of the tibia associated with dysplasia

10 Cross-References

▶ Case 102: Fracture of the Humerus Treated Initially with a Flexible Intramedullary Nail and Later Converted to Circular External Fixation due to Non-union

11 See Also in Vol. 1

Case 59: Intraoperative SSEP Monitoring of Circular External Fixation for Revision of Brown Rotationplasty

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Case 30: Multiapical Deformity of Knee, Tibia, and Ankle Treated with Osteotomy, Arthrodesis, and Arthroplasty

S. Robert Rozbruch

Contents

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Abstract

This is a case of a complex multiapical deformity of the lower extremity. Three levels of deformity included (1) malunion of the tibia, (2) deformity and arthrosis of the ankle, and (3) deformity, arthrosis, and instability of the knee. All components of the deformity were addressed using osteotomy, arthrodesis, and arthroplasty to provide a comprehensive solution.

1 Brief Clinical History

A 60 year old man was referred to our service for constant right knee pain and a severe valgus deformity of the right lower extremity. The pain had been progressively worsening over the past 5 years, and at presentation, he was unable to ambulate without assistance. At the age of 5, he suffered a crush injury to the right lower extremity that resulted in a foot drop. He required multiple surgeries on his right lower extremity including multiple skin grafts and a hindfoot arthrodesis at the age of 15. Of significance, he has a history of right tibial osteomyelitis from his previous injury. On examination, he was 5′5″ tall and 175 lbs with a valgus deformity of his right knee, tibia, and ankle; a recurvatum deformity of his right knee; and an external rotation deformity of his right foot. His right knee demonstrated 27° of hyperextension to 120° of flexion and a grade III valgus instability. The thigh–foot axis was 45° external on the right and 15° external on the left. In his right ankle, he could dorsiflex to neutral and had 30° of plantar flexion (10–40° on the left) with no true active dorsiflexion although it was felt that his tibialis anterior was contracting. Consistent with his previous fusion, his right subtalar joint had no motion; his left ranged from 20° of inversion to 10° of eversion. His neurovascular exam was consistent with a peroneal nerve palsy and was otherwise within normal limits.

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

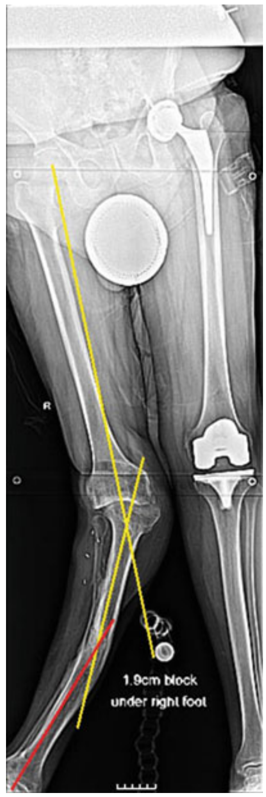

Fig. 1 51-in. AP hip to ankle radiographs showed a limb length discrepancy of 7.7 cm when measured indirectly; segmental measurements showed 4-mm and 2-mm differences in the femur and tibia, respectively. His mechanical axis deviation was 115 mm lateral. His LDFA was 83°, and his MPTA was 116°. Notice levels of deformity of the knee and tibia

3 Preoperative Problem List

Multiapical deformity of the knee, tibia, and ankle:

1. Twenty-eight degrees valgus of the right knee with osteoarthritis and grade III valgus instability
2. Twenty-seven degrees hyperextension instability at the knee
3. Tibial deformity (malunion) of 20° valgus with 30° of external rotation
4. Right ankle valgus deformity of 13° with pain and arthrosis
5. Leg length discrepancy of about 7.7 cm
6. History of infection/osteomyelitis

4 Treatment Strategy

Stages 1 and 2: Correct tibia deformity with osteotomy and correct ankle deformity/arthritis with fusion. Stage 3: Constrained total knee replacement (TKR) to correct the knee deformity and instability.

He underwent a tibial osteotomy with application of an Ilizarov/Taylor Spatial Frame (TSF) to correct the tibial diaphyseal malunion deformity (valgus and external rotation) and a tibiotalar arthrodesis to correct the ankle deformity as well as provide relief from the significant osteoarthritis of the tibiotalar joint. The arthrodesis relieved the ankle pain and valgus deformity about the ankle, and the foot frame was removed 6 months after surgery. The tibial

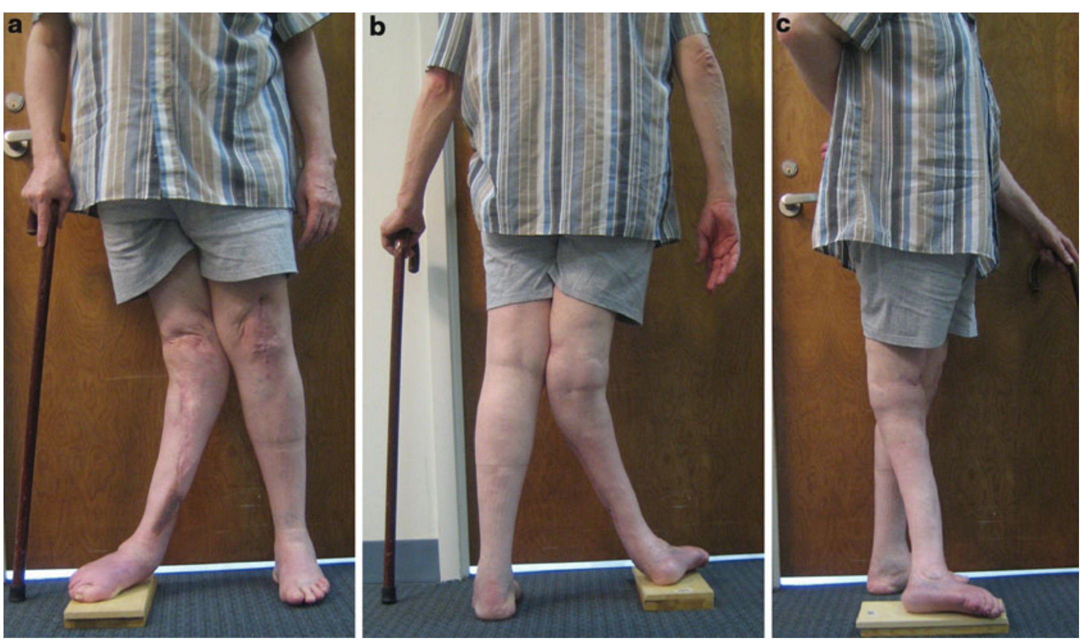

Fig. 2 Front (**a**), back (**b**), and side (**c**) views showing the large clinical deformity at 3 levels – the knee, tibia, and ankle

malunion required roughly 12 months in the frame. There was some concern about insufficient bony bridging at the tibial osteotomy site. Ten weeks after tibial frame removal, a tibial plate was inserted using a percutaneous technique to stabilize the osteotomy site. At the same time, a constrained total knee replacement was performed to correct the 17° of residual valgus deformity about the knee. Seven weeks postoperatively, the patient was noted to have some skin breakdown over the plate. The plate was removed, and a retrograde ankle fusion nail coated with antibiotic-impregnated cement was inserted, bypassing the site of the tibial osteotomy. With the wound breakdown over the nonunion, an antibiotic-coated nail was used as a prophylactic measure to avoid a deep bone infection.

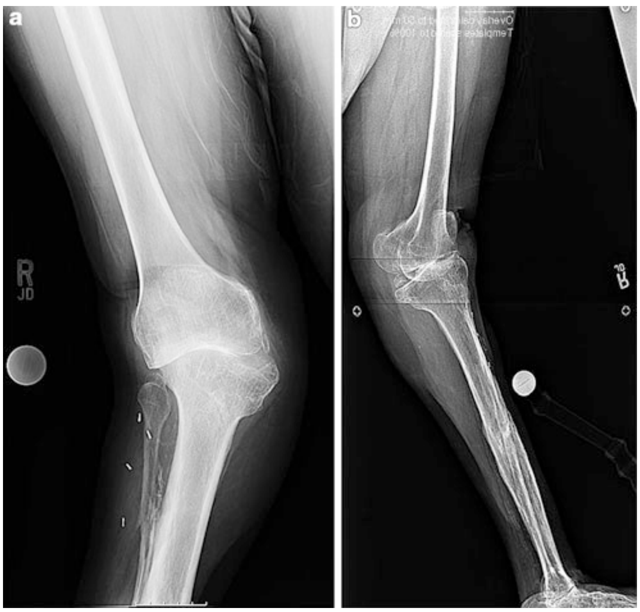

Fig. 3 (**a**, **b**) AP and lateral of the knee showing 28° of valgus and hyperextension of the knee of 27°

5 Basic Principles

Address the three levels of deformity. Extra-articular deformity of the tibia should be corrected prior to correcting the knee deformity with joint replacement. The ankle can be corrected at the same time as the tibia. Osteotomy is chosen to correct the tibia. Arthrodesis is chosen to correct the ankle to provide a comprehensive solution for arthrosis and deformity. Knee replacement is the final step to address deformity and arthrosis of the knee. A constrained implant is needed to address the large deformity and the instability of the knee.

6 Images During Treatment

See Figs. 5, 6, 7, and 8.

7 Technical Pearls

1. Correct tibia and ankle with a two-level frame – acute correction of the ankle and gradual correction of the tibia.
2. Use antibiotic-coated IM nail for the tibia since there was history of tibia osteomyelitis and there is currently wound breakdown.

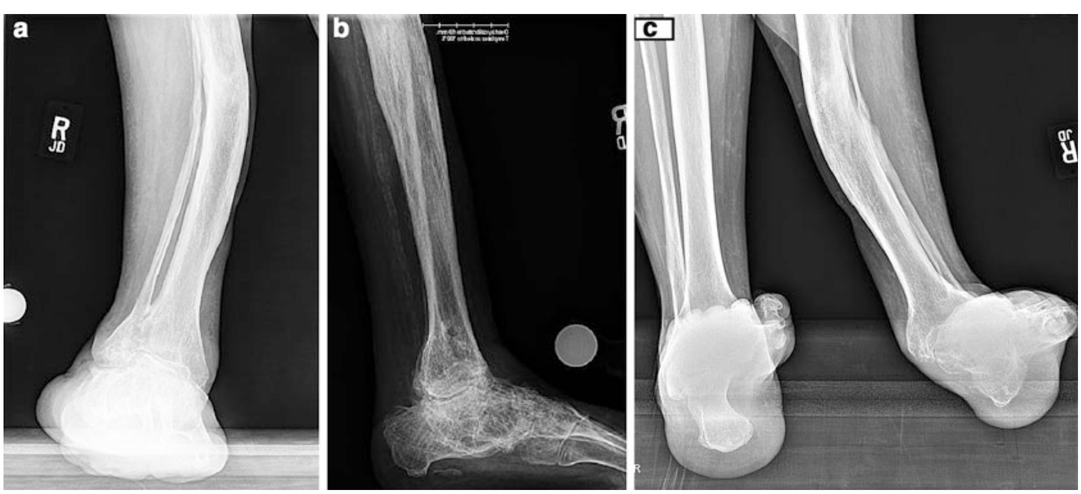

Fig. 4 (**a**) AP ankle X-ray showing valgus deformity of the tibia and ankle. (**b**) Lateral ankle X-ray showing arthrosis. (**c**) Hindfoot alignment X-ray showing valgus of the tibia and ankle

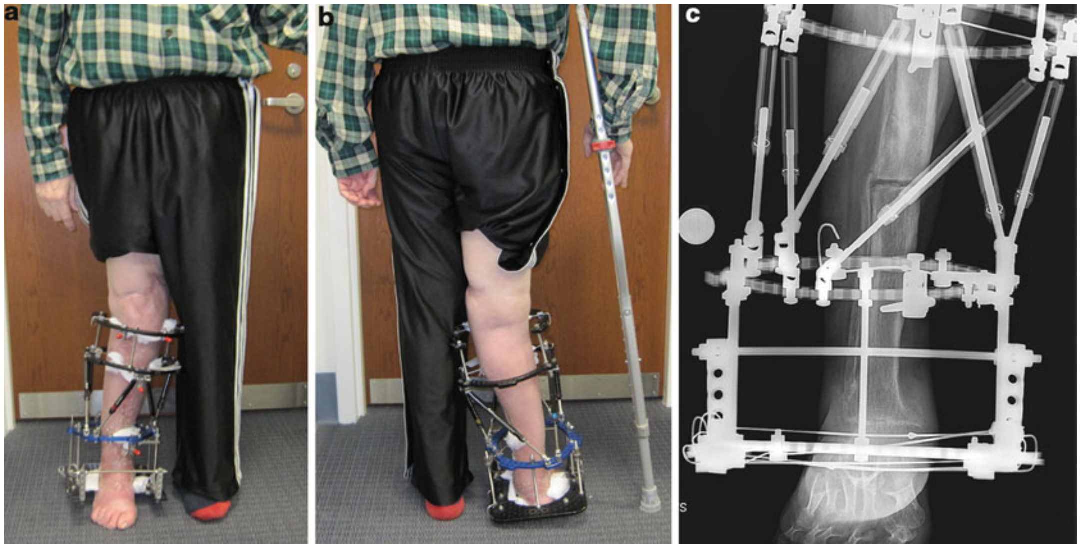

Fig. 5 (**a**–**c**) Clinical and radiographic views at the end of the tibia correction and the ankle fusion. A two-level Ilizarov/TSF was used. Acute correction of the ankle was done at the time of ankle fusion and this was stabilized with compression rods. Gradual correction was done for the tibia valgus deformity using a TSF

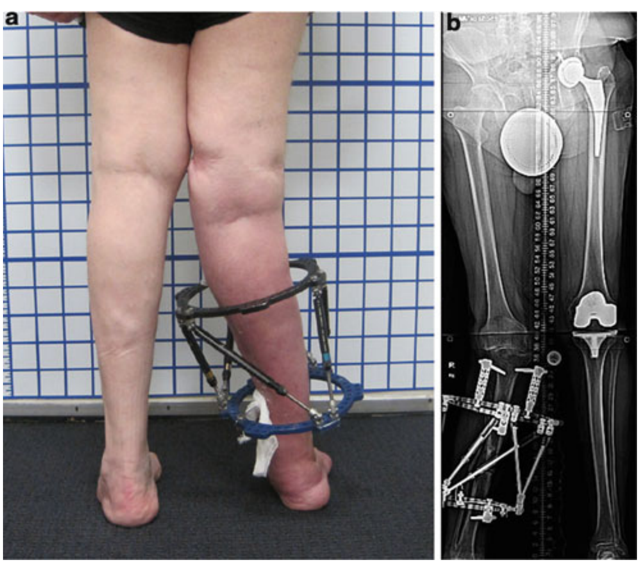

Fig. 6 There was delayed healing of the tibia. The ankle fusion part of the frame was removed and the TSF was maintained. (**a**, **b**) Back view and standing X-ray showing correction of the tibia and ankle with residual deformity at the knee

Fig. 7 After frame removal, there was concern about the tibia union and the likelihood of refracture

Fig. 8 Standing X-ray after percutaneous plating of the tibia with locked plate and constrained TKR. The skin was fragile over the plate and there was subsequent wound breakdown over the tibia plate. The plate was removed and an antibiotic cement-coated locked IM nail was inserted across the ankle fusion and tibial osteotomy retrograde from the plantar foot

8 Outcome Clinical Photos and Radiographs

See Figs. 9 and 10.

9 Avoiding and Managing Problems

1. With history of tibia osteomyelitis, poorly vascularized bone, poor soft tissue envelope, and large deformity, the primary plan was to perform a percutaneous osteotomy, correct deformity gradually, and avoid internal fixation.
2. The percutaneous plating of the tibia was done because there was a concern about refracture of the tibia after frame removal and there was tenuous skin.
3. When a wound problem occurred over the tibia plate, the plate was removed and an antibiotic-coated IM nail was inserted. A vacuum-assisted closure device was utilized.
4. A constrained TKR was done to prevent problems of postoperative instability in this unstable knee.

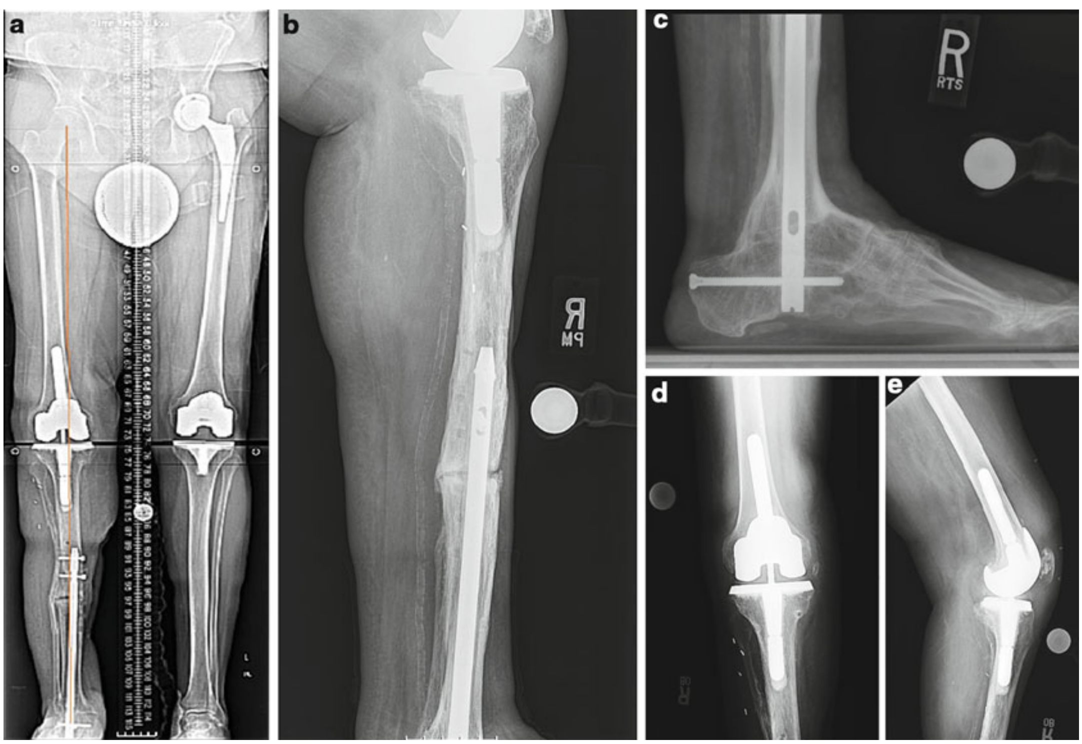

Fig. 9 Final X-rays 1 year after knee replacement. (**a**) Standing X-ray showing normal MAD line. (**b**) Lateral of tibia showing healing and stable tibia osteotomy. (**c**) Lateral of the ankle showing IM nail and healed ankle fusion. (**d**, **e**) AP/lateral of the knee showing a well-aligned constrained TKR

Fig. 10 Front (**a**), side (**b**), and back (**c**) views showing normal alignment of the knee, tibia, and ankle. Patient felt comfortable with a 17-mm lift

10 Cross-References

► Case 14: Femoral Shaft Varus Above a Total Knee Replacement Treated With a Circular Hexapod Fixator
► Case 33: Multiapical Deformity Correction in Bilateral Femur and Tibia in Rickets. LATP Technique to Decrease the Time of External Fixator

References and Suggested Reading

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Case 31: Treatment of Complex Deformity of the Lower Extremities in Hypophospatemic Rickets Using a Six-Pod Frame and Fixator Assisted Plating

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Contents

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Abstract

Proper limb alignment in hypophosphatemic rickets can be obtained using combined acute and gradual correction. Distal femoral valgus and distal tibial varus deformity were corrected with a fixator-assisted plating technique. Simultaneous deformity correction and lengthening were performed using a six-pod frame at the proximal tibia. Maintenance of proper level of serum phosphate (2.5 mg/dl) is recommended during limb lengthening of hypophosphatemic rickets patients. This case illustrates an approach to large complex multiapical and multi-segment bilateral deformity in a patient with metabolic bone disease and pathological bone.

1 Brief Clinical History

A 22 year old male suffered from hypophosphatemic rickets and complained of valgus and flexion deformities of the knee joint. Plain radiographs and clinical findings showed his both lower extremities with proximal femoral varus deformity, distal femoral valgus-flexion deformity, proximal tibial valgus deformity, and distal tibial varus deformity. His symptoms included joint pain and awkward gait, and the patient desired correction of the deformities and some modest lengthening of 3–4 cm.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

1. Varus deformity, proximal femur, bilateral.
2. Valgus deformity, distal femur, bilateral.

S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_203

Fig. 1 Photograph showing complex deformity of the lower extremity – the main problem was genu valga

Fig. 2 Photograph showing lack of full extension of both knees

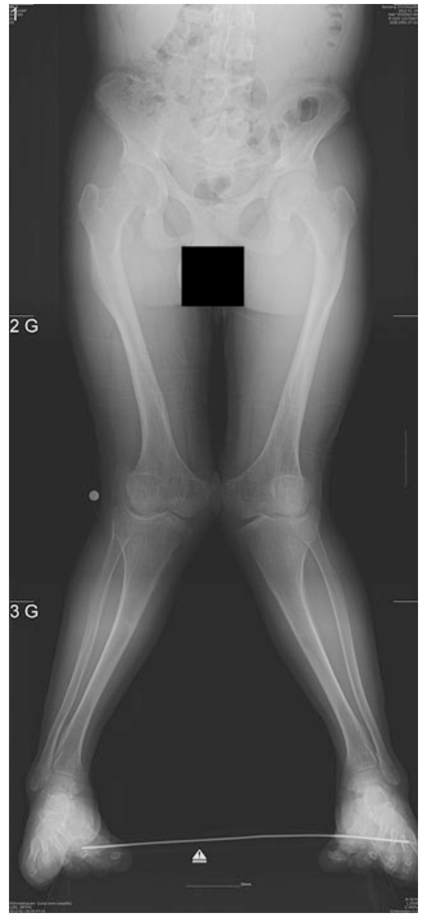

Fig. 3 Bipedal full-length standing X-ray shows his both lower extremities with varus deformity of proximal femurs (LPFA 100°/108°), valgus deformity of distal femurs (LDFA 77°/78°), valgus deformity of proximal tibias (MPTA 94°/97°), and varus deformity of distal tibia (LDTA 97°/96°)

3. Valgus deformity, proximal tibia, bilateral.
4. Varus deformity, distal tibia, bilateral.
5. Excessive anterior bowing, femur, bilateral.
6. The patient wants 3–4 cm lengthening of his lower legs.

4 Treatment Strategy

Three steps of surgeries were planned:

1. Acute correction for the distal femur and distal tibia using fixator-assisted plating technique and simultaneous lengthening and gradual correction for the proximal tibia, right side
2. Acute correction for the distal femur and distal tibia using fixator-assisted plating technique and simultaneous lengthening and gradual correction for the proximal tibia, left side

Fig. 4 Apparent knee flexion contractures due to apex anterior deformities of the femoral shafts

Fig 5 A schanz pin is inserted at distal femoral condyle from the medial side and another schanz pin is located proximal to the osteotomy level avoiding neurovascular structures. A transverse or dome-shaped osteotomy can be done and correction is performed acutely. Schanz pins can be used as "joysticks." After satisfactory correction is obtained, a pin-to-bar-type fixator is applied to maintain the alignment during insertion of the internal fixation

3. Removal of external fixator and insertion of internal fixation (intramedullary nail) to stabilize lengthened portion, if necessary

Varus deformity of the proximal femur was not addressed as it was not felt to be significant.

5 Basic Principles

Gradual correction is preferred to acute correction when the amount of correction is large, bone lengthening is necessary, and there are poor soft tissue conditions. When acute correction is planned, fixator-assisted technique is useful and a plate or an intramedullary nail can be inserted for bone stabilization.

6 Images During Treatment

See Figs. 5, 6, and 7.

7 Technical Pearls

1. Schanz pins for temporary fixation are inserted from the medial side to avoid the pathway of the plate in fixator-assisted plating technique of the distal femur.

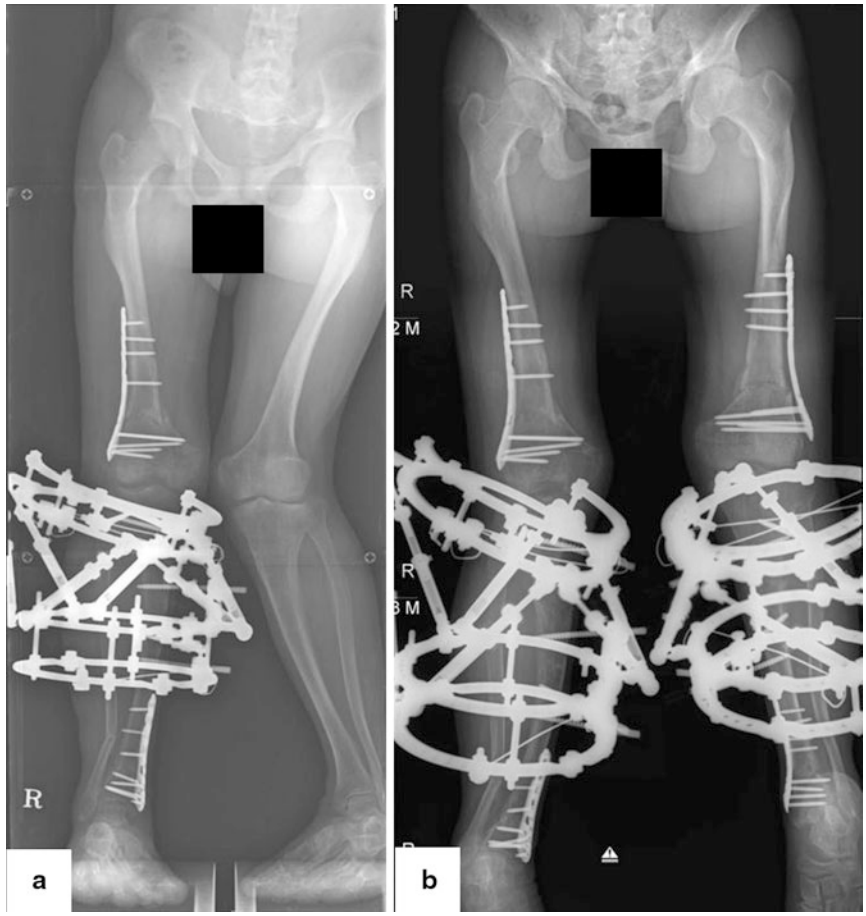

Fig. 6 Postoperative radiograph (**a**) shows adequate reduction of the distal femur and distal tibia in coronal plane. A Stewart-platform-type external fixator (Hexapod®) was applied to correct the proximal tibia valga and to perform simultaneous lengthening. Within an interval of 3 months, the *left* side was approached with the same procedures (**b**)

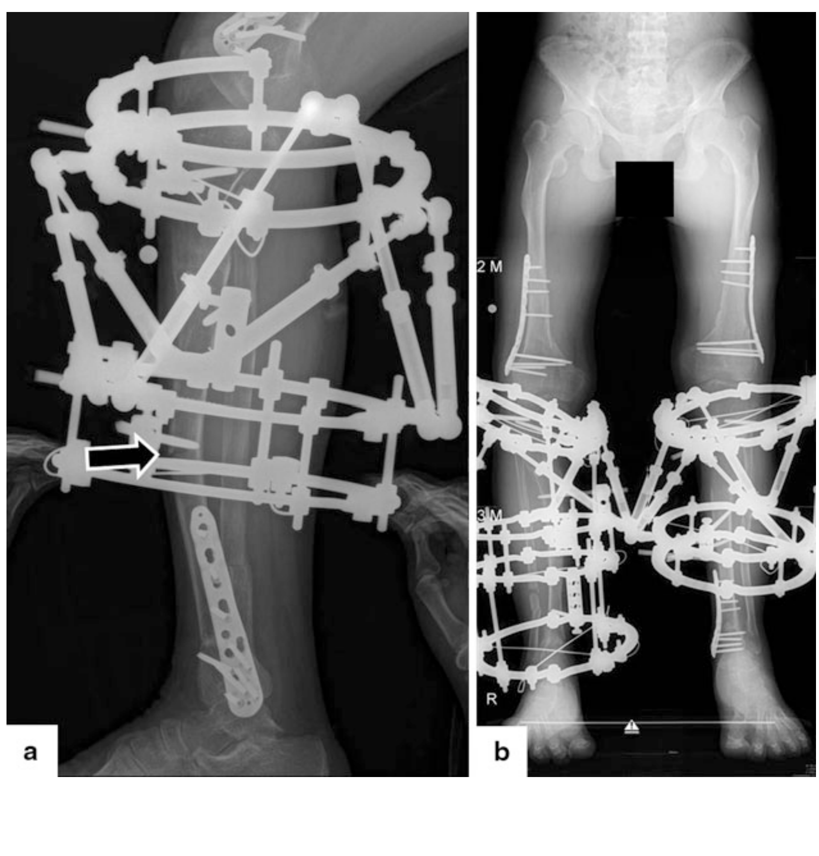

Fig. 7 Right tibia fracture (*black arrow*) occurred 5 months after the index surgery (**a**). The external fixator was extended to the distal tibia on the *right* side and the correction and lengthening (3 cm) for both proximal tibias were completed (**b**). Normal mechanical axis of both lower extremities has been restored

Fig. 8 Flexible and rigid intramedullary nails were used to augment the stability of the tibia, 2 weeks after removing the external fixators. Proper mechanical axis and joint orientation were obtained (**a**, **b**)

Fig. 9 Clinical photos after completion of the treatment

2. Prophylactic release of the peroneal nerve is recommended, if more than 20° of acute valgus correction is planned around the knee joint.
3. Conversion to internal fixation after prolonged external fixation requires a 2–3 week interval to help decrease the risk of the infection.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

Maintenance of serum phosphate level higher than 2.5 mg/dl is recommended for a proper regenerate bone healing.

10 Cross-References

▶ Case 33: Multiapical Deformity Correction in Bilateral Femur and Tibia in Rickets. LATP Technique to Decrease the Time of External Fixator

11 See Also in Vol. 1

Case 100: Hypophosphatemic Rickets with Bilateral Severe Genu Varum. Retrograde Fixator Assisted Nailing for Femurs and Double Level Tibial Osteotomies with TSF
Case 101: Vitamin D-Resistant Hypophosphatemic Rickets Treated by Double-Level Femoral Osteotomy with Internal Fixation and Proximal Tibial Osteotomy with Gradual Deformity Correction

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Part V

Adult Deformity: Integrated Fixation

Case 32: Acute Correction of Tibial Deformity and Plate Fixation, with Subsequent Lengthening Over Plate

Mahmoud A. El-Rosasy

Contents

Abstract

The use of circular external fixator for gradual correction of distal tibial deformity associated with hypertrophic nonunion has been a successful technique (Saleh M, Royston S, J Bone Joint Surg Br 78(1):105–109, 1996). Due to inconvenience of the external fixator, a more convenient fixation method could be used in carefully selected cases (McKee MD, Yoo D, Schemitsch EH, J Bone Joint Surg Br 80:360–364, 1998). Provided that the resultant leg length discrepancy after treatment is less than one inch and is acceptable by the patient, then acute correction of the deformity and fixation by a locked compression plate has been successful with gratifying results to both the patient and surgeon (Helfet DL, Jupiter JB, Gasser S, J Bone Joint Surg Am 74(9):1286–1297, 1992; El-Rosasy MA, El-Sallakh SA, Strateg Trauma Limb Reconstr 8(1):31–35, 2013). In this case fixator-assisted correction of a hypertrophic nonunion with deformity was done followed by plate insertion. Staged lengthening over the plate was performed with a monolateral frame. Two examples of integrated fixation techniques (fixator-assisted plating and lengthening over a plate) were combined in the treatment of this patient.

1 Brief Clinical History

The case of a 29 year old male patient is being presented. He had previous surgery, limb lengthening to increase stature; however, premature removal of the external fixator led to distal tibia regenerate fracture and valgus deformity of the distal tibia. Due to lack of proper fixation, a stiff and hypertrophic nonunion resulted, and this was how the patient presented to us.

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Fig. 1 (**a**, **b**) Preoperative clinical photos show angular deformity of the lower leg due to fracture of a lengthening regenerate. (**c**, **d**) Preoperative X-rays show hypertrophic nonunion of the lower third of the tibia with medial angulation

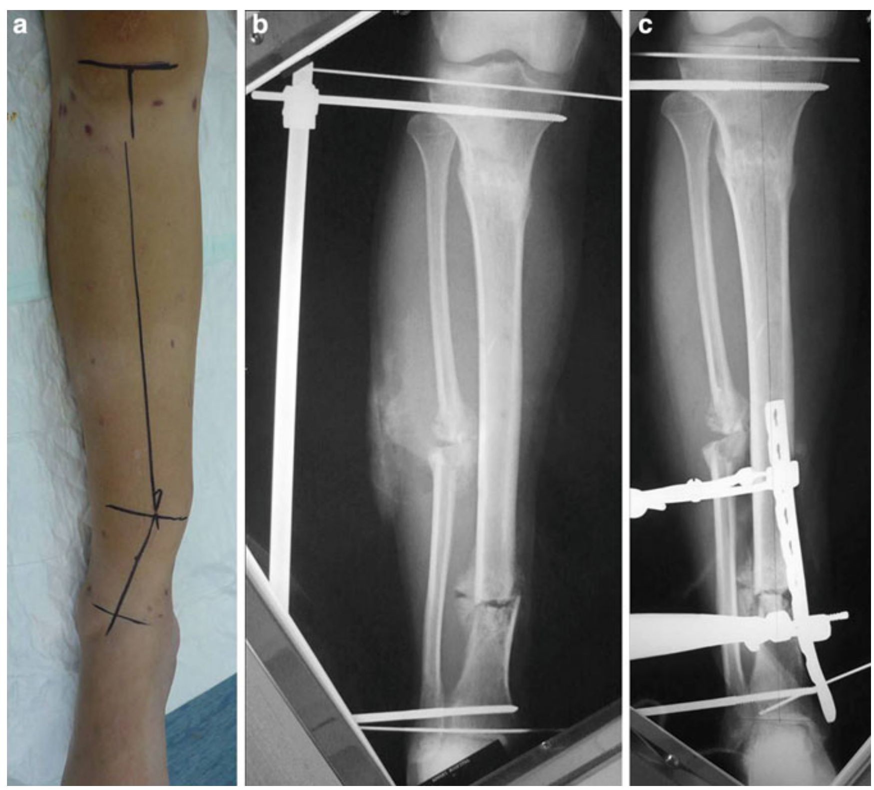

Fig. 2 (**a**) Intraoperative photo shows the planning of deformity correction. (**b**) Intraoperative radiograph after application of the temporary monolateral external fixator to hold the correction after osteotomy through the apex of the deformity. (**c**) Radiograph after deformity correction and preliminary application of a pre-contoured locked compression plate (*LCP*)

Fig. 3 (**a**, **b**) Immediate postoperative radiographs show the restoration of the mechanical axis and fixation with an LCP

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Stiff nonunion of the tibia with deformity.
2. The patient cannot accept another treatment using circular external fixator due to his previous experience with the device.
3. Expected leg length discrepancy of about 2 cm after deformity correction.

4 Treatment Strategy

The treatment strategy was to acutely correct the deformity using a temporarily applied external fixator to hold the correction during plate application. The external fixator is removed at the end of the procedure. A neutral wedge osteotomy is adopted to have good bone contact and minimize soft tissue stretching. In the follow-up, the patient

Fig. 4 (**a**–**d**) Follow-up radiographs and clinical photographs after consolidation of the nonunion and restoration of limb alignment

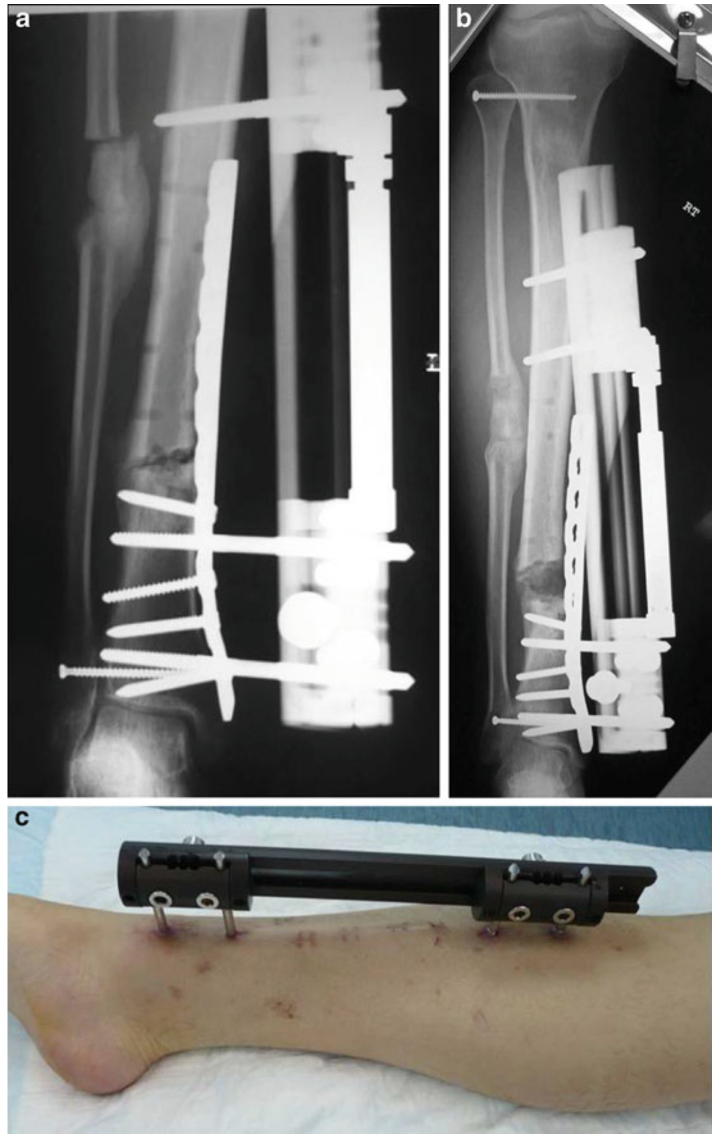

Fig. 5 (**a**, **b**) Radiographs show the application of a monolateral external fixator for tibial lengthening over plate after unlocking of the proximal screws and temporary fixation of the proximal and distal tibiofibular joints by percutaneously inserted cannulated screws to avoid tibiofibular dissociation. (**c**) Clinical photo shows the application of a monolateral external fixator (Orthofix LRS system) for distraction of the osteotomy

requested to correct a residual LLD of 2 cm, and then the plan was to do tibial lengthening over plate after application of a monolateral external fixator, unlocking of the proximal screws through stab incision over the head of each screw, and tibial lengthening osteotomy. After equalization of leg length, the screws were relocked at the end of distraction phase and the fixator was removed.

5 Basic Principles

1. Preservation of the soft tissue envelope and limitation of bone resection to minimum.
2. Careful application of a pre-contoured plate to avoid loss of reduction.
3. Avoid contact between internal and external fixation.
4. External fixator placement in a manner that does not interfere with insertion of subsequent internal fixation.

6 Images During Treatment

See Figs. 2, 3, 4, and 5.

7 Technical Pearls

The half-pins of the external fixator have to be inserted parallel to the joint line on the side opposite to plate insertion. The excess bone is shaved off the medial surface of the tibia and used as a local autograft to fill any resultant

Fig. 6 (**a**, **b**) After achievement of the desired leg length, the proximal screws were relocked, the fixator was removed, and the tibiofibular transfixion screws were extracted. The tibial and fibular osteotomies are consolidated

bone gap. An intraoperative hard-copy radiograph is obtained for evaluation of the correction (mechanical axis restoration) and conformity of the plate to the bone surface.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

The magnitude of the deformity and direction of correction should be considered to avoid sudden stretch of the neurovascular bundle. The direction of deformity correction should be considered to avoid sudden stretch of the neurovascular bundle, e.g., in case of distal tibial varus deformity, the posterior tibial neurovascular structures are at risk in which case a prophylactic decompression of the tarsal tunnel should be performed (Paley and Herzenberg 2002). The expected leg length discrepancy is explained to the patient. In case the patient was not happy with the residual leg length discrepancy, then, leg lengthening over the plate could be performed. Another consideration is the soft tissue condition and history of deep infection which would preclude the use of internal fixation.

During the lengthening over a plate, care must be taken to avoid contact between internal and external fixation to minimize the risk of infection.

10 Cross-References

▶ Adult Deformity: An Introduction
▶ Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique

11 See Also in Vol. 2

Case 26: Plating After Lengthening

References and Suggested Reading

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Case 33: Multiapical Deformity Correction in Bilateral Femur and Tibia in Rickets. LATP Technique to Decrease the Time of External Fixator

León Gonzalo Mora Herrera

Contents

Abstract

Lengthening and then plating (LATP) was used to decrease the total time needed in external fixation in this patient with complex bilateral mutiaplical oblique plane deformities. A 16 year old girl with rickets was treated with multilevel osteotomies of both femurs and tibias, and deformity correction and lengthening was performed with monolateral external fixators. Plating was performed, and frames were removed before complete bone union. This allowed early removal of frames and protection against refracture.

1 Brief Clinical History

A 16 year old girl presented with bilateral lower extremity varus, short stature, difficulty walking, and pain in both her knees. She was very unhappy with her appearance and impaired mobility, and this was associated with low self-esteem and socialization problems.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11.

3 Preoperative Problem List

- Severe bilateral lower extremity varus
- Multiapical deformities, oblique and rotational deformities
- Obesity and depression related to orthopedic condition
- Neurovascular structures at risk

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Fig. 1 Bilateral severe lower extremity varus defomities

Fig. 2 Multiapical bone deformities in femur and tibia

Fig. 3 Resolution CORA points – preoperative plan (AP X-ray)

Fig. 4 Mechanical axis preoperative planning, right femur, AP X-ray showing 27° varus deformity

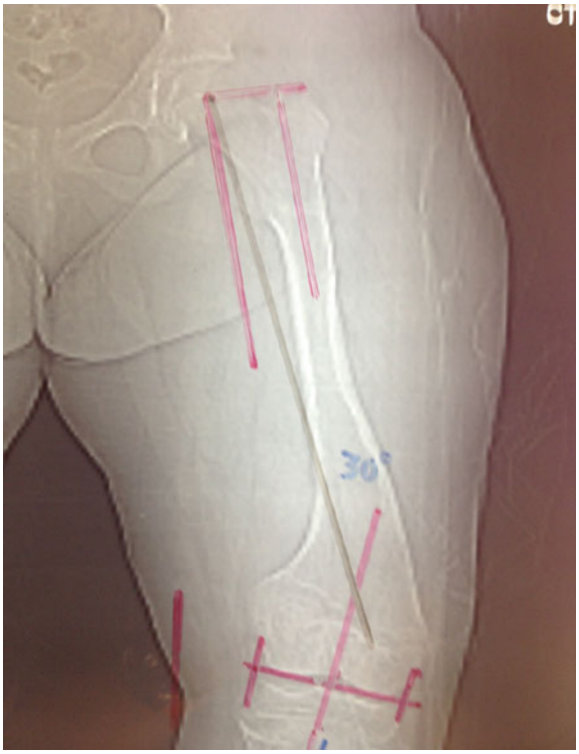

Fig. 5 Mechanical axis preoperative planning, left femur, AP X-ray showing 30° varus deformity

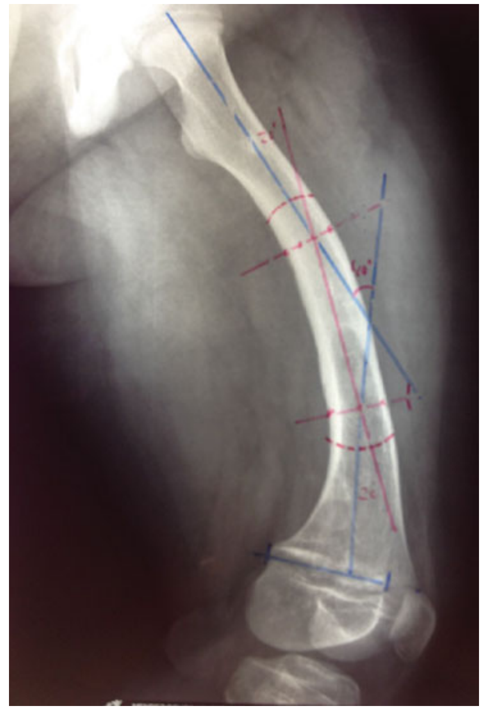

Fig. 7 Preoperative planning of left femur, lateral X-ray showing multiapical deformity. The total deformity is 50° but resolves best to a proximal deformity of 20° and a distal deformity of 26°

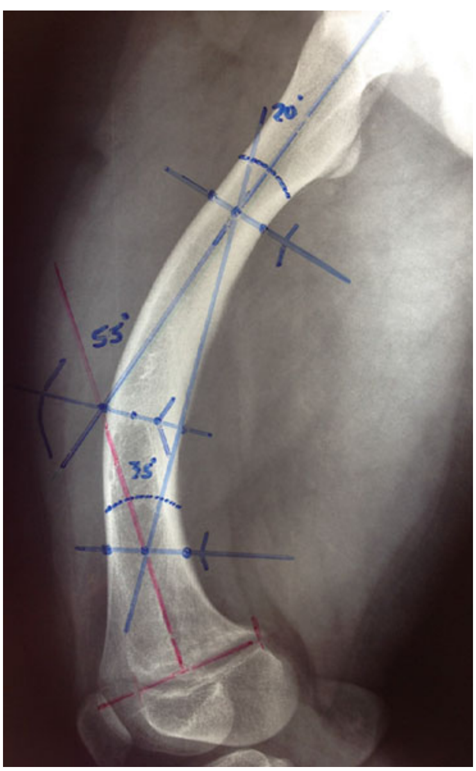

Fig. 6 Preoperative planning of right femur, lateral X-ray showing multiapical deformity. The total deformity is 55° but resolves best to a proximal deformity of 20° and a distal deformity of 35°

Fig. 8 Left femur preoperative planning showing anticipated two level osteotomy and placement of external fixation pins. Clusters of pins are placed orthogonal to each of the three segments

Fig. 9 Preoperative planning bilateral tibias showing anticipated osteotomies and placement of external fixation pins. Note plan for proximal and distal tibia-fibula pins to stabilize tibia-fibula joints

Fig. 10 Close up view of left ankle showing plan for distal tibia and fibula osteotomy and external fixation pin placement including tibia-fibula pin to stabilize syndesmosis

Fig. 11 Lateral view of both tibias showing planned sagittal plane corrections

4 Treatment Strategy

– Use multilevel monolateral external fixators for multiapical corrections.
– Less invasive external fixation with hydroxyapatite (HA)-coated half pins.
– Use a combination of acute and gradual correction. Acute correction of angular deformity is followed by gradual lengthening.
– Plan for early change from external fixation to internal fixation.
– Early and effective physiotherapy.

5 Basic Principles

– Stabilization of bone and periarticular segments.
– Preoperative planning and articular realignment.
– When building the external fixator on the bone, insert pins orthogonal to each segment. After osteotomy, the

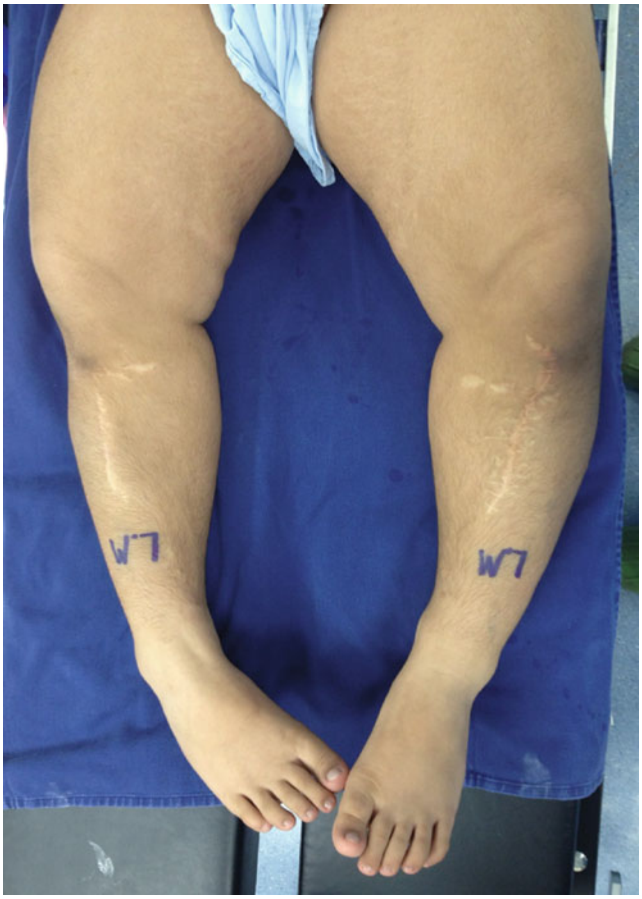

Fig. 12 Bilateral total lower extremity approach in operating room

segments and pins are manipulated to correct the deformities with resulting parallel pins.

– The combination of external fixation and then staged internal fixation has the principal advantage of decreasing the time in external fixation and protecting against refracture. However, the principal disadvantage and risk is infection. Strategies to decrease this risk of infection include minimization of contact between external and internal fixation.

6 Images During Treatment

See Figs. 12, 13, 14, 15, 16, and 17.

7 Technical Pearls

– Locked plate allows the plate to sit off the bone. As the plate is inserted, the locking nature of the screws does not pull the bone to the plate, which would cause undesirable deformity.
– At the time of plate insertion and frame removal, pin sites are excised. Care is taken to minimize contamination of the internal fixation.
– Plates are inserted using a minimal incision technique. This entails sliding the plate in a submuscular tunnel that is off plane to the external fixator.

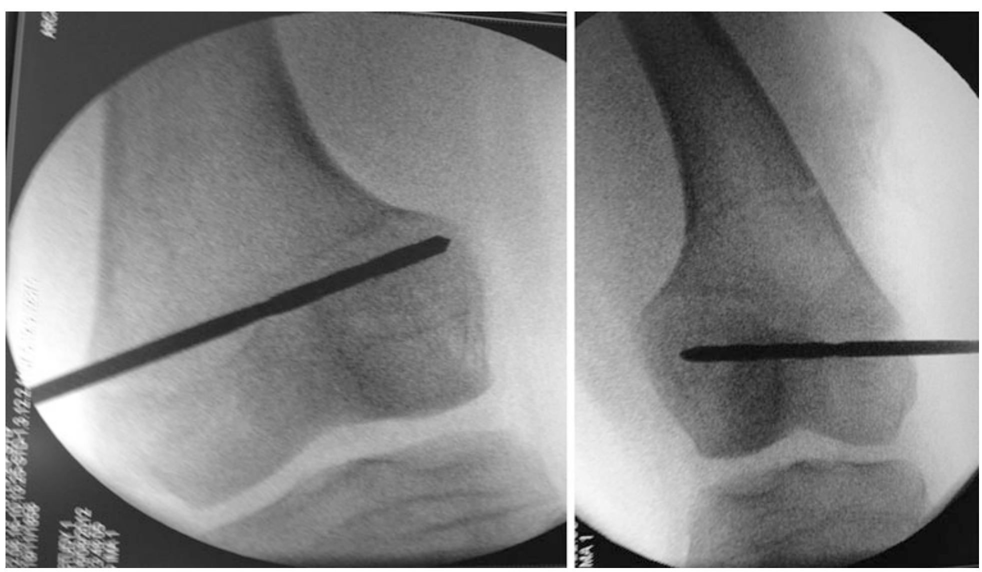

Fig. 13 Intraoperative insertion of half-pins orthogonal to the mechanical axis of the distal femur and knee

Fig. 14 After osteotomy of left distal femur with correction of angulation and intentional translation. This is Paley osteotomy rule two which necessitates translation when the CORA is at a different point than the actual osteotomy. Recall from Fig. 5 that the CORA was distal to the osteotomy made

Fig. 15 Postoperative stabilization in bilateral femur and tibia frames

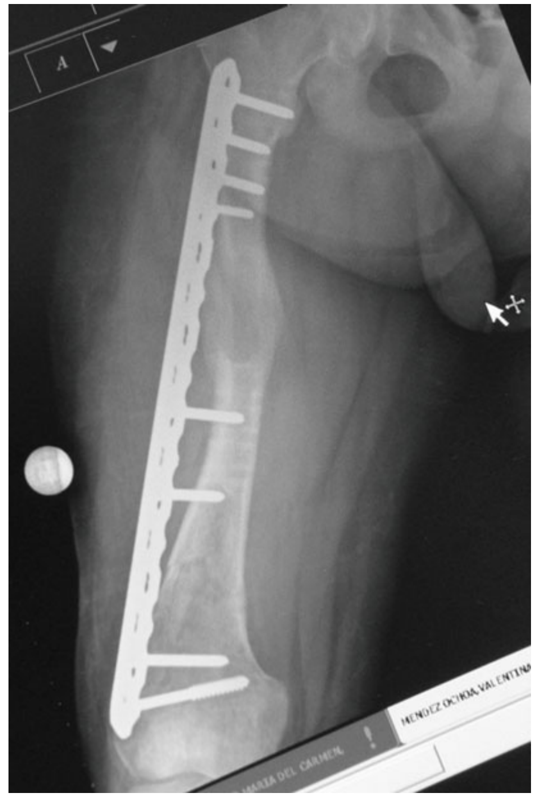

Fig. 16 After removal of frames and insertion of locked plate in right femur. Note progressive consolidation of proximal lengthening site

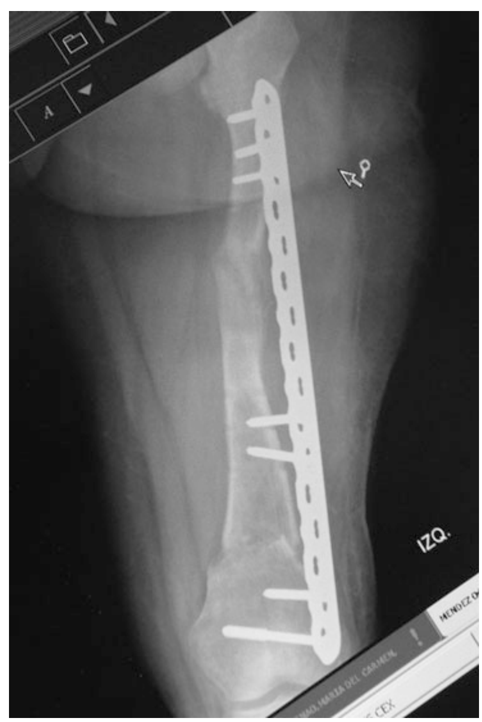

Fig. 17 After removal of frames and insertion of locked plate in left femur. Note progressive consolidation of proximal lengthening site

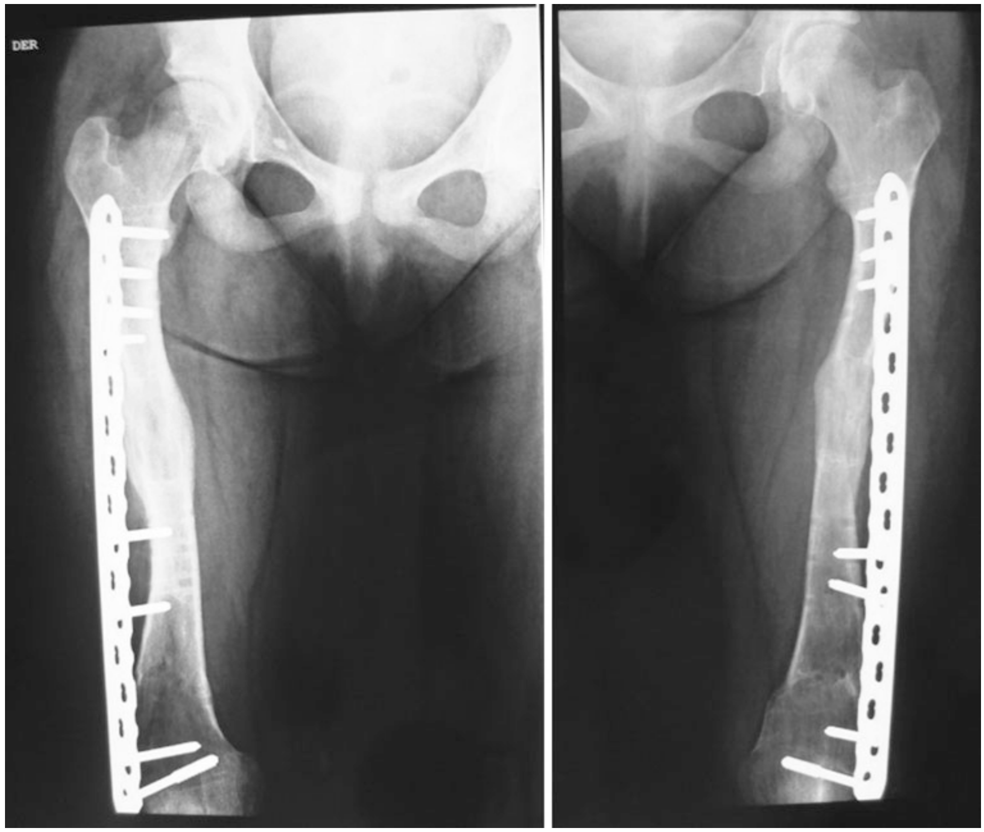

Fig. 18 Bilateral femur AP X-rays showing union and deformity correction with locked plates in place

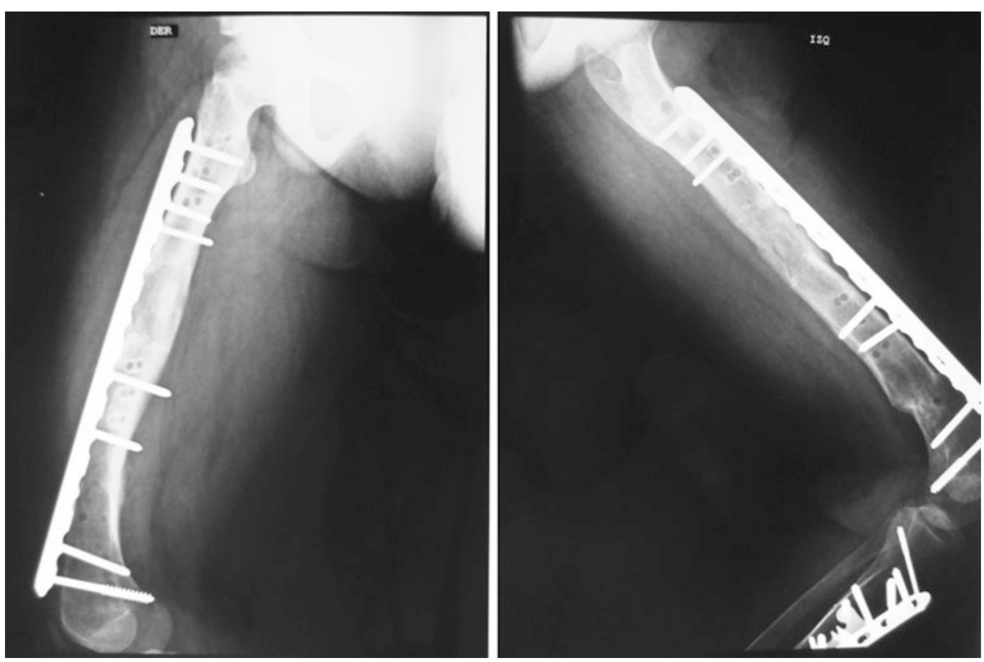

Fig. 19 Bilateral femur lateral X-rays showing union and deformity correction with locked plates in place. Note that the plates are positioned antero-lateral which is off plane from the fixators which were positioned from the lateral side

Fig. 20 Bilateral AP tibia X-rays with locked plates in place showing correction of deformity and bony union

8 Outcome Clinical Photos and Radiographs

See Figs. 18, 19, 20, and 21.

9 Avoiding and Managing Problems (SRR)

1. Infection
   (a) Avoid contact between internal and external fixation. In this case, the pin sites were excised, and the plate was inserted off plane to the external fixation pins.
   (b) Other approaches can be used in a general sense when performing LATP. The fixator can be applied in such a way as to leave a clean corridor for plating. This approach minimizes contact between internal and external fixation and even allows the fixator to remain in place when plating. The fixator is removed after the plate is inserted (Harbechuski R, Fragomen AT, Rozbruch SR).
   (c) Another approach is to delay the insertion of a plate after the fixator is removed. Patients may be hospitalized and placed on antibiotics during this interim period. The main disadvantage of this approach is that the bone is unprotected during this time and at risk for fracture and deformation.

Fig. 21 Final alignment noted on front view. Patient has gained several centimeters of height, correction of deformity, and thinning of legs. Dramatic aesthetic and psychological improvement has been achieved

2. Neurovascular injury
   (a) Large deformity correction places tension on soft-tissue structures in the concavity of the deformity.
   (b) Acute and/or gradual deformity correction is a strategy to avoid injury.
   (c) Pulses should be palpated before and after acute deformity correction to make sure that blood flow is not compromised.
   (d) Nerve injury can be minimized with nerve release and gradual deformity correction. An understanding of the nerves at risk with deformity correction is necessary. For example, valgus deformity correction at the knee stretches the peroneal nerve, Varus deformity correction at the ankle stretches the posterior tibial nerve in the tarsal tunnel.

10 Cross-References

▶ Case 20: Acute Correction of Combined Deformity of the Tibia by Double Level Osteotomy and Fixator Assisted Plating Technique
▶ Case 25: Correction of Windswept Rotational Deformity with Fixator Assisted Plating Technique
▶ Case 31: Treatment of Complex Deformity of the Lower Extremities in Hypophospatemic Rickets Using a Six-Pod Frame and Fixator Assisted Plating
▶ Case 32: Acute Correction of Tibial Deformity and Plate Fixation, with Subsequent Lengthening Over Plate

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Case 34: Simultaneous Lengthening and Deformity Correction over Customized Intramedullary Locking Nail (LON) for Multidimensional Deformity of the Proximal Tiba

Peter Helmut Thaller and Florian Wolf

Contents

Abstract

Deformity correction using intramedullary (IM) nailing is a well-established technique. Integrated techniques like lengthening over nail (LON), lengthening and then nailing (LATN), lengthening and then plating (LAP), and lengthening along a plate (LAAP) can substantially reduce external fixation time.

This is the case of a 17 year old patient with biplanar malalignment of the proximal tibia with minor rotational deformity and shortening. All aspects of the deformity could be addressed using a LON technique with a distraction index (DI) of 1 mm/d, an external fixation index of (EFI) 21 d/cm, and a weight bearing index (WBI) of 34 d/cm. The final result was excellent with fast recovery and early return to sports. The latest follow-up after 2.5 years confirmed full recovery.

1 Brief Clinical History

The 17 year old patient presented with a leg length discrepancy of minus 20 mm of the right leg and disabling instability of the right knee joint. He reported the cause to be from a hard hit by an ice hockey puck at the proximal tibia when he was younger. The clinical examination of the right knee showed apparent hyperextension with a range of motion of E/F 20-0-140 and a clinically evident patella baja. In 0° extension position, the knee joint had severe medial-lateral instability. In addition there was a valgus malalignment and there was a slight torsional deviation of 10° less external torsion compared to the left lower leg.

The patient underwent acute correction of the deformity, insertion of an IM nail, and LON with a circular external fixator. Removal of circular frame and distal interlocking were performed after 40 days. Partial weight bearing was administered for 10 weeks after initial surgical procedure, and within this time the patient reached full, symmetric range of motion of both knees. A distraction index (DI) of

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_291

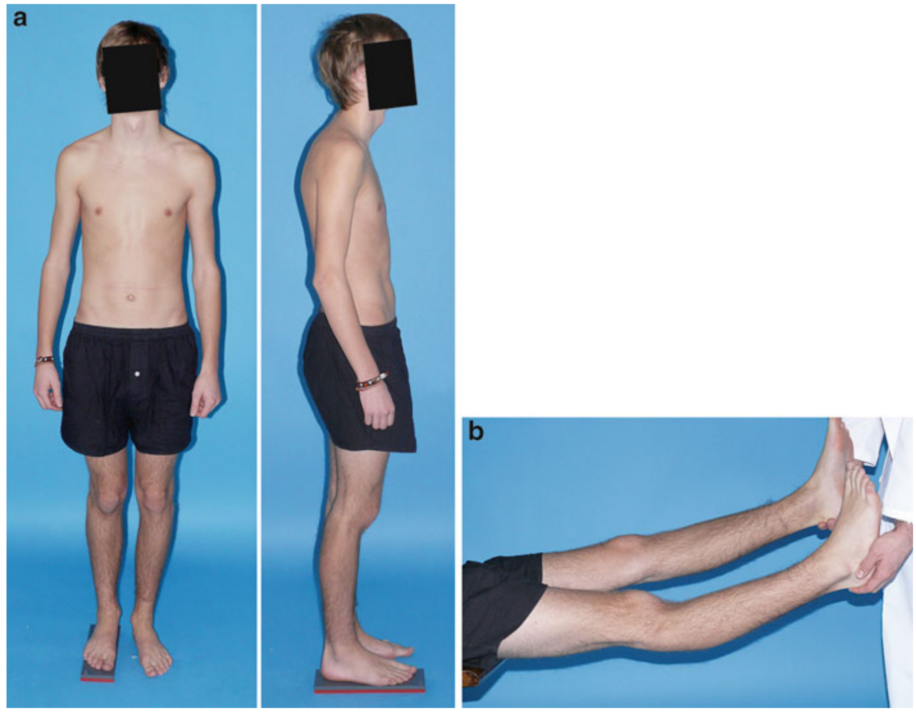

Fig. 1 (**a**) Leg length discrepancy of minus 20 mm at the right side. (**b**) Apparent hyperextension of 20° of the right knee with instability in neutral position

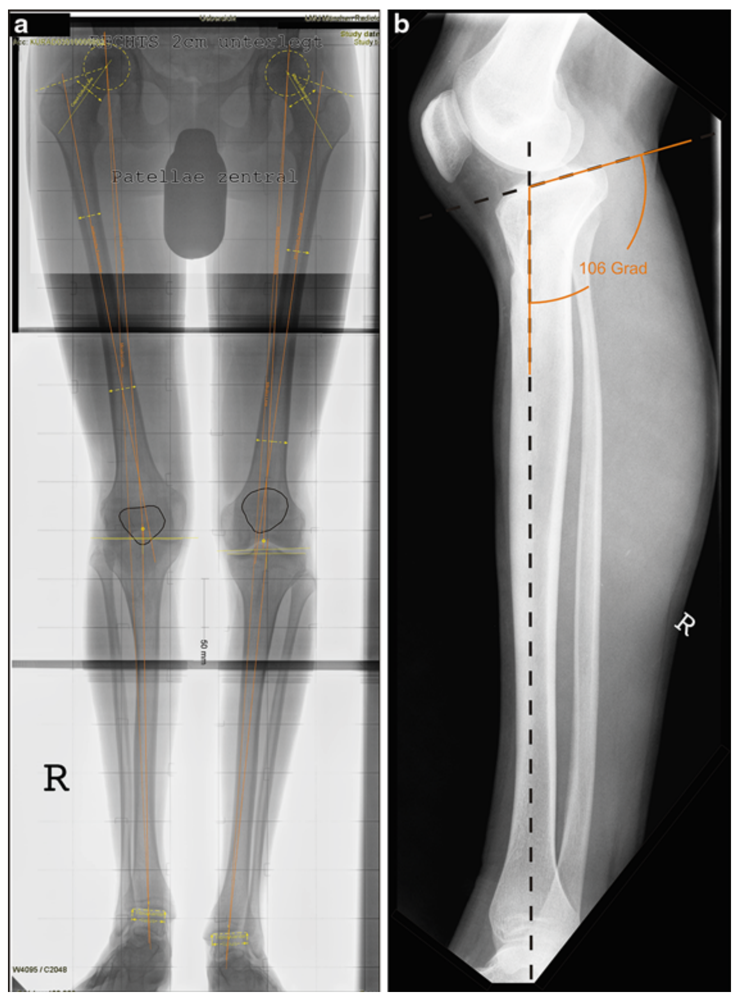

Fig. 2 (**a**) Digital analysis (CorelDraw®) of the long-standing radiograph (*LSR*). Mechanical and anatomic axes are marked and the projection of the patellae is outlined. The valgus deformity of the right leg shows a mechanical axis deviation of 16 mm lateral to midline indicating valgus. In total the length discrepancy with predominant shortening of the right lower leg is 20 mm. (**b**) On the lateral view the posterior proximal tibial angle (*PPTA*) is 106° (normal is 75–85°)

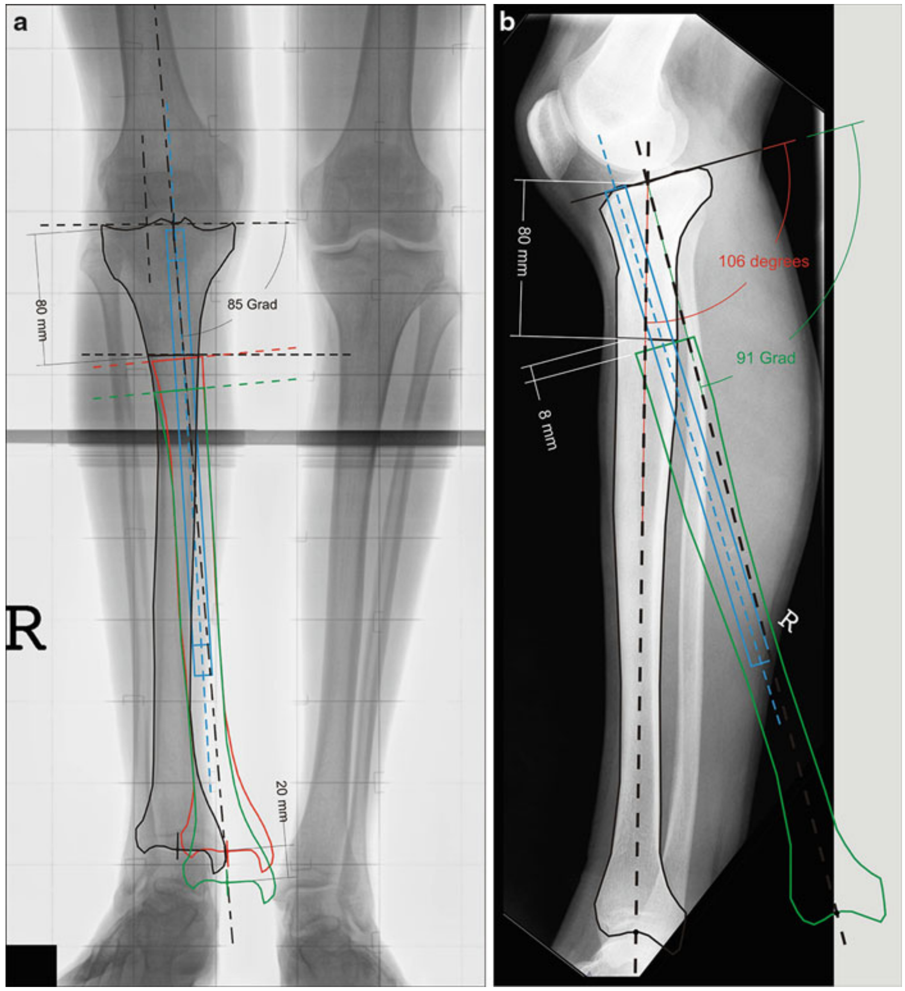

Fig. 3 (**a**) Preoperative digital endpoint first (*EPF*) planning of deformity correction in the frontal plane. (**b**) Correction of the PPTA is planned by illustrating the required aiming direction of the stiff reamers in the proximal fragment and by measuring of the required frontal open wedge

1 mm/d was reached and treatment could be finished with an external fixation index (EFI) of 20 d/cm and a weight bearing index (WBI) of 35 d/cm. At a late follow-up examination after 2.5 years, the patient did not report about any complaints or physical limitations.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

Combined biplanar and torsional deformity of the proximal tibia with:

(a) Pathologic posterior proximal tibial angle (PPTA) of 106° representing apex posterior deformity of the proximal tibia
(b) Malalignment with mechanical axis deviation (MAD) of 16 mm lateral to midline
(c) Leg length discrepancy (LLD) of minus 20 mm
(d) Slight torsional deformity with 10° less external torsion of the right lower leg
(e) Patella baja with subsequent limited nailing approach to the proximal tibia
(f) Disabling knee joint instability in neutral position

4 Treatment Strategy

Lengthening over a conventional intramedullary nail with multiple proximal interlocking options was combined with acute deformity correction and fixation by circular Ilizarov frame for the distraction period. For the correction of the PPTA, preparation of the medullary cavity of the proximal fragment was done with a special steel sleeve system and rigid reamers. Because of a lack of sufficient experience with

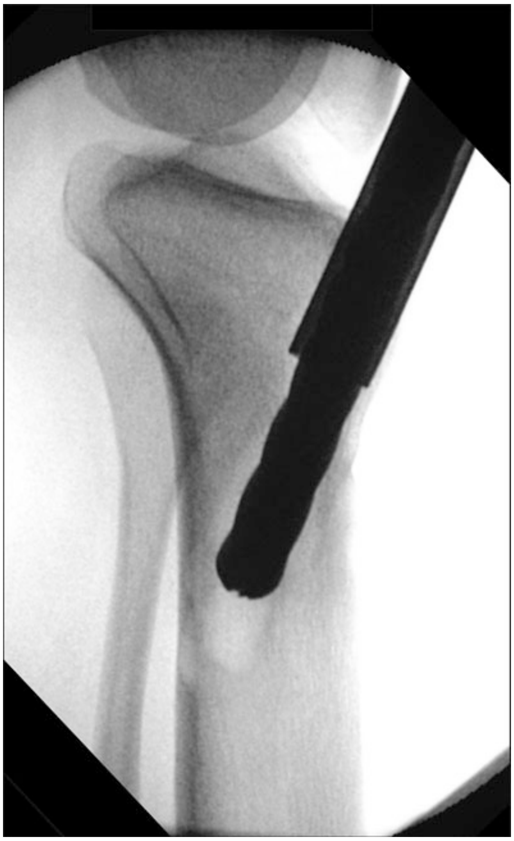

Fig. 4 Preparation of the proximal fragment: steel sleeves protect the entry point in the bone, patellar tendon, and surrounding soft tissue and enable minor subluxation of the tibia

the new suprapatellar approach at that time, the surgery was planned and performed with an infrapatellar approach. The titanium alloy intramedullary nail was customized in its curvature in both planes by a sterile custom-made bending device.

In contrast to HEF, the LON technique does not allow later correction of the alignment, and a preoperative "endpoint first" (EPF) planning was performed, which defines the precise osteotomy position and the shape of the intramedullary cavity's preparation.

Steps of the surgical procedure:

1. Preparation of the medullary cavity (path of the nail) in the proximal fragment
2. Minimally invasive drill bit osteotomy, minimal-open osteotomy of the fibula
3. Preparation of the medullary cavity of the distal fragment
4. Osteosynthesis with intramedullary nail and intraoperative control of axis by X-ray grid method and control of range of motion
5. Removal and customizing of the nail for final axial corrections
6. Reinsertion of the nail with proximal interlocking and mounting of an Ilizarov circular frame, considering the desired torsional correction
7. Distal interlocking and removal of the Ilizarov frame in a second minor surgical procedure after reaching the distraction goal (confirmed by low-dose CT scout)

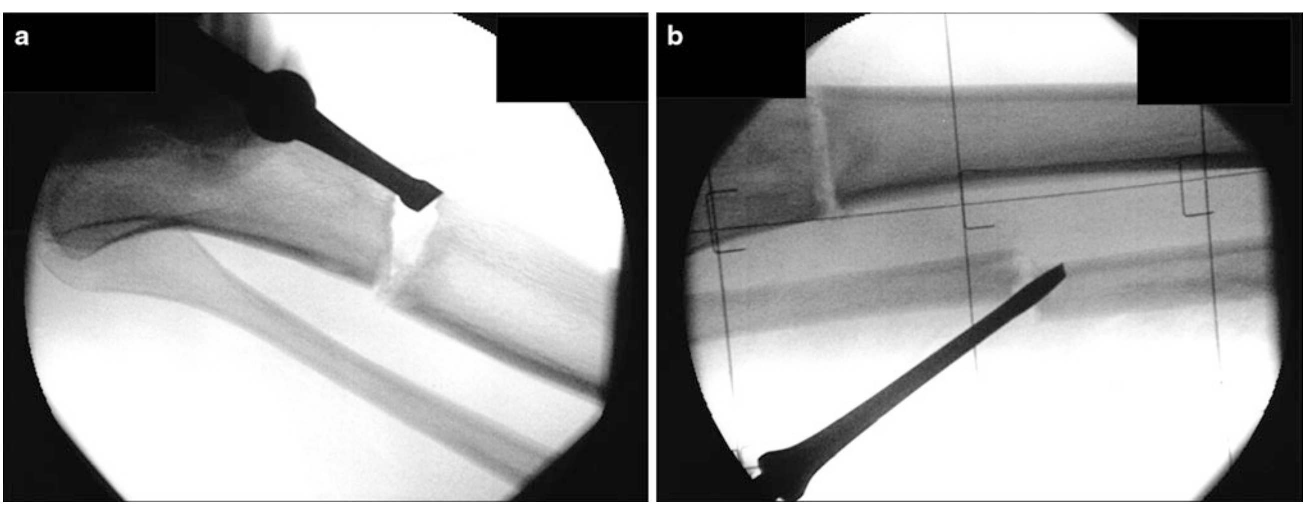

Fig. 5 (**a**) Drill bit osteotomy of the tibia via stab incision and completion with an osteotome. (**b**) The osteotomy of the fibula is done via minimal-open approach

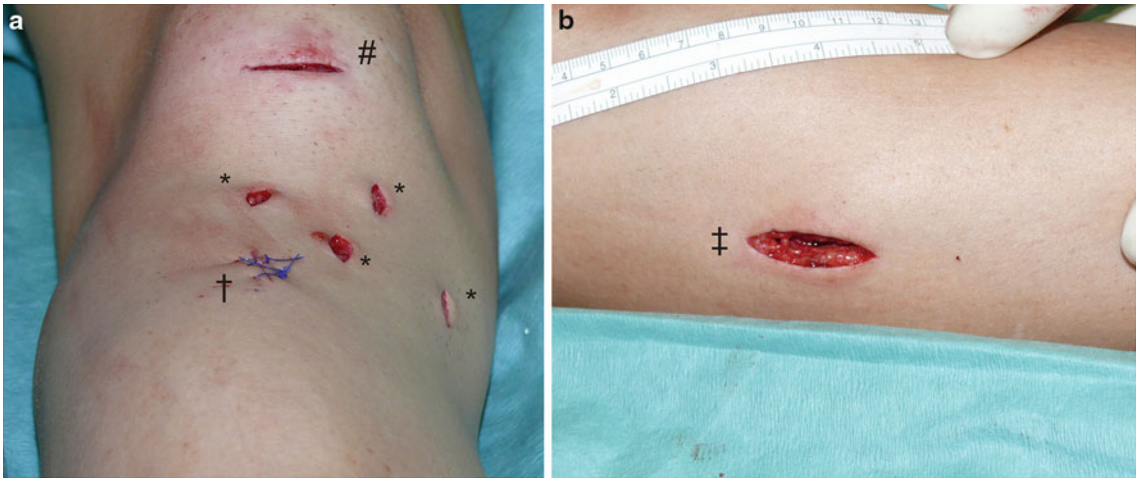

Fig. 6 Minimal incision approach. (**a**) Access to the medullary cavity via transverse approach (#), incision for osteotomy of the tibia with drill bit technique (†), stab incisions for proximal interlocking of the nail (*), (**b**) incision for fibular osteotomy (‡)

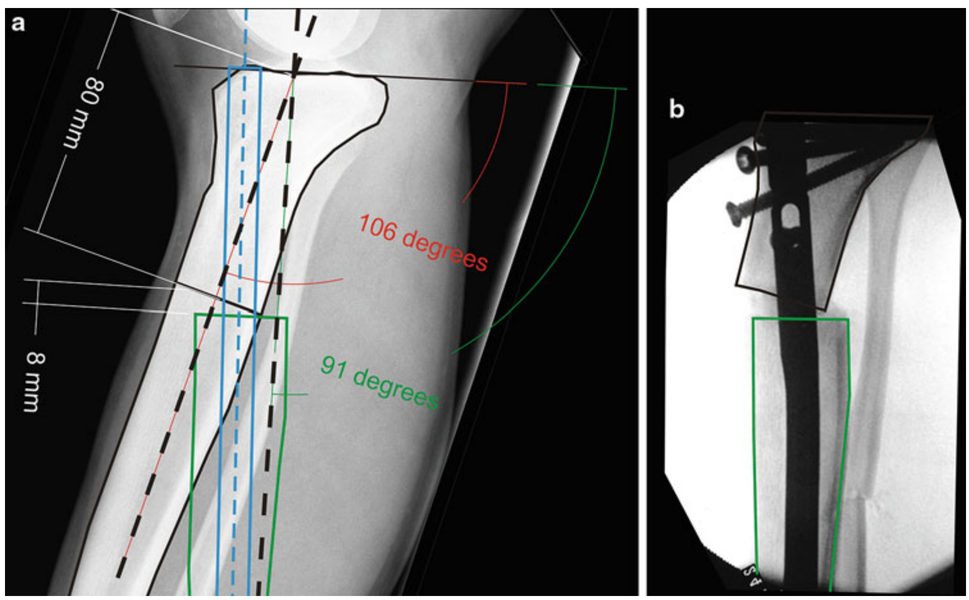

Fig. 7 (**a**, **b**) Intraoperative control of the required amount of correction by comparison of the preoperative planning with the intraoperative X-ray

5 Basic Principles

This case requires meticulous preoperative clinical and radiological analysis of the deformity (Thaller et al. 2005). Clinical findings and radiological analysis of alignment and angles show a deformity of the proximal tibia, which results in valgus axis and recurvatum deformity of the proximal tibia. It is important to understand that the hyperextension of the knee on physical exam was apparent and that the etiology is an apex posterior (recurvatum) deformity of the proximal tibia. A growth plate injury of the anterior aspect of the proximal tibial growth plate resulted in asymmetrical growth and the apex posterior deformity.

6 Images During Treatment

See Figs. 4, 5, 6, 7, and 8.

7 Technical Pearls

- Digital preoperative planning of multiplanar deformity correction by applying the EPF method
- Lengthening over nail (LON) technique
- Stable fixation of the short proximal fragment by five proximal interlocking bolts and angular stable locking system (ASLS)

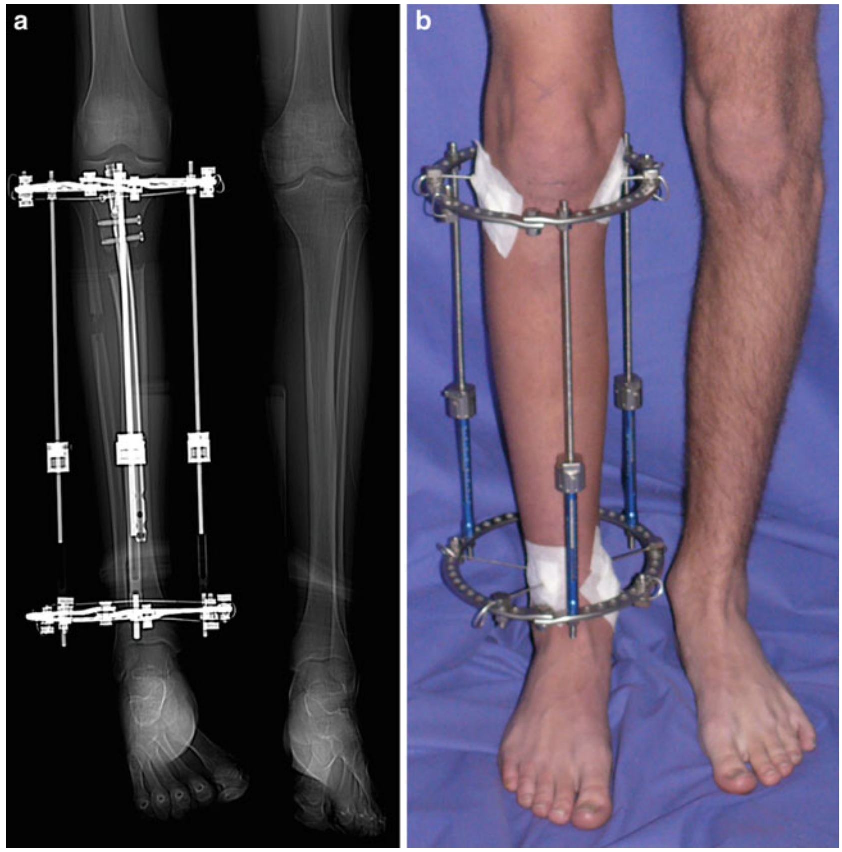

Fig. 8 (**a**) Control of equal leg length by low-dose CT scout. (**b**) Clinical examination after 20 days of lengthening for determination of leg length

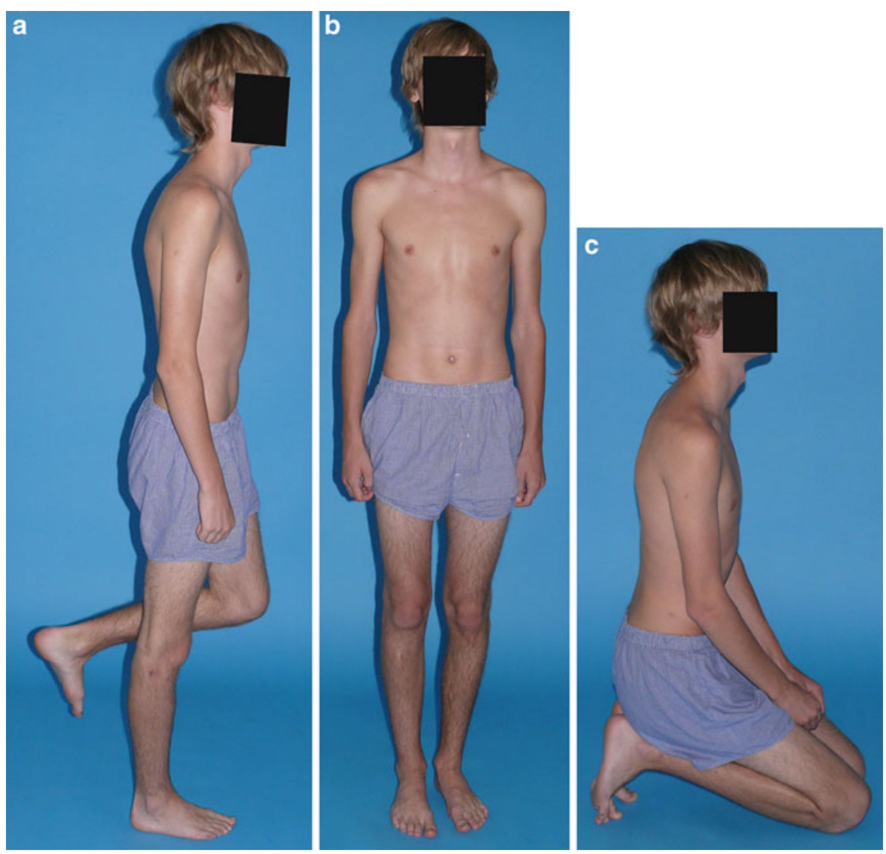

Fig. 9 (**a**) Three months after the beginning of the treatment (hair on the right lower leg has not yet grown again), stable standing on the right leg is possible. (**b**) Symmetric leg axis and length. (**c**) Full range of motion of the right knee

Fig. 10 (**a**) LSR 3 months after operation; symmetric leg axis is shown. Note the fast consolidation of the bone regenerate. (**b**) Implant removal was performed 1 year after the first surgical procedure. This late follow-up of LSR after 2.5 years shows very good bone remodeling. (**c**) Excellent bone remodeling also on the side view

- Precise deformity correction with customized (bent) nail with:
  – Intraoperative control of alignment by X-ray grid method.
  – Sleeve system and rigid reamers for preparation of the medullar cavity.
  – Minimally invasive approaches and drill bit osteotomy of the tibia.
  – Short external fixation time.
  – Intraoperative use of external fixation to assist with the deformity correction (fixator-assisted nailing) and/or blocking screws can also be helpful in this case (editor's comment, SRR).

8 Outcome Clinical Photos and Radiographs

See Figs. 9 and 10.

9 Avoiding and Managing Problems

Lengthening over a nail has several advantages in comparison to only external fixation by circular frame. The main advantage is mechanical stability and shorter external fixation time. Disadvantage is the lack of possibilities for further axial correction during the lengthening procedure. Therefore simultaneous lengthening over a nail and deformity correction requires meticulous preoperative planning according to the principles of deformity correction with intramedullary fixation. Preoperative long-standing radiographs are essential (Thaller et al. 2005). Meticulous planning by "endpoint first method" EPF and precise intraoperative controlled transfer, e.g., by applying the X-ray grid method, can provide proper alignment.

With all high tibial osteotomies, dorsal tilting of the tibial head is a common problem. A locking nail with polyaxial locking options and/or a blocking screw can help provide the necessary stability.

Drill bit osteotomy is a technique with a certain learning curve, and the risk of neurovascular damage should not be underestimated.

10 Cross-References

▶ Case 2: Tibia Lengthening with Precice Internal Lengthening Nail
▶ Case 21: Complex Tibial Deformity: Acute Correction and IM Nail Fixation
▶ Case 32: Acute Correction of Tibial Deformity and Plate Fixation, with Subsequent Lengthening Over Plate

11 See Also in Vols. 1 and 2

Case 20: Proximal Tibial Growth Arrest with Varus, Recurvatum, and Shortening After ACL Reconstruction. Correction with TSF (Vol. 1)
Case 26: Plating After Lengthening (Vol. 2)

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Case 35: Acute Correction with Marrow (Intramedullary Canal) Narrowing Technique and Subsequent Lengthening Over Nail for the Femoral Shortening Combined with a Deformity

Dong Hoon Lee

Contents

Abstract

Distal femoral deformity with shortening can be managed successfully by acute correction of deformity using marrow (intramedullary canal) narrowing technique with blocking screw(s) and subsequent gradual femoral lengthening with lengthening over nail (LON) technique.

1 Brief Clinical History

A 41 year old female complained of left knee pain and leg length inequality with unknown origin. Plain radiographs and clinical findings showed her left lower extremity with 23 mm of shortening, distal femoral valgus deformity, and apparent flexion contracture of the knee from distal femoral procurvatum deformity.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4

3 Preoperative Problem List

- Leg length inequality (23 mm shortening in the left side)
- Valgus deformity (9°), distal femur, Lt
- Flexion deformity (15°), distal femur

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Fig. 1 A photograph showing shortening of the left lower extremity

Fig. 3 A long bone coronal radiograph showing valgus deformity of the left distal femur (LDFA 80°) and shortening of the left lower extremity (total 23 mm, 12 mm in the femur and 11 mm in the tibia)

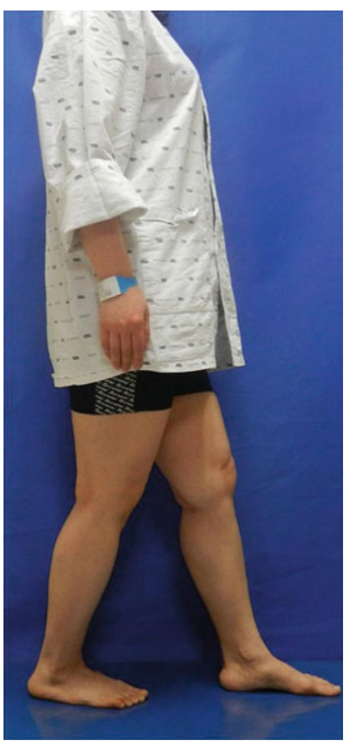

Fig. 2 A photograph showing apparent lack of full extension of the left knee

Fig. 4 A long bone sagittal radiograph of the left lower extremity in her maximum knee extension showing apparent flexion contracture of the left knee and a flexion deformity of the distal femur (PDFA 78°)

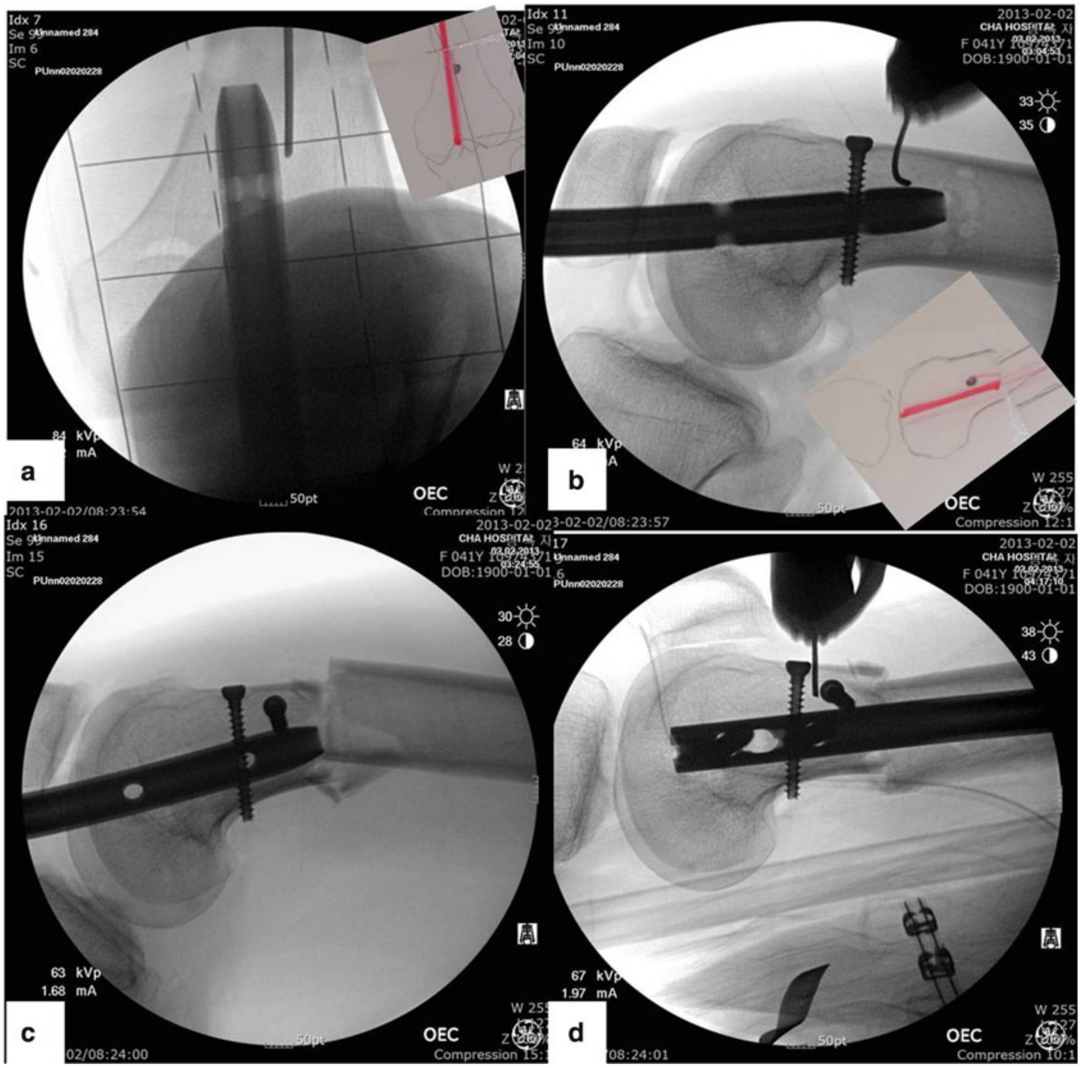

Fig. 5 Multiple blocking screws were placed as planned preoperatively (**a**, **b**), which narrowed the wide metaphyseal area. The automatic correction of deformities was achieved with nail advancement (**c**, **d**)

4 Treatment Strategy

First, a preventive release of the peroneal tunnel was performed. Distal femoral valgus and procurvatum deformities were corrected acutely by using the marrow (IM canal) narrowing technique with blocking screws. The exact locations of the blocking screws were determined from the preoperative planning. Acute correction is achieved by passing the intramedullary nail through a narrowed pathway made by blocking screws. Then gradual femoral lengthening with lengthening over nail technique is followed using the monolateral external fixator.

5 Basic Principles

Proper placement of blocking screw narrows a metaphyseal area for the intramedullary nail advancement, which can provide reduction and stability after osteotomy. The location of the blocking screws should be at the points which resist the maximal deforming force. Narrowing of all metaphyseal area around the osteotomy site is recommended with blocking screw placement to achieve intended acute deformity correction and to prevent possible deformity which can occur during the distraction.

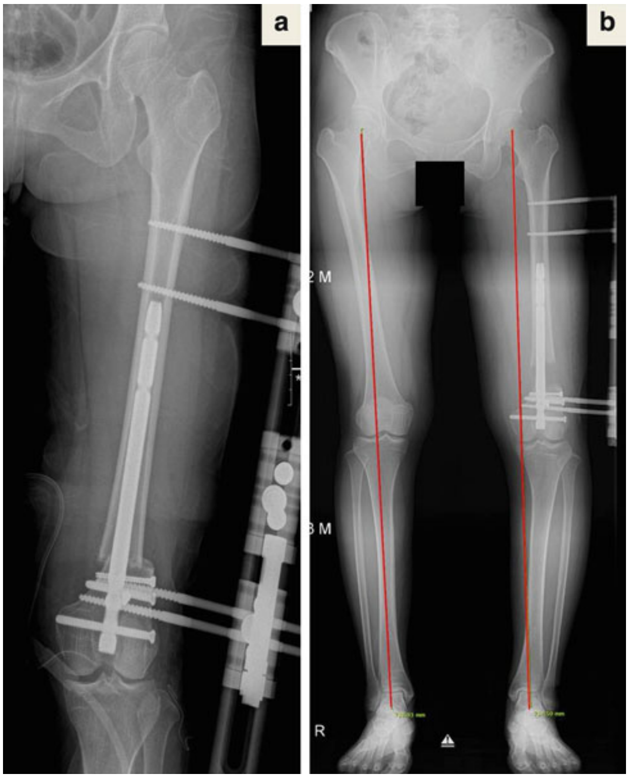

Fig. 6 Immediate postoperative radiograph (**a**) shows satisfactory correction in coronal plane (LDFA 88°). At the time of completion of lengthening, varus deformity occurred at the distal femur (LDFA 93°) (**b**)

6 Images During Treatment

See Figs. 5, 6, 7, 8, and 9

7 Technical Pearls

Preoperative planning is important to decide the location of the blocking screws which will narrow the medullary canal and facilitate deformity correction with advancement of the nail. Avoid deformity during lengthening in LON by anticipating the nail location at the end of distraction. It is also important to insert preventive blocking screws at the metaphyseal area around the osteotomy (in the proximal segment as well) which can resist the deformation force during the distraction. Also a longer nail is beneficial to prevent the deformation during LON.

8 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, 12, and 13

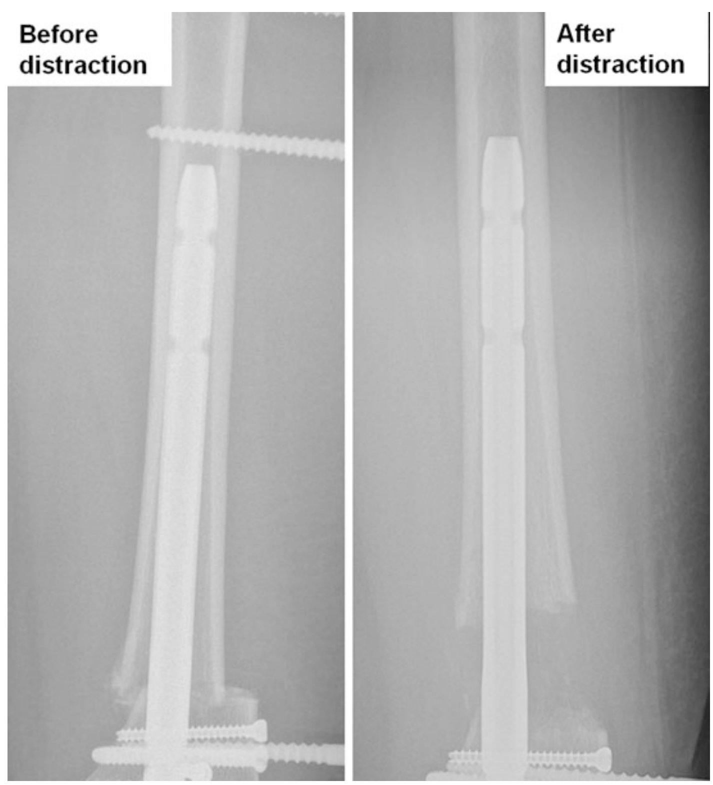

Fig. 7 Before (*left*) and after (*right*) plain radiographs of her left femur show the varus deformity between the intramedullary nail and the proximal segment which occurred during the distraction

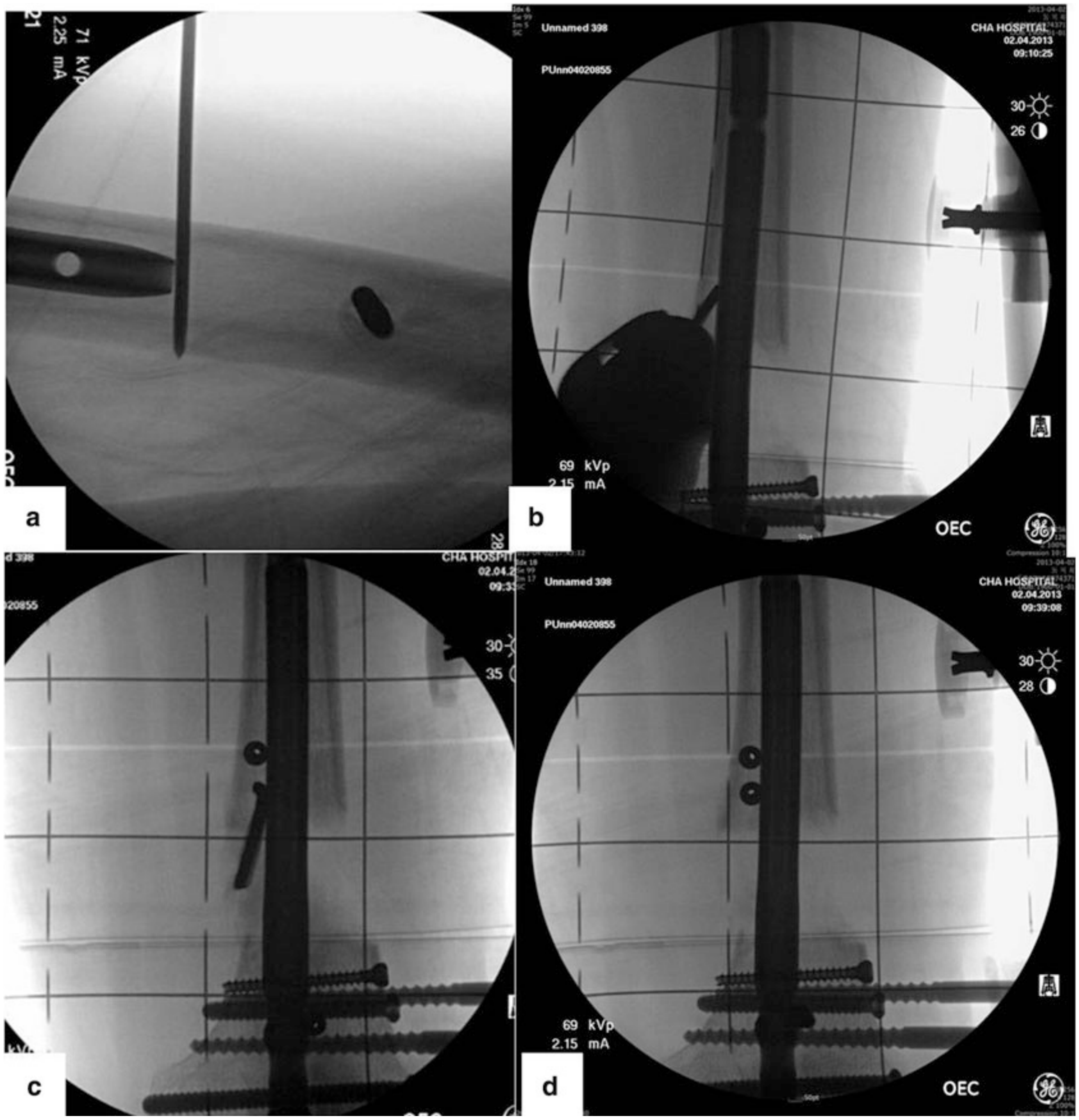

Fig. 8 To correct the varus malalignment which occurred during the distraction, a 3 mm Steinmann pin was placed at the proximal end of the nail. By blocking proximal migration of the nail when the external fixator was removed, it maintained the length distracted (**a**). Then acute correction of the varus deformity was made by using repeated blocking screw insertions (**b–d**)

9 Avoiding and Managing Problems

Although varus deformity can develop during the distraction of a femur, it can be corrected with multiple blocking screw insertions (Fig. 8). A preventive insertion of blocking screws at the right place is recommended. Peroneal nerve decompression is useful to decrease the risk of nerve injury with acute correction of valgus and flexion which leads to stretching of the peroneal nerve.

10 See Also in Vol. 1

Case 23: Valgus/Flexion and Shortening of the Distal Femur from Growth Arrest Treated with a Monolateral Frame

Case 24: Valgus Deformity of the Distal Femur and LLD Secondary to Posttraumatic Physeal Arrest: Femoral Lengthening with FITBONE Retrograde Intramedullary Nail

Fig. 9 A long bone coronal view showing a neutral alignment gained after that

Fig. 11 A final long bone sagittal radiograph shows correction of procurvatum deformity of the distal femur and complete consolidation at a site of extension osteotomy

Fig. 10 A final long bone coronal radiograph shows a normal limb alignment and equal leg lengths

Fig. 12 A photograph of her shows both normal limb alignment and equal leg lengths

Fig. 13 Though extension osteotomy was performed, her left knee still shows some degrees of flexion contracture due to lengthening procedure using external fixator. If lengthening is done using intramedullary lengthening devices, this kind of postoperative contracture may have been reduced

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Part VI

Adult Deformity: Hip

Case 36: Advanced Hip Arthrosis, Massive Perceived LLD and Pelvic Obliquity due to Adduction Contracture Treated with THR

Amgad M. Haleem and S. Robert Rozbruch

Contents

Abstract

These two cases represent patients with advanced hip arthrosis and massive perceived limb length discrepancies (LLD) due to concomitant ipsilateral adduction and flexion contractures of the involved hip. Despite having moderate true LLD, the perceived LLD by both patients was massive. Alleviation of end-stage arthritis symptoms was achieved by performing a total hip replacement (THR). Correction of the flexion and adduction hip deformities by soft-tissue releases around the hip resulted in almost complete and complete resolution of the perceived LLD in the first and second cases, respectively. The joint replacement and soft-tissue releases unlocked the adduction deformity of the hip and the Pelvic obliquity due to adduction contracture of the hip (POACH), leading to correction of the apparent LLD, which was the main contributing factor to the massive perceived LLD.

1 Brief Clinical History

Case 1: A 54 year old man presented with a history of a pathological fracture of the right femoral neck due to a simple bone cyst that was surgically managed by curettage, screw fixation, and hip spica casting at the age of 12 years and was subsequently complicated by avascular necrosis (AVN) of the femoral head and end-stage arthrosis. He had been using a 10-cm shoe lift and had early complaints of low back pain from the LLD and associated imbalance. Examination of the patient revealed an antalgic as well as a Trendelenburg gait on the right hip. In the standing position, the right side of the pelvis was elevated compared to the left. This was corrected in the sitting position where the pelvis was leveled, denoting a flexible pelvic obliquity without any fixed sacroiliac or lumbosacral spine deformity. The right hip exhibited a fixed flexion deformity (FFD) of 25° and an adduction contracture of 25° as well as painful,

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Fig. 1 Preoperative clinical photographs of the (**a**) *front*, (**b**) *side*, and (**c**) *back views* of the patient showing a massive perceived LLD, with the patient feeling comfortable with a 10-cm block under the right lower extremity

extremely limited, or no internal/external rotation. Hip radiographs revealed a deformed right hip with end-stage arthrosis and a retained screw in the femoral neck.

Case 2: A 26 year old female with a history of untreated Perthes disease of the right hip presented with right hip pain and a perceived LLD of 9 cm with the right lower extremity being shorter than the left. The patient had a similar presentation as that of case 1 and similar right hip and low back pain. Clinical examination findings were similar with a right hip FFD of 30° and an adduction hip contracture of the same magnitude. Radiographs also revealed similar findings, yet with no retained hardware.

2 Preoperative Clinical Photos and Radiographs

Case 1:
See Figs. 1 and 2.
Case 2:
See Fig. 3.

3 Preoperative Problem List

1. Right hip dysplasia with end-stage arthrosis
2. Adduction + flexion contracture of the R hip
3. Massive perceived LLD and short right lower extremity
4. Pelvic obliquity due to adduction contracture of the hip (POACH)

4 Treatment Strategy

1. Performing a THR for advanced end-stage hip arthrosis. The THR along with soft-tissue releases enables correction of the adduction contracture.
2. Correction of true LLD due to bony deficiency by increasing the femoral neck length to match the contralateral hip, based on preoperative templating and planning.

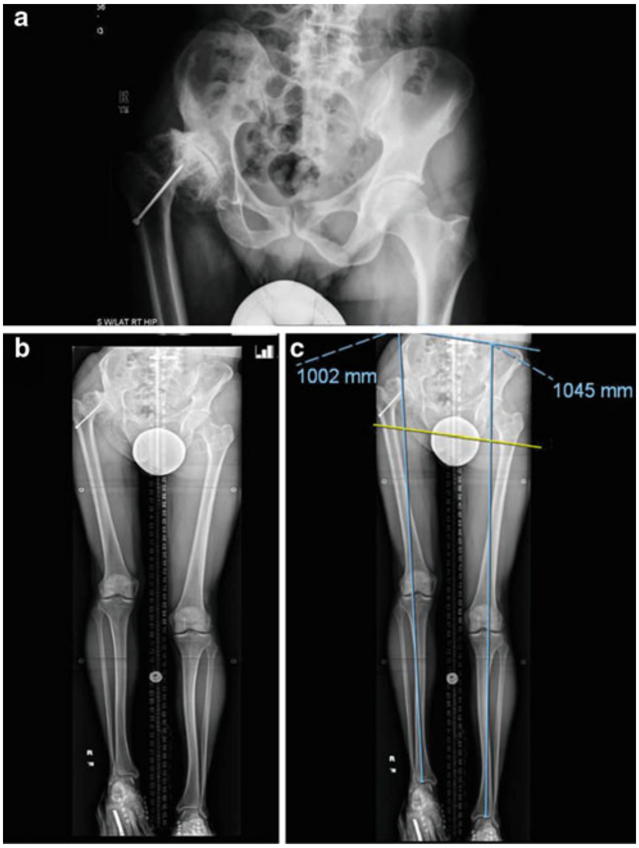

Fig. 2 Preoperative (**a**) anteroposterior (*AP*) view of the pelvis demonstrating end-stage (Ficat IV) AVN of the *right hip* with a deformed femoral head and end-stage arthrosis. (**b**, **c**) 51-inch-long erect radiographs of the hip to the ankle demonstrate a true LLD of 43 mm, due to bony deformity (shortening and varus of the femoral neck and the large mushroom-shaped femoral head) as well as flexion contracture of the hip. The apparent LLD of 100 − 43 = 57 mm was from pelvic obliquity due to adduction contracture of the hip (*POACH*). With POACH, the hemipelvis is elevated, shortening the leg, and the patient cannot bring it level. True LLD = 43 mm; perceived LLD = 100 mm; apparent LLD = 57 mm. Please refer to Sect. 6 for further related definitions and schematics

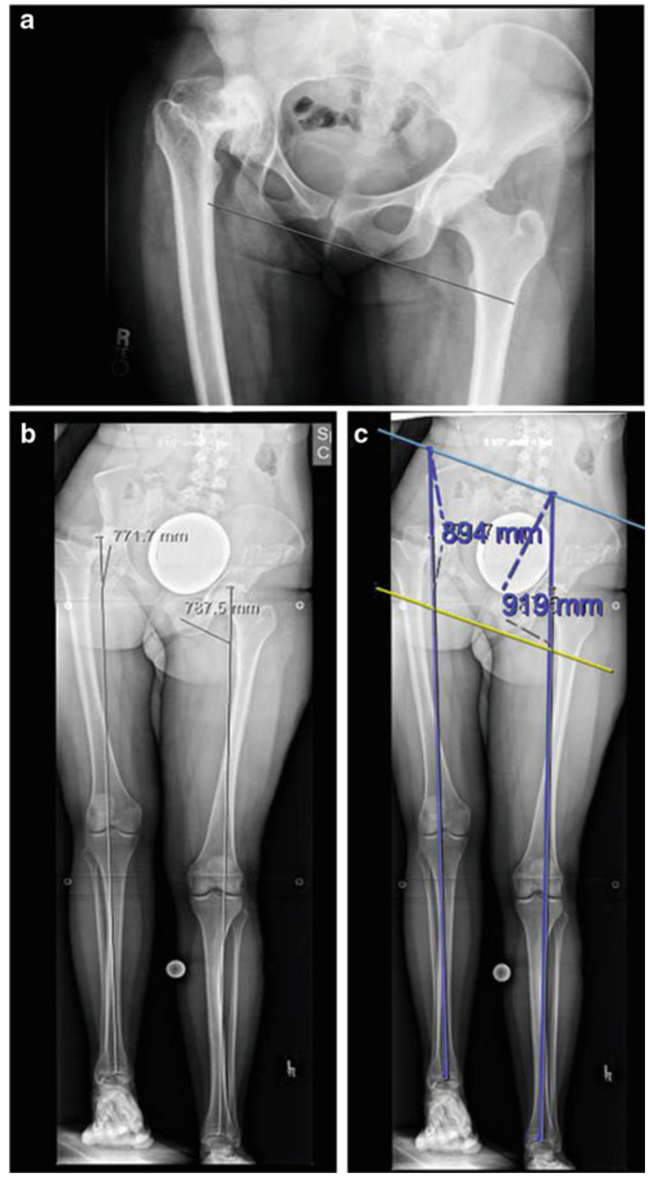

Fig. 3 Preoperative (**a**) anteroposterior (*AP*) view of the pelvis demonstrating end-stage arthrosis of the right hip with a deformed, superiorly subluxated femoral head and a dysplastic acetabulum. (**b**, **c**) 51-inch-long erect radiographs of the hip to the ankle demonstrate a true LLD of 25 mm, due to bony deformity and soft-tissue contractures around the hip. The patient felt comfortable with a 90-mm block under her right lower extremity. True LLD = 25 mm; perceived LLD = 90 mm. Apparent LLD from POACH was 65 mm in this case

3. Increasing the femoral neck offset of the femoral stem to increase stability postoperatively and restore the abductor moment arm and strength is mandatory, especially in the presence of a coxa vara and breva as in these two cases. This should be, again, guided by preoperative templating and planning.
4. Correction of the apparent LLD by releasing the tight soft tissues around the hip, contributing to the flexion and adduction contractures. For the flexion contracture, release of the iliopsoas tendon, rectus femoris, and anterior hip capsule is performed. A percutaneous adductor tenotomy at the end of the THR is carried out for the adduction contracture.

5 Basic Principles

1. Clinical examination is of utmost importance to detect fixed versus flexible pelvic obliquity as well as hip flexion and adduction contractures. This helps in formulating the surgical plan and the need for additional muscle releases

during the anticipated THR to resolve apparent LLD resulting from such contractures.

2. It is necessary to perform such soft-tissue release when the flexion or adduction contractures are equal to or greater than 15–20°.
3. Residual perceived LLD can be corrected over time as the released structures stretch over time postoperatively with rehabilitation. However, some residual perceived LLD can persist due to partially fixed pelvic obliquity at the spinal-pelvic junction that would not be resolved by the soft-tissue releases.
4. Assessment of hip version clinically is challenging in the face of advanced arthrosis and limited rotation of the hip. If severe version abnormality is noted on plain radiography from the profile of the trochanters compared to the contralateral normal side, then a CT version study of the hip is useful and a modular stem THR allowing for anteversion adjustment should be considered.

6 Images During Treatment

The following definitions are important for the readers to understand:

1. **True LLD** arises from actual shortening of the affected lower extremity bones (including femoral neck shortening) as well as deformed and proximally migrated femoral head as in developmental dysplasia of the hip (DDH). Measurement of true LLD in such cases is best measured from a line crossing the highest point of the pelvis at the level of the posterior superior iliac spines (PSIS), passing through the center of the hip to the ankle. Alternatively, it can be measured from a transpelvic line connecting the lowest part of both inferior pubic rami to the ankle (Fig. 1). See Fig. 4.
2. **Apparent LLD** may be the result of other abnormalities, including (a) fixed pelvic obliquity at the spine-pelvic junction, (b) causes at the level of the pelvis as pelvic obliquity due to adduction contracture of the hip (POACH) (Fig. 2), and (c) infra-pelvic causes as contractures of the knee, ankle, or foot. See Fig. 5.
3. **Perceived LLD** is the discrepancy in limb length difference that the patient perceives and is usually reflected on the shoe lift the patient wears or the block height placed under the short extremity on clinical examination required to make the patient comfortable with the short extremity reaching the ground. **Perceived LLD** is due to the summation of **true LLD** and **apparent LLD.**
4. **(Perceived LLD = True + Apparent LLD).**

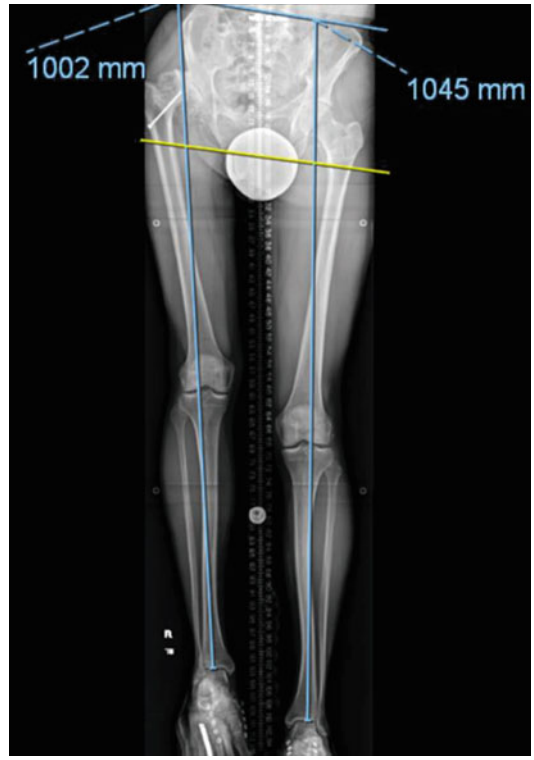

Fig. 4 Preoperative 51-inch-long erect radiographs of the hip to the ankle of a 54 year old male patient (Case 1) who presented with a massive perceived LLD of 10 cm. True LLD was measured as 43 mm via lines crossing the highest point of each hemipelvis at the level the posterior superior iliac spines (*PSIS*), passing through the center of the hip to the ankle. The patient felt comfortable with a 10-cm shoe lift (perceived LLD = 10 cm). The difference between the true LLD and the perceived LLD is attributed to the POACH which accounts for the remaining apparent LLD of 57 mm

7 Technical Pearls

1. A thorough clinical examination in cases of hip arthrosis with massive perceived LLD is of utmost importance to detect soft-tissue contractures around the hip joint. The LLD from flexion contracture is seen as true LLD. The apparent LLD from the adduction contracture is seen as elevation of the pelvis and POACH.
2. Assessment of combined hip version (acetabular and femoral version) with CT should be always considered if the rotational profile appears grossly abnormal on clinical exam and plain radiographs. Extremely abnormal version should be ideally managed by a modular femoral stem allowing anteversion adjustment, which must be anticipated, and the implant made available at the time of surgery after adequate preoperative templating. If such implants are not readily available, then a proximal femoral derotational osteotomy fixed by a long stem femoral prosthesis is an alternate option.

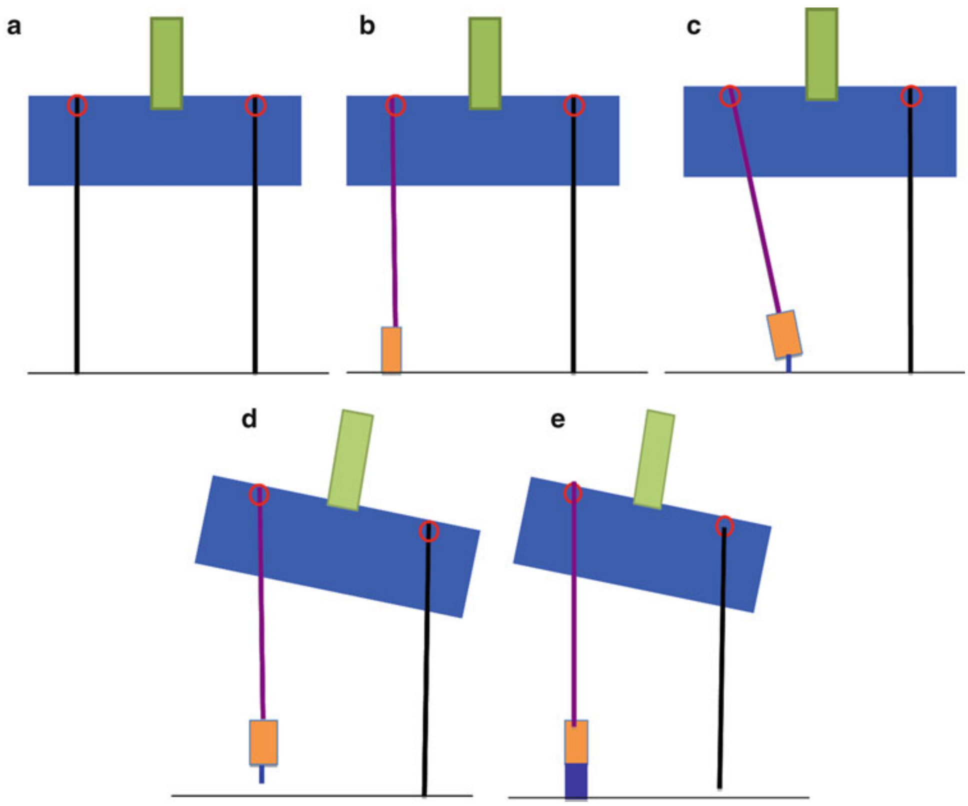

Fig. 5 Schematic diagram representing the development of massive perceived LLD with POACH. (**a**) Normal leveled pelvis with equal limb lengths. (**b**) A pelvis with true LLD (*orange* block) due to actual shortening of the bones of the right lower extremity (*RLE*). (**c**) Further development of adduction contracture of the right hip leads to (**d**) compensatory elevation of the hemipelvis on the *right side* to bring the extremity perpendicular to the ground to facilitate walking. (**e**) True LLD (*orange* block) and apparent LLD (*blue block*) contribute to the patient's perceived LLD (*blue* and *orange* blocks)

3. Restoration of femoral neck length should be aimed for by adjusting the level of the femoral neck cut and the prosthetic femoral neck length to equalize true LLD resulting from head and neck shortening/deformity.
4. Likewise, restoration of femoral neck offset with a high offset stem is necessary to increase hip abductor moment and increase hip stability postoperatively. This, again, should be accounted for during preoperative templating.
5. After placement of the THR prosthetic components, assessment of the range of motion of the hip dictates the sequential release of periarticular soft tissues. If hip extension is impeded, flexion contractures are managed by releasing the anterior hip capsule, followed by recessing the iliopsoas tendon insertion onto the lesser trochanter and then the rectus femoris if necessary. Likewise, if hip abduction is restricted, adduction contracture is managed by percutaneous adductor tenotomy at the end of the THR procedure.
6. While it is generally safe in the adult reconstruction to lengthen the lower extremity with a THA up to 2–4 cm without any complications, the most concerning complication is sciatic nerve palsy. This is of no concern in massive perceived LLD due to POACH. We have not encountered any cases of postoperative sciatic nerve palsy. This is due to the fact the sciatic nerve lies posterior to the plane of correction of the adduction hip deformity (the coronal plane) and is therefore not subjected to any stretch upon correction from hip adduction to an abducted position. Moreover, correction of the FFD of the hip does not pose any jeopardy to the sciatic nerve. The sciatic nerve lies in the convexity of the deformity of the flexed hip in the sagittal plane. Therefore, correction of the FFD of the hip actually relieves the stretch on the sciatic nerve as the hip is brought into extension.
7. Gait training and stretching exercises can reduce residual early postoperative perceived LLD by gradual stretch of the released muscles. Abductor strengthening and increased range of motion postoperatively also enhances adductor stretching. Long leg standing radiographs are recommended for follow-up as they aid in identifying residual fixed bony changes, residual apparent LLD, and its response to rehabilitation protocols.

8 Outcome Clinical Photos and Radiographs

Case 1:

See Figs. 6 and 7.

Case 2:

See Fig. 8.

Fig. 6 Postoperative clinical photographs of the (**a**) *front* and (**b**) *back views* of the patient showing an almost complete correction of the perceived LLD. The patient was able to reduce the height of his shoe lift from 35 mm at 2 weeks postoperatively to 17 mm at 1 year postoperatively due to gradual stretching and rehabilitation of the released flexors and adductors of the right hip. He had excellent functional outcome and was extremely satisfied with his surgery

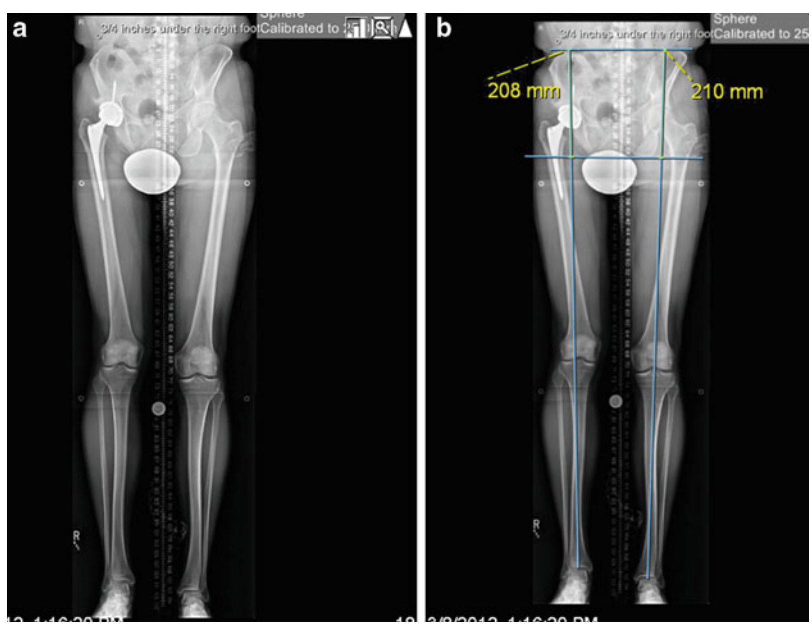

Fig. 7 (**a**, **b**) Postoperative 51-inch-long erect radiographs of the hip to the ankle demonstrate a perceived LLD of 17 mm at 1 year after THR. The patient felt comfortable with a 3/4-in. (17 mm) shoe lift under the right lower extremity which leveled his pelvis on the long-standing radiograph. Residual LLD seemed to be from spinal-pelvic deformity

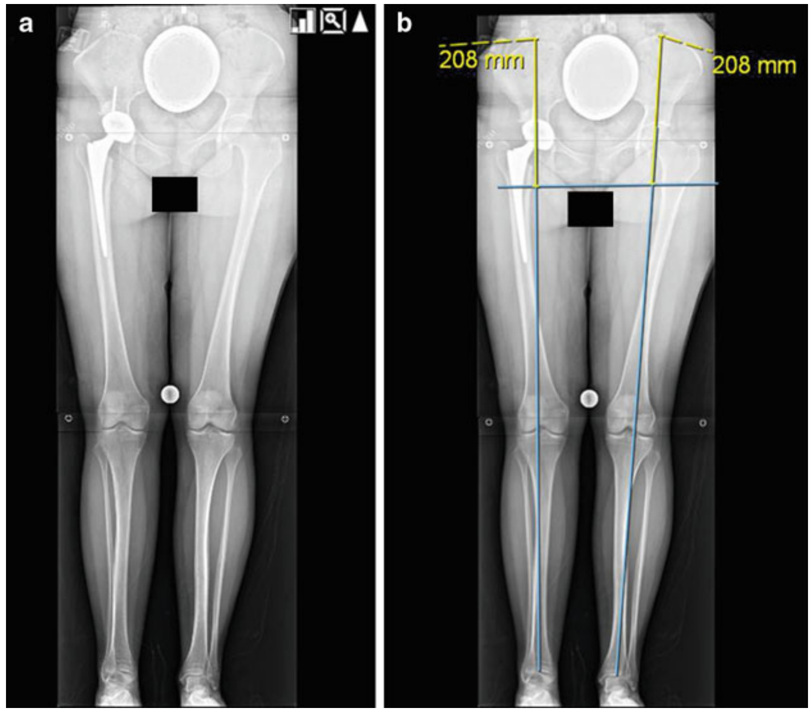

Fig. 8 (**a–b**) Postoperative 51-inch-long erect radiographs of the hip to the ankle demonstrate complete restoration of limb length equality and complete resolution of perceived LLD 1 year after THR. The patient had no apparent LLD and did not need any shoe lifts postoperatively. This is likely due to the patient's young age and the complete reducibility of the POACH without any structural bony changes that allowed full correction with the soft-tissue releases and THR

9 Avoiding and Managing Problems

1. If femoral version is found to be severely abnormal intraoperatively, resorting to a modular femoral stem allowing version adjustment is the optimal solution and should be anticipated for. If not available, then a subtrochanteric derotational femoral osteotomy and a long stem traversing the osteotomy are alternative options.
2. "Balancing" the THR once both femoral and acetabular components are placed and range of motion (extension and abduction) is tested intraoperatively is crucial for resolving apparent LLD due to soft-tissue flexion and adduction contractures. Soft tissue releases should be carried out sequentially as outlined above.
3. Restoring femoral neck length increasing the femoral neck length is required to resolve true LLD from femoral head/neck bony deformity and will also increase implant stability. Safe lengthening up to 2–4 cm can be carried out without significant risks to neurovascular structures.
4. If, after an appropriate femoral component with the desired femoral neck length is placed, the hip is still "unstable" or "loose" with a visible "chuck" on "push-pull" testing, then stability can be enhanced by a high offset stem that will increase stability without affecting the femoral neck length.

10 See Also in Vol. 1

Case 103: Septic Destruction of the Hip and Significant LLD Treated by Pelvic Support Osteotomy and Femoral Lengthening
Case 104: Ilizarov Hip Reconstruction for Post Infective Femoral Head Destruction

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Case 37: Ipsilateral Secondary Hip Osteoarthritis and Leg Length Discrepancy: Treated Simultaneously with Total Hip Replacement and Motorized Lengthening

Metin Kucukkaya and Abdullah Gogus

Contents

Abstract

Leg length discrepancy (LLD) after total hip replacement (THR) has been associated with gait disturbance, back pain, and patient dissatisfaction (Maloney and Keeney, J Arthroplasty 19:108–110, 2004). LLD can be minimized with meticulous preoperative planning and its execution. Since significant acute lengthening of the leg over 3–4 cm can be a contributory factor in the development of nerve palsy, LLD cannot be safely eliminated in some cases. This section presents a case of 42 year old male with right-sided secondary hip osteoarthritis and 8 cm femoral shortening resulting from Perthes disease plus constitutional LLD who was treated with noncemented THR and motorized lengthening nail insertion at the same setting. Remaining LLD after THR was corrected by distal femoral lengthening postoperatively.

1 Brief Clinical History

A 42 year old male presented with the complaints of groin pain, severe limping, gait disturbance, and severe back pain due to secondary hip osteoarthritis and femoral shortening on the right side. He underwent surgery when he was 8 years old, but the details of the operation were missing. He walked on his sole with ankle equinus without using a shoe lift with a flexed knee on left (contralateral) side.

2 Preoperative Clinical Photographs and Radiographs

See Fig. 1

3 Preoperative Problem List

- Severe hip osteoarthritis with 45° flexion contracture and very limited range of motion on the right side
- Femoral shortening of 6.5 cm

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Fig. 1 (**a**) Clinical picture of the leg-length equalization with 8 cm blocks. (**b**) The long-standing radiograph (LSR) with the patellae oriented anteriorly showing large LLD. (**c**) Range of motion of the right hip was severely restricted with a 45° of flexion contracture. (**d**) Preoperative anteroposterior view of the pelvis and lateral view of the right femur. (**e**) To eliminate the effect of flexion contracture, anteroposterior view of both femurs in sitting position was obtained. It revealed that the exact shortening of the right femur was 6.5 cm, which resulted partially from Perthes disease above the lesser trochanter and partially due to constitutional LLD below the lesser trochanter

4 Treatment Strategy

- Non-cemented THR and application of motorized retrograde lengthening nail (Fitbone TAA 24.5 cm, maximum stroke 80 mm, Wittenstein; Ingersheim, Germany) during the same surgery (Baumgart et al. 2006)
- Lengthening for the remaining discrepancy using motorized retrograde intramedullary nail after THR.

5 Basic Principles

The apparent LLD is from several sources – hip proximal migration, shortened femoral neck, soft-tissue contracture, and shortened femur. Equalization of leg lengths can be achieved with both the THR and additional femur lengthening.

Total available femur length was 40 cm in this case. After preoperative templating of the hip, the shortest non-cemented

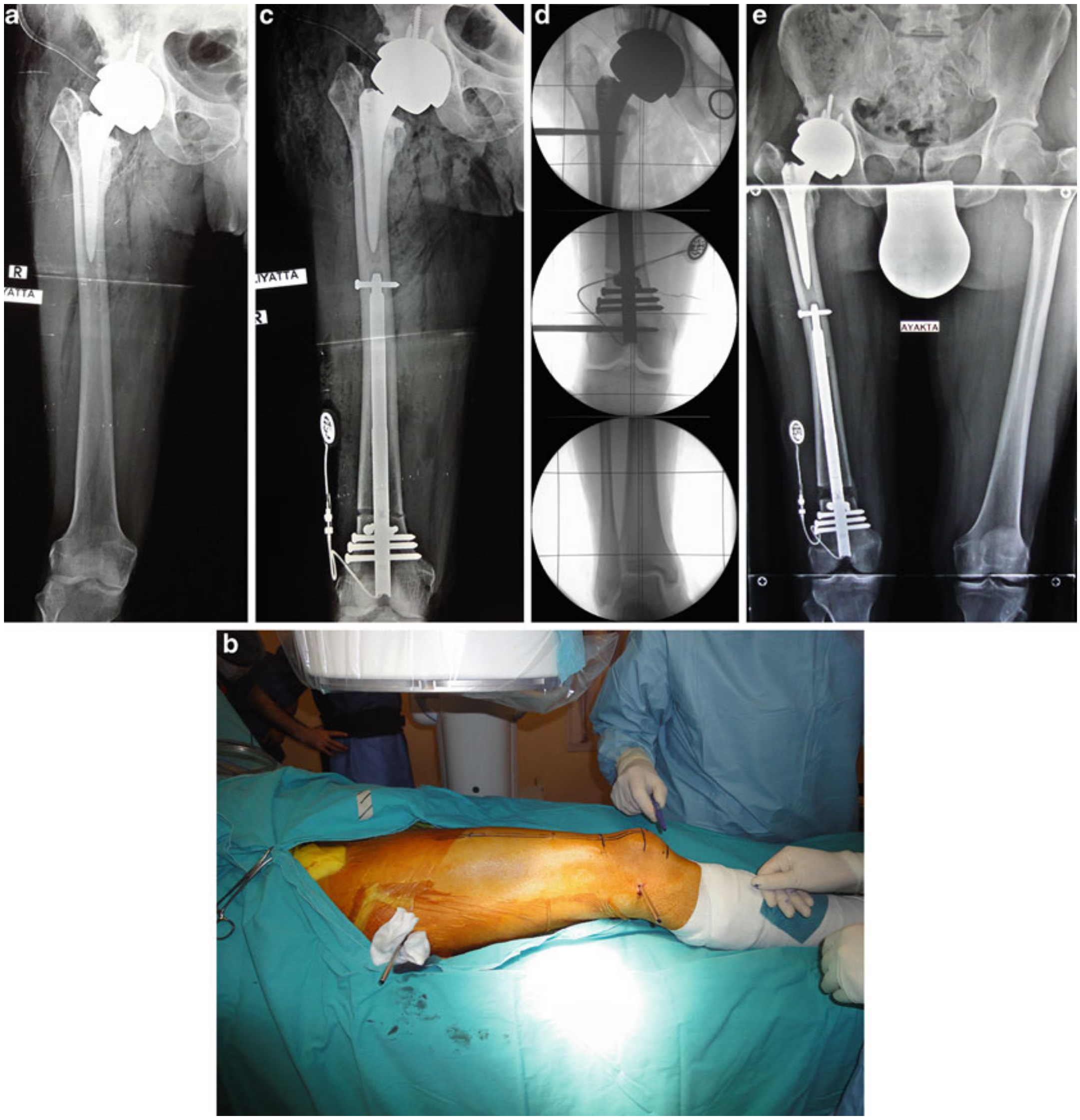

Fig. 2 (**a**) Intraoperative full length X-ray of the femur after non-cemented THR. (**b**) Intraoperative view of the leg after insertion of the temporary parallel Schanz pins to prevent malrotation after osteotomy. (**c**) Intraoperative full length X-ray of the femur after osteotomy and insertion of the motorized nail. (**d**) Position of the blocking screws and intraoperative alignment control using a grid plate. (**e**) Distraction of the osteotomy site was started with 0.5 mm/day at postoperative 5th day using the external transmitter. X-ray after completed lengthening for the remaining discrepancy following THR

stem design was selected and it measured 14.5 cm in length. Motorized lengthening nail for the femur is 24.5 cm in length (Fitbone TAA 1180) and tip of the nail should lie 1 cm beneath the intercondylar notch of the knee.

The placement of total hip prosthesis, entry site, canal diameter, osteotomy site, and positions of the blocking screws were determined on the LSR and the anteroposterior radiograph of the pelvis.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

A posterior approach in the lateral decubitus position was used to avoid further damage to the already weak abductor muscles. After THR the patient was positioned supine on a radiolucent operating table with the knee in semi-flexion. There was insertion of two parallel Schanz pins; the distal Schanz pin was inserted first and placed posterior to the reamer and nail passage. The second Schanz pin was placed at the level of the lesser trochanter without interfering with the femoral stem (Fig. 2d). The lengthening nail was placed as described in “▶ Case 5: Combined Deformities of the

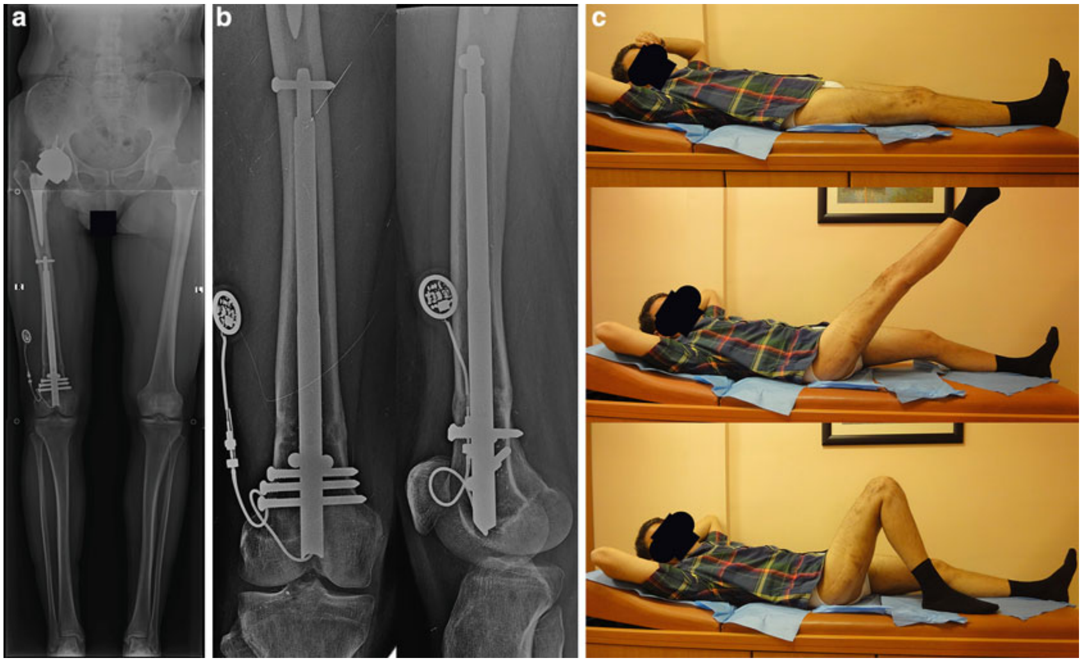

Fig. 3 (**a**) LSR at 1 year follow-up. (**b**) Anteroposterior and lateral view of the osteotomy site at 1 year follow-up. (**c**) Clinical photos at 1 year follow-up

Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate".

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

To decrease postoperative higher dislocation rate of the posterior approach and to increase the range of motion of the hip, big head THR was preferred. Therefore, metal on metal articulation was selected at that time.

During reaming of the medullary canal with rigid reamers, great attention must be paid not to damage the tip of the femoral stem using c-arm control.

10 Cross-References

▶ Case 5: Combined Deformities of the Femur and Tibia with 9 cm Shortening Treated with a Retrograde Femoral Motorized Lengthening Nail and a Tibial Plate

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Case 38: LLD After Total Hip Replacement Treated with Precice Nail

Pablo Wagner, Renee Hunter, and John E. Herzenberg

Contents

Abstract

This is a case of limb length discrepancy (LLD) after having a left total hip replacement (THR) due to a history of avascular necrosis of the hip. A 2 cm discrepancy was present after the THR with the left operated side being longer. We describe this case and the correction of the LLD using the Precice nail for lengthening of the short right femur.

1 Brief Clinical History

A 51 year old woman had a limb length discrepancy on the right after having a left THR due to a history of avascular necrosis of the left hip in 2008. The patient experienced back pain, left knee pain, right hip pain, and bilateral groin pain due to the discrepancy. When the patient presented to us, she had a discrepancy of 2.0 cm, right side short.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. LLD – 2 cm short on right side
2. Back, hip, and knee pain

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Fig. 1 51″ EL radiograph with a 2 cm lift. Note the pelvis is level, and a trans-pelvic line is the best way to measure the proximal extent of the lower extremity. Measurement from the hip is not reliable after THR

Fig. 2 Right long leg lateral X-ray

4 Treatment Strategy

1. Iliotibial band release.
2. Drill holes at the osteotomy site.
3. Temporarily apply a lateral external fixator to control rotation of the femur.
4. Antegrade femoral Precice nail: greater trochanter entry.
5. Insert the nail until the osteotomy site.
6. Complete the osteotomy and pass the nail.
7. Lock the nail.
8. Test the nail-lengthening mechanism using the external remote controller (ERC).

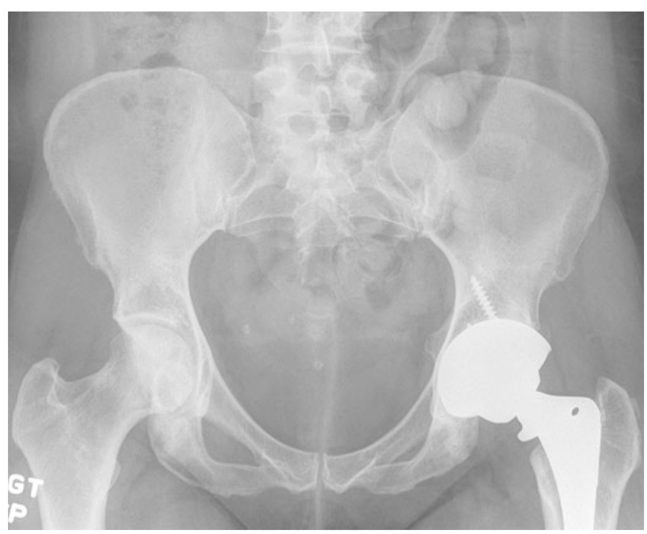

Fig. 3 AP pelvis showing a well-fixed THR

5 Basic Principles

1. Trial period of shoe lift before proceeding with the surgery. This should alleviate the pain in hips and legs.
2. Make sure that the contralateral hip has no or minimal degenerative disease.
3. Patients that undergo lengthening with an internal rod in comparison with external fixation have less infection and joint contractors and have a better and easier rehabilitation.

Fig. 4 Intraoperative lengthening suing the ERC. The purpose of this was to check the functionality of the nail and its ability to distract the osteotomy

Fig. 5 AP femur X-ray during early stages of lengthening. The proximal locking screws are anterior to posterior

4. In this case, with a retained prosthesis, the risk of infection has to be minimized to avoid any bacterial seeding on the hip replacement.
5. Make sure THR is painless and well fixed. Alternative treatment would be revision THR if the left hip prosthesis was painful or loose.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

Always perform an iliotibial band release prior to femoral lengthenings. Stabilize the femur with a transitory external fixation during the Precice nail insertion. This allows a better rotational control. The entry point for the Precice nail can be through the trochanter or piriformis fossa. The decision of which approach to use is based on the local anatomy and the age of the patient.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

1. Always "try before you buy" – have patient use a shoe lift to see if symptoms adequately improve.
2. Use vitamin supplementation to help with bony healing. We use Vitamin D and calcium or silica supplements.
3. Always start by performing an iliotibial band release. If no release is performed, knee stiffness and even subluxation could occur during the lengthening stage.

Fig. 6 AP femur X-ray at the end of lengthening showing a 2 cm distraction gap

Fig. 7 Lateral femur X-ray in the advanced stage of bone healing

Fig. 8 AP femur X-ray in the advanced stage of bone healing

Fig. 9 51″ EL radiograph after Precice nail removal showing equal leg lengths and a level pelvis

4. Always perform drill holes at the osteotomy site prior to reaming. This will allow the reamings to exit through these holes and stay in the vicinity to enhance bone healing. In addition, these vent holes lower the intramedullary pressure during reaming, decreasing the risk of fat embolism.
5. If using a trochanteric entry, the nail could jam at the entry site if the distal nail (actuator) segment hits the medial femoral cortex. If this is the case, do not try to force the nail through (breakage of the lengthening mechanism could happen). Remove the nail and enlarge the entrance hole as much as necessary to allow a smooth nail passage.

10 Cross-References

► Case 36: Advanced Hip Arthrosis, Massive Perceived LLD and Pelvic Obliquity due to Adduction Contracture Treated with THR
► Case 37: Ipsilateral Secondary Hip Osteoarthritis and Leg Length Discrepancy: Treated Simultaneously with Total Hip Replacement and Motorized Lengthening

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Part VII

Adult Deformity: Knee

Case 39: Sustained Clinical and Structural Benefit After Five Years Following Joint Distraction in the Treatment of Severe Knee Osteoarthritis

Peter M. van Roermund

Contents

Abstract

Treatment of severe osteoarthritis (OA) in relatively young patients is challenging. Although successful, total knee prosthesis has a limited life span, with the risk of revision surgery, especially in active young patients. Knee joint distraction (KJD) provides clinical benefit and tissue structure modification. The present case evaluates whether this benefit is preserved during the fifth year of follow-up. Clinical parameters compared with baseline (BL) were assessed by using the WOMAC questionnaire showing a clinical improvement from 62 to 75. Radiographic minimum joint space width (min JSW) was significantly increased from 0.01 to 1.98 mm. The mean maximal affected compartment joint space width increased from 0.65 to 2.7 mm. Cartilage thickness observed by MRI (1.6 mm) at BL was still significantly greater at 5-year follow-up (2.34 mm). The percentage denuded area of subchondral bone visualized by MRI (44.7 %) was still significantly decreased at 5-year follow-up (15.3 %).

1 Brief Clinical History

A 49 year old male who worked as an upholsterer presented with a progressively painful left knee (over 7 years) due to an end-stage knee OA with a VAS pain ≥60 mm following a total medial meniscectomy at the age of 18. In routine practice, this would be an indication for total knee replacement. Physical examination showed muscular atrophy, medial knee joint line tenderness on palpation without swelling, or ligamentous instability. Active and passive flexion in this knee was possible from 0-0-130°. The right normal knee showed a hyperextension of 15°. The X-ray (Fig. 1) demonstrated a severe osteoarthritis in the medial compartment and patellofemoral joint with joint space narrowing, subchondral sclerosis, and osteophytes.

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Fig. 1 Weight bearing semi-flexed AP X-ray shows a narrowing of the medial knee joint space width with other signs of osteoarthritis

Fig. 2 The weight bearing semi-flexed lateral X-ray shows irregular joint surfaces, osteophytes, sclerosis, and subchondral cysts in both the tibiofemoral and patellofemoral parts of the knee joint due to osteoarthritis

Fig. 3 MRI shows minimal cartilage in the medial compartment

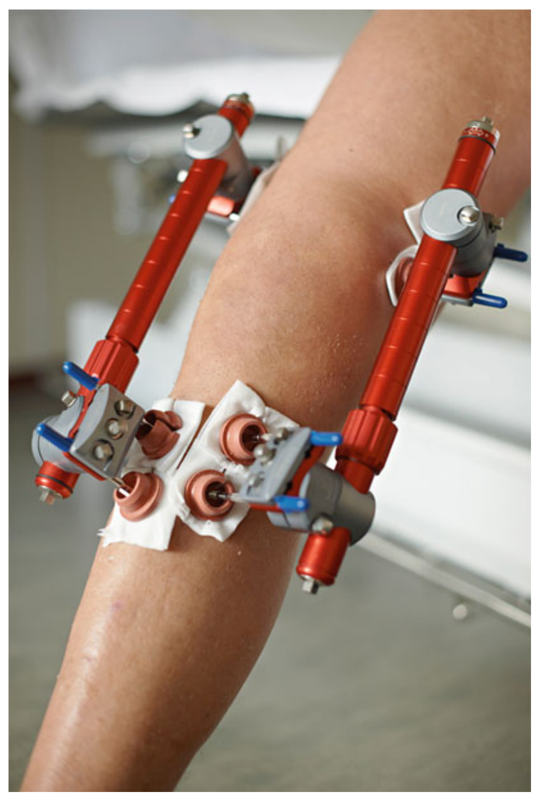

Fig. 4 Clinical view of the knee distracted by using skeletal pins and two monotubes

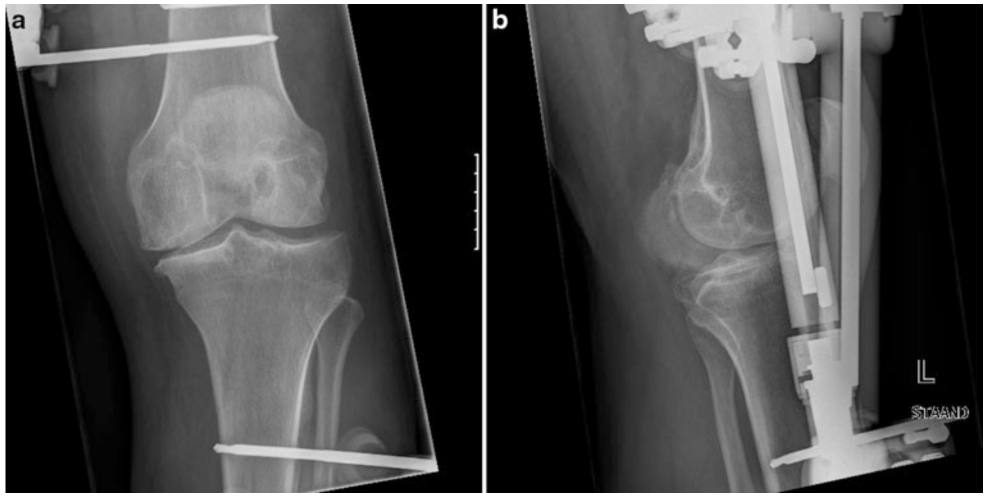

Fig. 5 (**a**, **b**) An AP and lateral X-ray view of the left OA knee joint during a 5 mm distraction by using both monotubes

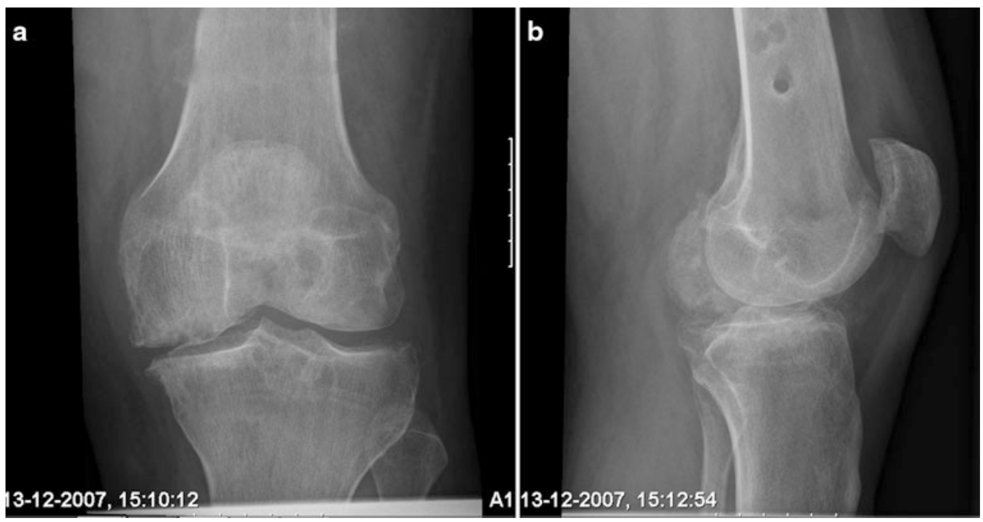

Fig. 6 (**a**, **b**) An AP and lateral view of the left knee, 2 months following removal of the external fixators showing a remarkable irregularity of the medial femoral condyle

Fig. 7 (**a**, **b**) Two years after distraction, weight bearing semi-flexed X-rays show still an increase in joint space width

Fig. 8 (**a**, **b**) Five years after distraction, weight bearing semi-flexed X-rays show still an increase in joint space width. Radiographic minimum joint space width (min JSW) was significantly increased from 0.01 to 1.98 mm. The mean maximal affected compartment joint space width increased from 0.65 to 2.7 mm

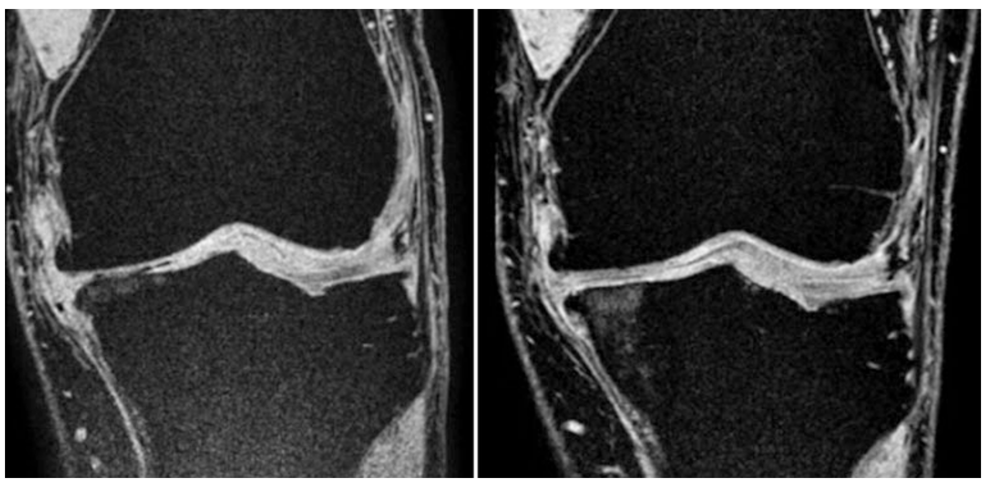

Fig. 9 MRI before (*left*) and 5 years (*right*) after knee joint distraction showing a maintained increase in cartilage volume in the medial compartment

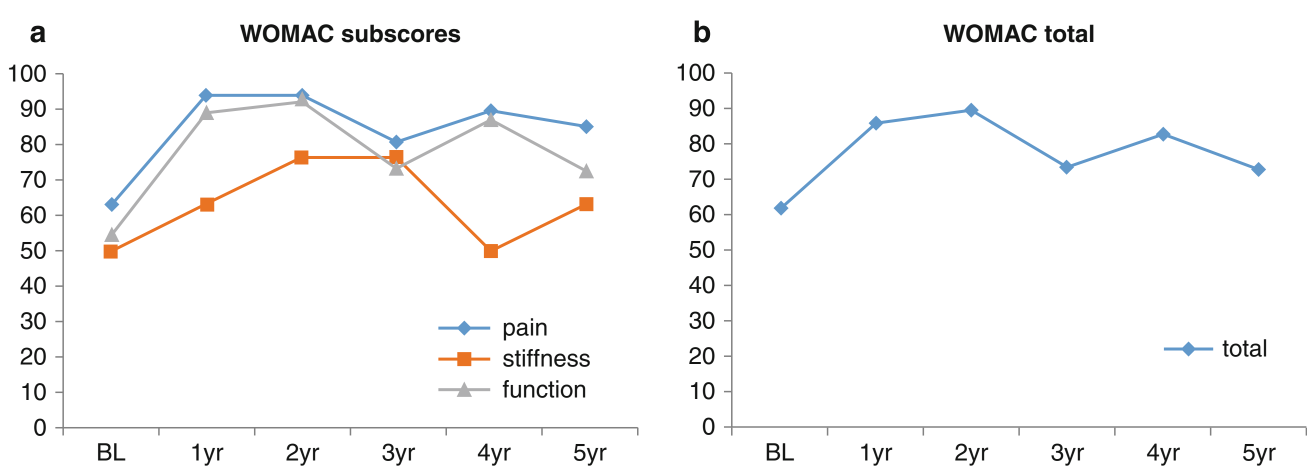

Fig. 10 (**a**, **b**) Total WOMAC questionnaire showing a clinical improvement from 62 to 75

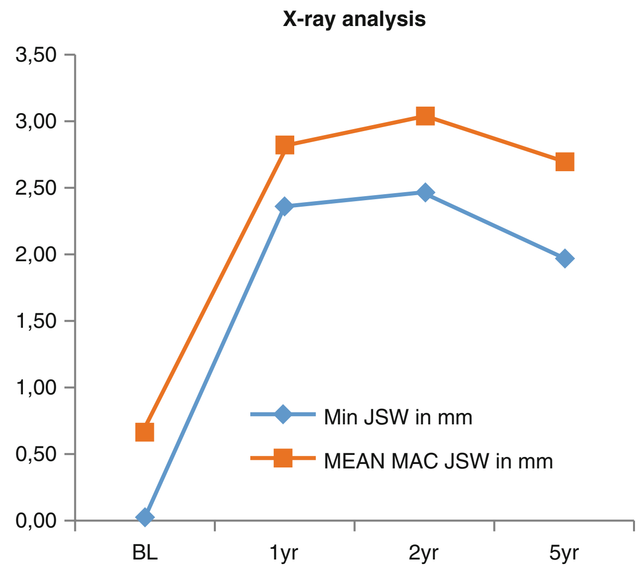

Fig. 11 Increase in cartilage thickness on the medial side 5 years after joint distraction

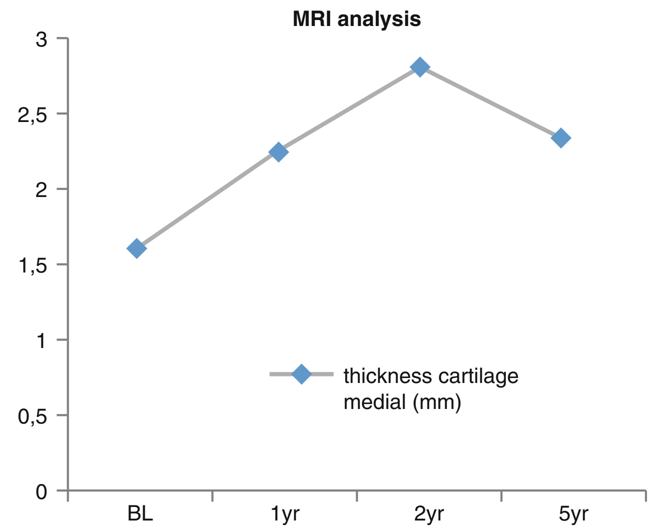

Fig. 13 Increase in cartilage thickness on the medial side 5 years after joint distraction. Cartilage thickness observed by MRI (1.6 mm) at BL remained significantly greater at 5-year follow-up (2.34 mm)

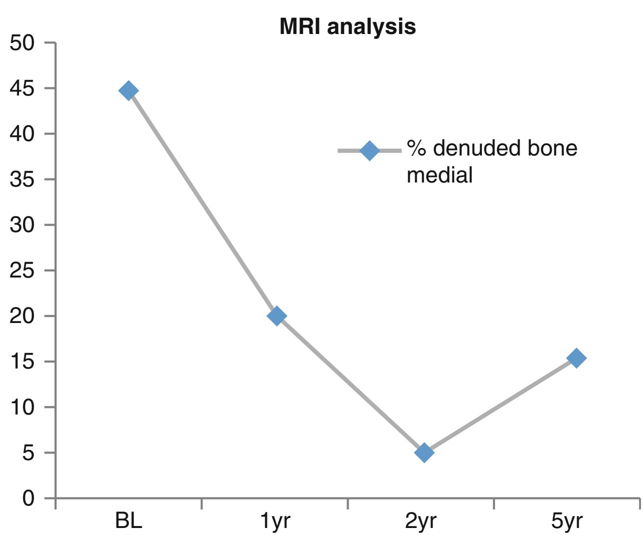

Fig. 12 Changes in the percentage of the denuded bone on the medial side 5 years after joint distraction. The percentage denuded area of subchondral bone visualized by MRI (44.7 %) remained significantly decreased at 5-year follow-up (15.3 %)

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Varus malalignment of the left knee
2. Advanced osteoarthritis of the knee

4 Treatment Strategy

Joint preservation technique of knee distraction technique is described. The left osteoarthritic knee is placed in full extension. Two bi-cortical 5 mm diameter half pins were inserted from both the medial and lateral sides of the distal femur parallel to the knee joint. Two bi-cortical 5 mm half pins were inserted from both the anterior and medial surfaces of the tibia. These pins were connected to clamps onto bilateral spring-loaded monotubes which were used to acutely apply 2 mm knee joint distraction (Fig. 4). In the next 3 days, 0.5 mm distraction was performed two times a day until the joint space seemed to be increased to 5 mm. Walking and partial weight bearing with the use of crutches were allowed. After 2 months, the external fixators were removed, and the stiffened knee was manually mobilized under general anesthesia. Physiotherapy was given, and a full recovery of the previous knee function could be obtained after 3 months.

5 Basic Principles

The assumption was made that unloading of both damaged cartilaginous surfaces by distraction while maintaining the intermittent intra-articular fluid forces may stimulate cartilage repair.

6 Images During Treatment

See Figs. 4 and 5.

7 Technical Pearls

Skeletal pins at the medial side of the distal femur were drilled close to the joint without penetrating the synovial tissue. Pins were inserted into the lateral side of the tibia with great care not to damage the tibialis anterior muscles.

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7, 8, 9, 10, 11, 12, and 13.

9 Avoiding and Managing Problems

Knee joint distraction may be a stressful procedure to patients, especially when pin track infections occur. Proper procedure information and attention to all details related to the use of external fixators will be helpful in making a proper selection of patients and in getting satisfactory results of treatment.

10 Cross-References

- ► Case 40: Neglected Rotatory Knee Dislocation Treated with the Taylor Spatial Frame
- ► Case 44: Treatment of Severe Knee Joint Stiffness with Soft Tissue Release and External Fixation

11 See Also in Vol. 2

Case 50: Ankle Distraction for Arthrosis Using the SBI RingFIX^{TM} RAD Frame

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Case 40: Neglected Rotatory Knee Dislocation Treated with the Taylor Spatial Frame

Amgad M. Haleem and S. Robert Rozbruch

Contents

Abstract
This case is about a young woman with a neglected rotatory knee dislocation associated with fixed malrotation of the tibia with respect to the femur, valgus instability, lateral patellar dislocation, and knee stiffness. Correction of the rotational deformity was carried out both acutely after lysis of adhesions and gradually with the use of a Taylor Spatial Frame (TSF). However, patellar dislocation persisted which necessitated a tibial tubercle osteotomy and transfer, which resulted in excellent patellar alignment and tracking. Residual knee stiffness was subsequently managed by quadricepsplasty. At 8 years postoperatively, the patient had a very good knee range of motion (0–90° flexion), no instability, and normal patellar tracking.

1 Brief Clinical History

A 27 year old female presented 3 years after having sustained a polytrauma with multiple fractures due to a motor vehicle accident. The injuries included an irreducible posterolateral knee dislocation with a vascular injury. The limb was revascularized at an outside medical center with multiple vascular reconstructions. The knee dislocation was managed with an external fixator "in situ" without reduction of the knee. After attention to all other injuries, the fixator was removed, leaving the left knee in a dislocated position with fixed external rotation and patellar dislocation. This resulted in knee pain, deformity, and limited range of motion.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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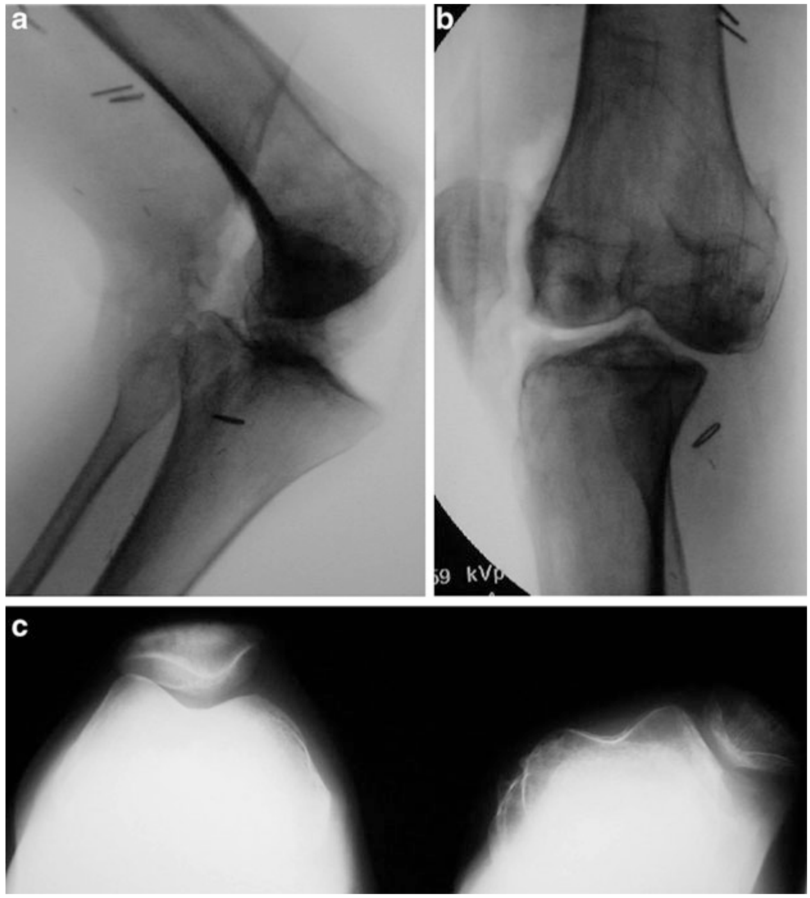

Fig. 1 Preoperative (**a**) anteroposterior (*AP*) and (**b**) lateral radiographs of the left knee demonstrating rotatory knee dislocation with the tibia externally rotated approximately 70° in relation to the femur. (**c**) Merchant views demonstrate lateral patellar dislocation on the left side

3 Preoperative Problem List

1. Neglected rotatory knee dislocation with external rotational deformity of knee
2. Neglected patellar dislocation
3. Knee stiffness with limited range of motion
4. Valgus instability
5. History of vascular compromise of left lower extremity

4 Treatment Strategy

1. Acute and then gradual correction of knee dislocation with knee arthrotomy, lysis of adhesions, and Taylor Spatial Frame application. With lateral release and internal rotation of the tibia, there is an expectation for some or complete correction of the lateral patella dislocation.
2. Conversion of the rigid TSF to a hinged fixator once knee reduction is complete in order to regain knee range of motion and to prevent further stiffness.
3. Residual patellar dislocation after correction of the femorotibial deformity will be addressed with distal patellar realignment including lateral release and tibial tubercle osteotomy and transfer, if necessary.
4. Third-stage quadricepsplasty and manipulation under general anesthesia for residual knee stiffness.

5 Basic Principles

1. Avoid excessive acute correction and manipulation in attempted reduction of a neglected rotatory knee dislocation with history of vascular compromise. After lysis of adhesions, some gentle acute correction can be done. Remaining deformity can be corrected gradually with the TSF.
2. Check the pulses and perfusion of the limb during surgery to make sure you are not causing vascular compromise of the extremity.

Fig. 2 Intraoperative photograph of the left lower extremity with TSF applied in situ. Note the residual 35° (after acute correction) difference between the master tab (*yellow arrow*) on the proximal ring aligned with the proximal mechanical axis of the limb and the anti-master tab (*blue arrow*) aligned with the externally rotated patella and tibial tubercle

3. Assess final patellar position after correction of knee dislocation for accurate patellofemoral alignment. Stage correction intraoperatively using soft tissue reconstruction then bony realignment when deemed necessary.
4. Avoid overzealous knee manipulation after quadricepsplasty to avoid periarticular fractures.

6 Images During Treatment

See Figs. 2, 3, and 4.

7 Technical Pearls

1. Perform a formal arthrotomy and removal of any intra- or extra-articular incarcerated tissue in the knee joint (scar tissue, menisci, capsule, MCL complex) that might have caused irreducibility of the rotatory knee dislocation before attempting gradual correction of the deformity.
2. Convert the static TSF circular frame to a hinged frame once rotational correction is complete to allow early range of motion and to prevent further knee stiffness.
3. Reassess all components of the deformity (femorotibial and patellofemoral) after first-stage gradual correction and

Fig. 3 Postoperative (**a**) AP and (**b**) lateral radiographs of the left knee at the end of gradual correction with the TSF showing complete rotational realignment of the femur and tibia

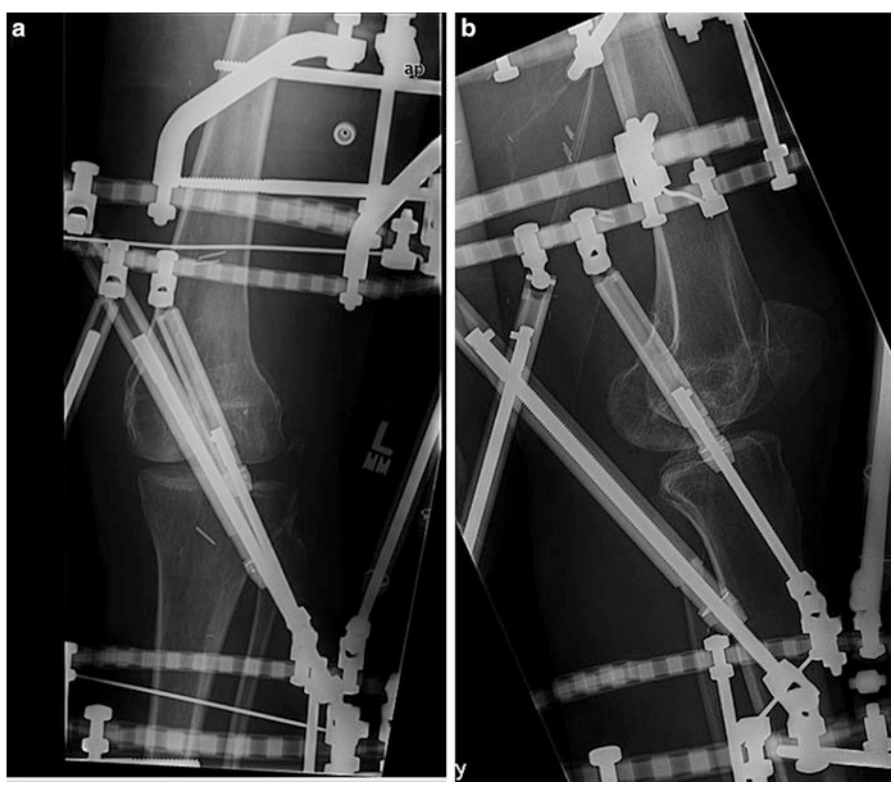

Fig. 4 (**a**, **b**) Clinical photographs in the hinged frame that allows knee motion. The TSF frame with struts was converted to a hinged knee frame that allows knee range of motion. Patella has been realigned

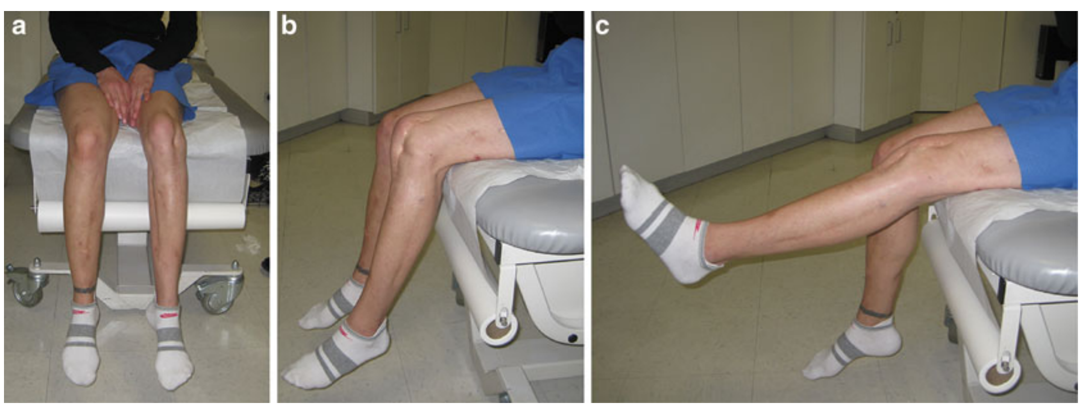

Fig. 5 Clinical photographs of the patient 8 years postoperatively showing (**a**) maintained knee and patellofemoral alignment with very good range of motion, (**b**) flexion 85° and (**c**) extension −5°, and no extensor lag

plan for patellar realignment accordingly, considering potentially resorting to bony realignment if soft tissue releases are insufficient for complete correction.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

9 Avoiding and Managing Problems

1. Prompt early reduction and diagnosis/treatment of associated neurovascular injuries is mandatory to avoid limb compromise. During emergent surgery on an irreducible dislocated knee, prompt reduction with removal of incarcerated tissue as well as simple primary repair of injured soft tissue structures encountered during the surgical exposure is mandatory.

Fig. 6 Eight-year follow-up postoperative (**a**) AP and (**b**) lateral radiographs of the left knee demonstrating a stable congruent femorotibial joint, healed tibial tubercle transfer, and mild arthritic changes in the femorotibial joint. (**c**) Merchant views demonstrate restoration of patellofemoral congruency. The patient had minimal anterior knee pain 8 years postoperatively

2. Correction of neglected knee dislocation with concomitant patella dislocation in a vascularly compromised limb should be performed gradually in a staged fashion to prevent vascular injury and incomplete correction of any residual deformity. While some acute correction can be done safely, excessive acute correction is dangerous. Monitoring of pulses and avoiding aggressive acute correction during surgery will prevent problems. Use of the TSF for gradual correction of residual deformity is the key strategy.
3. Managing postoperative knee stiffness with reverting to a hinged knee brace and physical therapy. Residual stiffness can be addressed with quadricepsplasty and manipulation under anesthesia followed by aggressive physical therapy.

10 Cross-References

► Case 27: Correction of Varus Deformity of the Femur and Tibia in Patient with LCL Laxity
► Case 44: Treatment of Severe Knee Joint Stiffness with Soft Tissue Release and External Fixation

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Case 41: Knee Joint Osteochondral Reconstruction Using Fresh Femoral Head Autograft

Tamer Mettyas, Patrick Weinrauch, and Kevin Tetsworth

Contents

Abstract

Following chemotherapy for acute lymphocytic leukemia (ALL) in a young woman, the articular surfaces of both femoral heads and the right knee lateral femoral condyle collapsed, resulting in significant pain and disability. Using a novel technique, the articular surface of the knee was reconstructed using fresh bulk osteochondral autograft harvested from the ipsilateral femoral head during a simultaneous total hip arthroplasty. Fresh osteochondral autografting enabled rapid osseous integration and articular surface reconstruction using living host cartilage, resulting in an excellent clinical outcome. Although uncommon, concurrent avascular necrosis of multiple large joints is occasionally encountered and management options are particularly limited in young patients. We recommend that this innovative technique be considered in those patients who satisfy the criteria for bulk osteochondral grafting procedures where total hip replacement is also required.

1 Brief Clinical History

A young girl, initially 14 years old, presented for evaluation of bilateral hip osteonecrosis she developed following chemotherapy used in the management of ALL. She reported multiple other complications due to chemotherapy including bilateral humeral head osteonecrosis, bilateral distal femoral osteonecrosis, peripheral sensory and motor neuropathy, and a bowel perforation requiring partial resection and ileostomy. She was intermittently wheelchair bound on the basis of her hip pathology (Fig. 1), superimposed upon the ataxia secondary to her peripheral motor neuropathy. Over the preceding months both hips had become persistently symptomatic with moderate pain on a daily basis, with a significant reduction in function and difficulty with ambulation (Weinrauch et al. 2013).

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Hip replacement was delayed due to the high risk of infection related to her ongoing chemotherapy and the presence of an ileostomy. Nonoperative therapy had included intravenous bisphosphonate infusions and analgesia. She reported increasing pain at the lateral aspect of her right knee with radiographic evidence of osteonecrosis of the lateral femoral condyle (Figs. 2 and 3). Three years later, now 17 years old, after recovering from chemotherapy she was a better candidate for reconstructive surgery. Despite drill decompression, and subsequent arthroscopic debridement of the lateral condyle, the right knee continued to deteriorate with increasing pain, stiffness, and mechanical symptoms (Fig. 4).

Fig. 1 AP radiograph of the pelvis demonstrating advanced osteonecrosis of both femoral heads, with significant collapse and loss of sphericity (Grade III/IV bilaterally)

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Seventeen year old Female, history of ALL, prior chemotherapy
- Osteonecrosis bilateral femoral heads, requiring total hip replacement
- Osteonecrosis lateral femoral condyle right knee, with disabling pain and instability
- Difficulties procuring a suitable fresh osteochondral allograft to reconstruct knee

4 Treatment Strategy

Total hip replacement provides a very predictable reconstruction alternative for destructive arthropathy of the hip, even in young patients; total knee replacement is a far less attractive option. Harvest and salvage of the remaining intact cartilage on the femoral head during a simultaneous

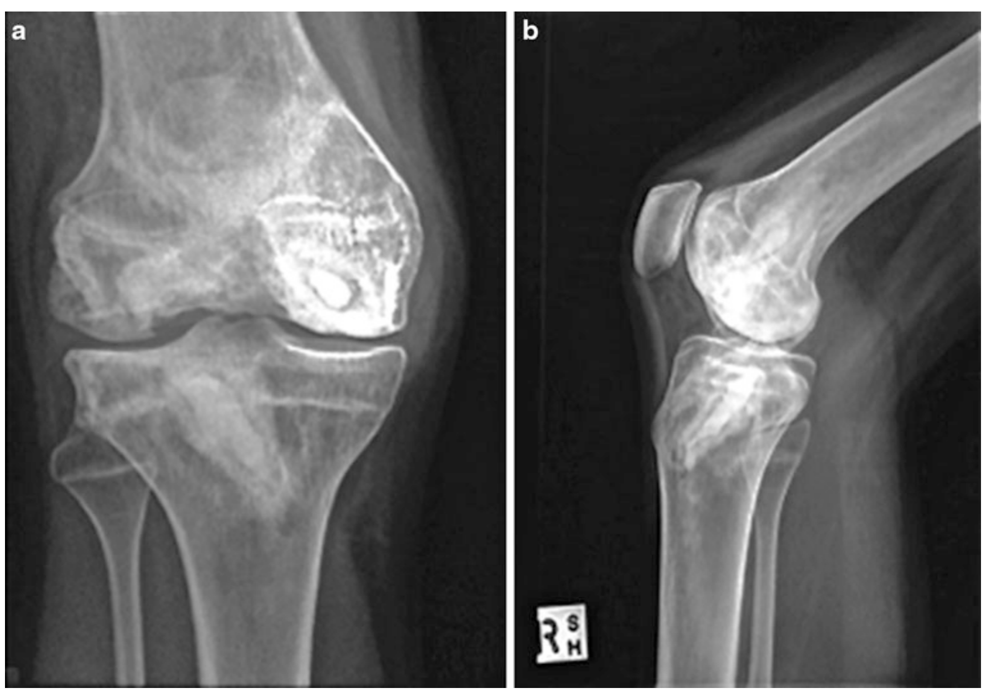

Fig. 2 Weight-bearing AP (**a**) and lateral radiographs (**b**) of the right knee, with marked changes consistent with osteonecrosis of the femoral condyles

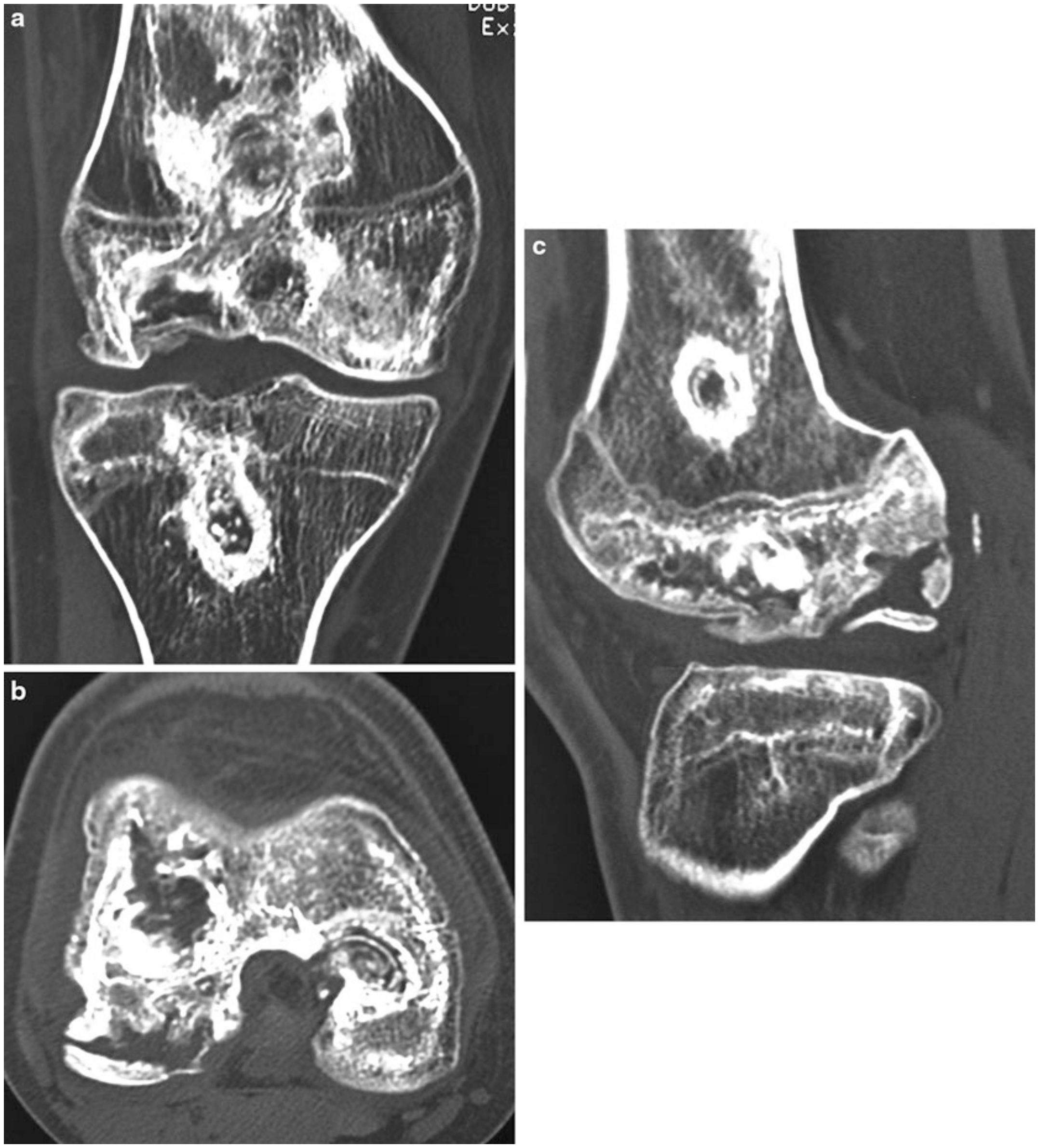

Fig. 3 (**a**–**c**) CT scan images of right knee showing extensive areas of osteonecrosis, with advanced collapse of most of the lateral femoral condyle. (**a**) (coronal), (**b**) (axial), and (**c**) (sagittal)

hip arthroplasty provided a unique opportunity to reconstruct the destroyed portions of the lateral femoral condyle using fresh osteochondral autograft.

See Fig. 3.

5 Basic Principles

By the time she turned 17, she described increasing symptoms attributable to both hip joints, as well as pain and instability in the right knee. Chemotherapy had been ceased with no recurrence of leukemia, the ileostomy had been reversed and the peripheral neuropathy resolved. Considering the marked pain and significant disability, bilateral total hip arthroplasty was recommended. Preoperative imaging demonstrated the posterior and inferior aspect of the right femoral head was relatively unaffected by avascular necrosis with an overall shape potentially suitable for osteochondral reconstruction of the right knee lateral femoral condyle. This procedure was preceded by uncemented left total hip arthroplasty; however, the left femoral head was considered unsuitable for use in osteochondral autografting on the basis of global articular surface damage (Weinrauch et al 2013).

Fig. 4 Right femoral head immediately after resection during simultaneous THA, with the least damaged cartilage on the inferior aspect (*left* in image)

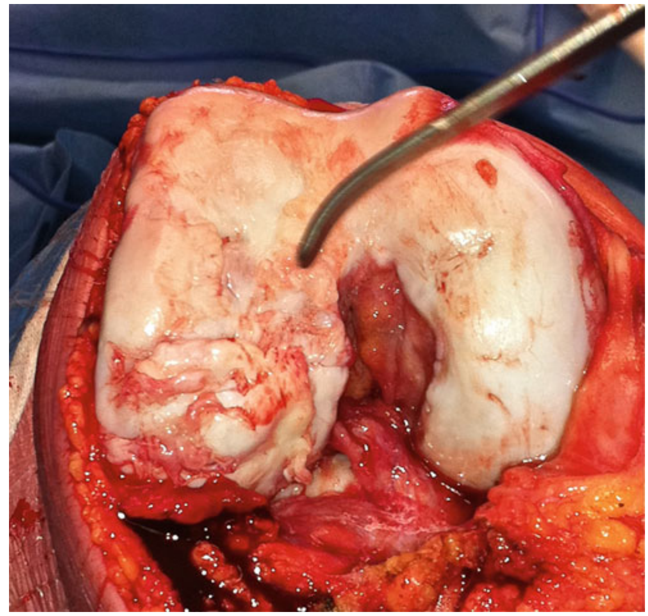

Fig. 5 Extensive articular surface damage of the lateral femoral condyle is clearly evident

6 Images During Treatment

See Figs. 4, 5, 6, 7, and 8.

7 Technical Pearls

During total hip replacement surgery, the femoral head was found to have undamaged cartilage surfaces in the inferior aspect (Fig. 4). A second surgical team prepared the graft maintaining 10 mm of thickness, while the total hip arthroplasty procedure was completed. Exposure of the right knee was achieved through a midline incision and a medial parapatellar arthrotomy (Fig. 5). The involved areas of the lateral femoral condyle were resected, resulting in a trapezoidal defect; native bone was retained where viable, creating a vascular bed of cancellous bone (Fig. 6). The trapezoidal shape of the resection facilitated primary stability of the bulk auto-graft; the graft was prepared to best match the shape of the defect. The intact articular surface of the femoral head was unfortunately discontinuous, and the autograft was therefore harvested in two distinct sections (Fig. 7). The thickness of the autograft was maintained at a minimum of 10 mm throughout. After graft impaction and final seating, internal fixation was performed using four headless compression screws (Fig. 8; Weinrauch et al. 2013).

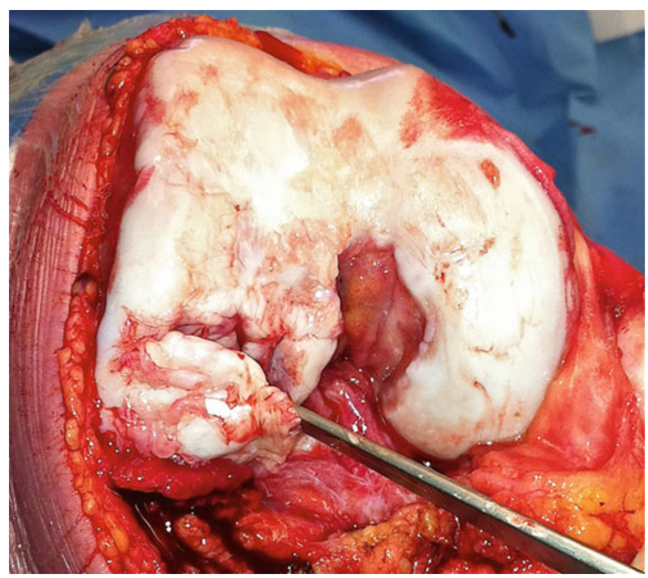

Fig. 6 Freely mobile osteochondral flap overlying the area of avascular bone on the lateral femoral condyle

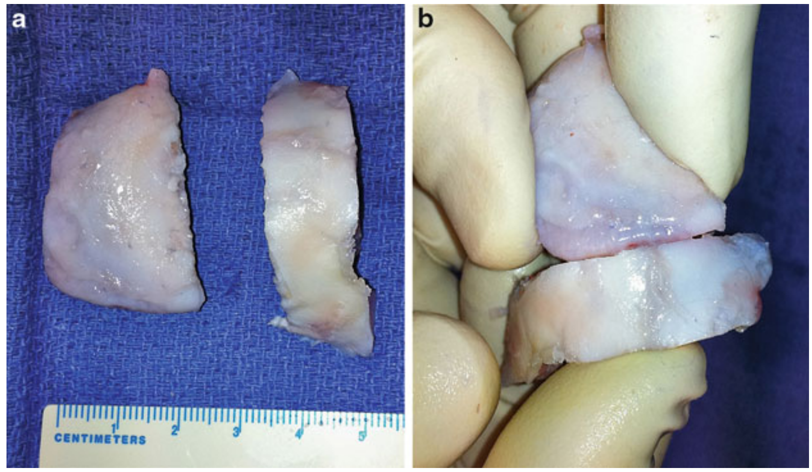

Fig. 7 (**a**, **b**) The least damaged articular cartilage was harvested from the femoral head (**a**), and then optimally configured (**b**) to match the osteochondral defect of the lateral femoral condyle following debridement

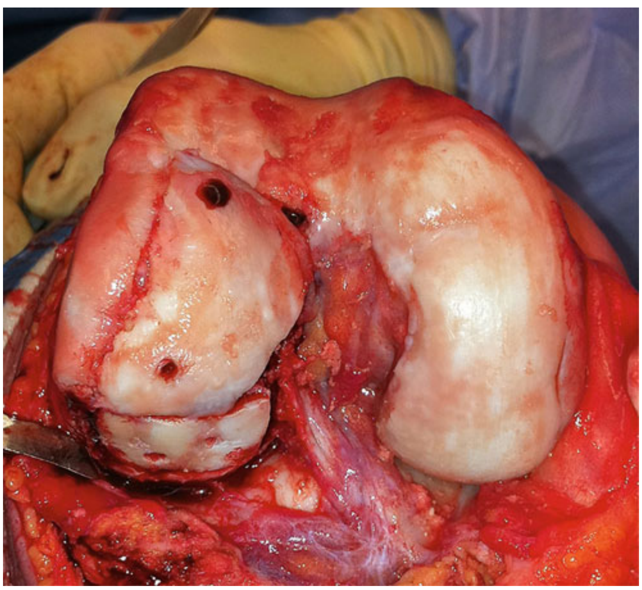

Fig. 8 The autograft has been secured in position using headless compression screws, very closely reproducing the desired elliptical contour of the lateral femoral condyle

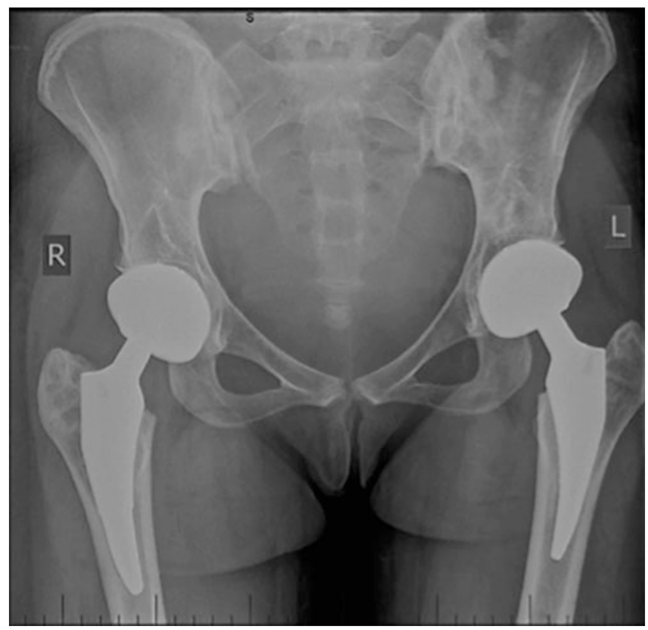

Fig. 9 Postoperative AP radiograph of the pelvis and hips, demonstrating bilateral uncemented THAs in excellent position

8 Outcome Clinical Photos and Radiographs

The right knee and hip underwent a graduated program of protected activity with touch weight bearing for a period of 6 weeks, progressing to partial weight bearing for a further 6 weeks. Early knee range of motion exercises were permitted as tolerated without restriction. At 12 months postoperative both hips remained pain free and radiographs demonstrated that the hip implants were stable and integrated (Fig. 9). The Modified Harris Hip Score (mHHS) improved from 37.4/100 (preoperatively) to 100/100 (postoperatively). The right knee was causing only very minor and occasional discomfort about the medial aspect. There was no effusion and the range of motion was almost equal to the contralateral side, with full extension and flexion to 160° (Figs. 10 and 11). The Knee Outcome Score (KOS) 12 months after the procedure was 113/125. The knee

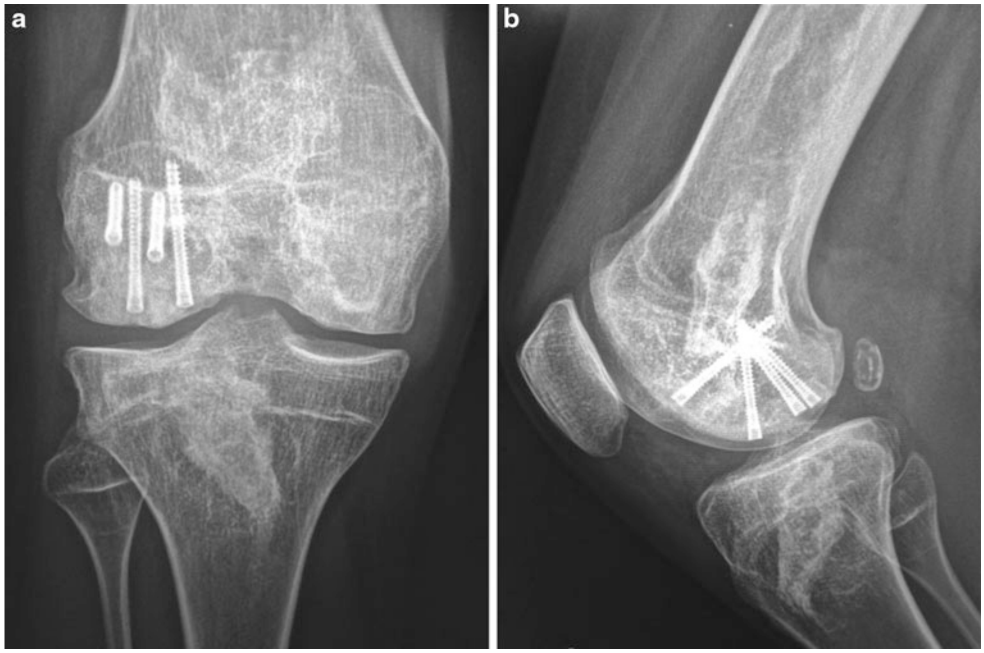

Fig. 10 AP (**a**) and lateral (**b**) radiographs of the right knee 2 years after reconstruction, confirming that the osteochondral autograft has united completely with no evidence of necrosis, loss of reduction, or change in position of the hardware. The knee joint surfaces appear smooth, with a contour very closely approximating normal

Fig. 11 (**a**, **b**) Clinical photographs 2 years after completing the reconstruction, confirming full extension (**a**) and flexion of 160° (**b**). She is able to ambulate full weight bearing without a limp, and has resumed all activities without restriction

remained stable to varus/valgus stress, patellar tracking was unremarkable, and there was no ligamentous instability (Weinrauch et al 2013). Further review, 2 years after the procedure, confirmed that the clinical outcome had not deteriorated appreciably.

See Figs. 9, 10, and 11.

9 Avoiding and Managing Problems

This procedure is preferably performed with two separate teams, one completing the hip arthroplasty while the other reconstructing the knee. An MRI of the hip preoperatively can help determine if adequate cartilage is intact; however, the decision regarding the suitability of the remaining cartilage must be made based on its macroscopic appearance. Exposure of the knee was not begun until the quality of the intact cartilage on the femoral head was first confirmed visually. If the cartilage on the femoral head is unsuitable, an alternative reconstruction strategy must be considered.

10 Cross-References

► Case 42: Reconstruction of a Lateral Femoral Condyle Articular Surface Defect with a Fresh Osteochondral Allograft
► Case 43: Salvage of an Infected Malunion of a Lateral Tibial Plateau with Staged Revision to a Bulk Osteochondral Allograft and Associated Lateral Meniscal Transplant

References and Suggested Reading

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Case 42: Reconstruction of a Lateral Femoral Condyle Articular Surface Defect with a Fresh Osteochondral Allograft

Constantin Edmond Dlaska and Kevin Tetsworth

Contents

Abstract

This 31 year old man sustained an intra-articular open distal femur fracture resulting in a significant osteochondral defect in his lateral femoral condyle. He underwent initial fracture reduction and fixation with a lateral distal femoral plate; the osteochondral defect was not recognized until more than a year later, when he developed further joint deterioration with resulting pain and disability. We chose to reconstruct the articular surface of the lateral femoral condyle with a fresh osteochondral allograft. A second procedure was subsequently undertaken to achieve more favorable joint alignment through an extra-articular supracondylar correctional osteotomy.

1 Brief Clinical History

This now 31 year old man had been involved in a motorcycle accident 2.5 years previously. He was hit by a car and sustained multiple injuries, including an open comminuted fracture of the lateral condyle of the right distal femur with a fracture dislocation of the patella. There was substantial loss of the articular surface of the lateral femoral condyle and of the patella. He had undergone an urgent lavage and debridement of the fracture; the articular surface was repaired as well as possible back to the remaining lateral condyle, and these fragments were then reduced to the femoral shaft and intact medial condyle and secured with a distal femoral locking plate. During a second look procedure within 48 h, the patella and the extensor mechanism was repaired and the wounds closed. After an initial period of immobilization of the knee, he started to regain function and gradually increased weight bearing. On further review, a valgus deformity of the right knee was noted, resulting from malreduction of his initial fracture. His mobility and knee range of motion gradually improved,

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Fig. 1 AP radiograph of the right knee 15 months after initial ORIF and immediately postoperative from an arthroscopic/limited open debridement procedure. A 40 × 20 mm defect was identified in the lateral femoral condyle articular surface

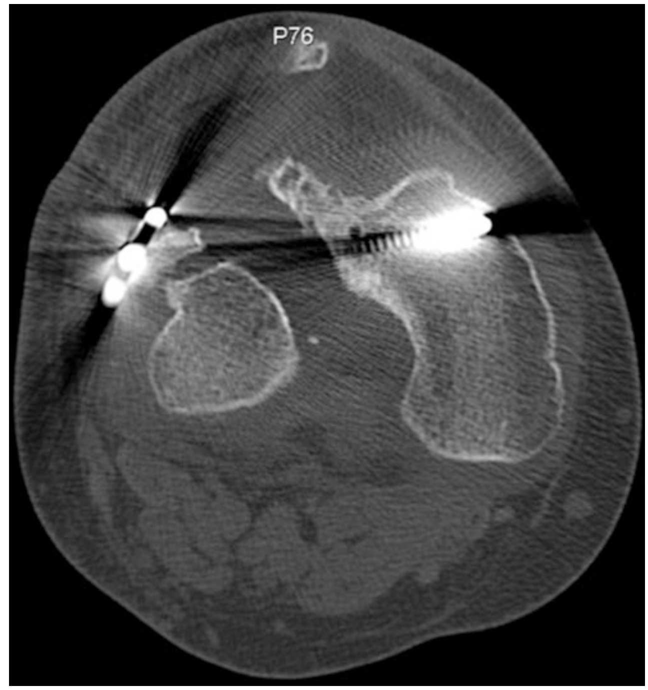

Fig. 2 CT scan obtained to better define the size and margins of the lateral femoral condyle articular cartilage defect

with 125° flexion and a flexion contracture of 10°; he was mobile without any walking aide.

Over the next year, he developed increasing pain in his right knee; an arthroscopy was performed for removal of loose bodies and assessment of the articular surface. Extensive scarring of the synovium and synovitis was noted arthroscopically, but the lateral compartment was not accessible. A lateral arthrotomy was performed, and one screw and scar tissue in the lateral compartment was debrided. An articular surface defect measuring greater than 40 by 20 mm was documented, and the patient was referred on for definitive reconstruction of the femoral condylar articular surface.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Osteochondral defect of the weight-bearing surface and anterior aspect of the right lateral femoral condyle sized 49 by 29 mm; the remainder of his joint surfaces were preserved, with adequate functional ROM.
- Relative youth of the patient – considered unsuitable for total knee replacement.
- 14° valgus deformity of the knee due to malunion of the original fracture causing abnormal excessive load on the lateral compartment.
- Fixed flexion contracture of 10°.

4 Treatment Strategy

The articular surface in this instance is too large to consider for mosaicplasty using multiple osteochondral autografts. We chose to reconstruct the lateral femoral condyle with fresh osteochondral allograft, meticulously crafted to best fit the debridement defect. The graft was secured with multiple diverging headless cannulated screws, placed from the periphery to avoid damaging the weight-bearing aspects of the articular surface. We staged the reconstruction to determine how much, if any, of the deformity would be corrected by restoring the articular surface using allograft. This allowed us to properly plan the realignment osteotomy used in the second procedure to correct the valgus and fixed flexion deformity of his knee.

5 Basic Principles

- Reconstruction of the lateral femoral condyle reduces peak stress to the cartilage of the lateral tibial plateau, thereby reducing further deterioration and best preserving joint function.
- Unfrozen osteochondral allograft has been shown to have superior biomechanical and biological properties, and for these large defects, we prefer to use fresh osteochondral allograft when available.
- Valgus deformity of the knee results in increased loads on the lateral compartment; correction to a neutral mechanical axis will significantly unload the lateral compartment.
- Established fixed flexion deformities are notoriously difficult to fully correct with soft tissue releases alone. The distal femoral osteotomy to correct valgus was already planned, and we secured the fragment in slight extension to correct the fixed flexion deformity simultaneously.

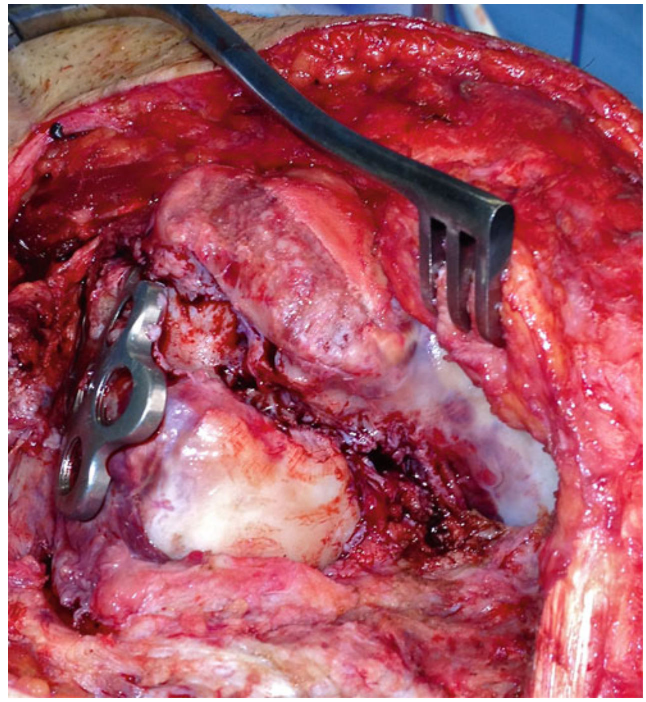

Fig. 3 Intraoperative photograph demonstrating the extent of cartilage loss was somewhat larger than expected but principally restricted to the lateral femoral condyle

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

7 Technical Pearls

- Use fresh osteochondral allograft when available, and ideally transplant into the recipient less than 24–48 h after the graft is procured.
- After resecting the affected area of the articular surface, use bone cement to form a template of the defect. This is the best way to fashion a graft that very closely matches the size, shape, and orientation of the original articular surface.
- Measure off the PMMA template, rather than attempt to determine the size and shape of the defect itself; this limits the risk of inadvertently osteotomizing the allograft incorrectly.
- Use fine blades on an oscillating saw to cut a piece of condyle out of the allograft that recreates the size and shape of the PMMA template.
- Secure the allograft with headless cannulated screws; where possible choose screw trajectories that avoid the most critical articular surfaces.

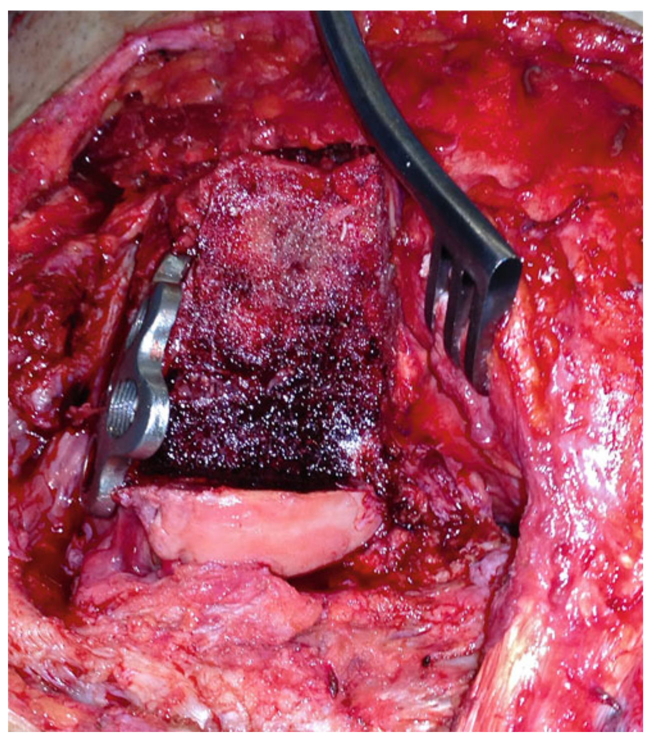

Fig. 4 Debridement defect following resection of the area involved, exposing well-vascularized cancellous bone

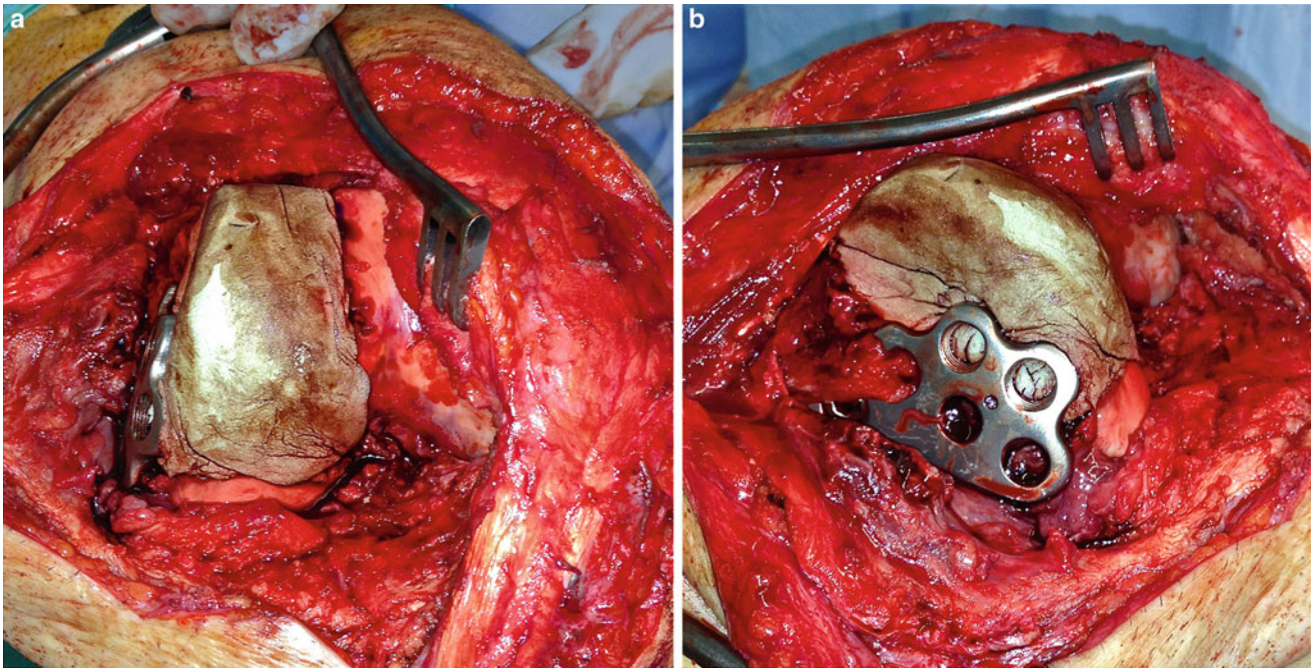

Fig. 5 (**a**, **b**) A PMMA-positive mold was made of the resected bone and cartilage, to serve as a template to fashion the fresh osteochondral allograft

Fig. 6 Comparison of the PMMA template and the fresh osteochondral allograft; the graft measured 29 × 49 mm

- Bury the headless screws well under the level of the articular cartilage, instead capturing subchondral bone. This limits the potential for a screw to protrude above the articular surface at any point in the future.

8 Outcome Clinical Photos and Radiographs

See Figs. 8, 9, 10, and 11.

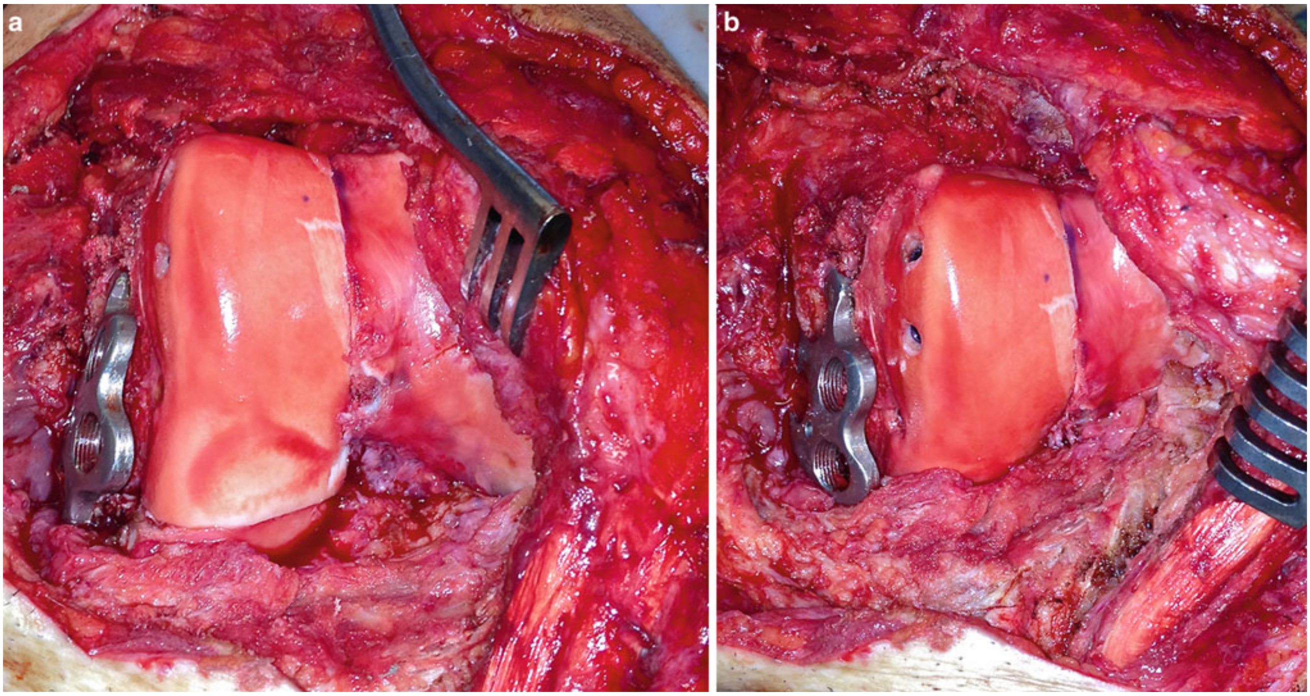

Fig. 7 (**a**, **b**) The fresh osteochondral allograft had been carefully contoured to precisely match the size, shape, and orientation of the defect. The graft was rigidly secured using three headless screws positioned peripherally

Fig. 8 Long-standing AP radiograph 3 months postoperative, demonstrating the 14° valgus malunion resulting from the initial ORIF

Fig. 9 Long-standing AP radiograph 3 months postoperative following a supracondylar corrective osteotomy (correcting valgus and flexion), done as a secondary procedure to address the 14° valgus malunion. The mechanical axis has been restored to neutral alignment

Fig. 10 AP (**a**) and lateral (**b**) radiographs of the osteotomy to confirm progression toward union; full weight bearing was allowed from this point forward. Note intentional extension of the distal fragment to improve extension at knee

Fig. 11 (**a–c**) Clinical photographs 3 months postoperative, demonstrating wound healing and satisfactory ROM; he was already able to achieve near complete extension and 100° flexion, a minor improvement when compared to prior to the osteochondral allograft reconstruction

9 Avoiding and Managing Problems

Using a fresh allograft for reconstruction of a joint surface faces the problem of timing, availability, and transmission of disease. These grafts cannot be stored for more than 7–14 days; however, ideally, the time from harvesting to implantation should not exceed 48 h. Any patient who is a candidate for this procedure must be available on short notice.

This procedure is best conducted at those hospitals that have a transplant harvest program already in place, with the requisite laboratory capacity and experience, and the expertise to examine specimens as necessary to exclude any possible communicable diseases.

10 Cross-References

▶ Case 41: Knee Joint Osteochondral Reconstruction Using Fresh Femoral Head Autograft

▶ Case 43: Salvage of an Infected Malunion of a Lateral Tibial Plateau with Staged Revision to a Bulk Osteochondral Allograft and Associated Lateral Meniscal Transplant

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Case 43: Salvage of an Infected Malunion of a Lateral Tibial Plateau with Staged Revision to a Bulk Osteochondral Allograft and Associated Lateral Meniscal Transplant

Kevin Tetsworth

Contents

Abstract

Following internal fixation of a tibial plateau fracture, this 44 year old woman developed a chronic indolent infection with methicillin-resistant *Staphylococcus epidermidis* (MRSE). After removal of the plate and screws, the subchondral bone resorbed and the articular surface collapsed, with significant pain and disability. Considered relatively young for joint replacement, this was salvaged and the joint restored in a staged fashion using a functional antibiotic polmethylmethacrylate (PMMA) cement spacer. This was later definitively reconstructed using a frozen osteochondral allograft, including an associated lateral meniscus.

1 Brief Clinical History

This otherwise healthy 44 year old nurse had sustained a comminuted Schatzker 2 left lateral tibial plateau fracture in a motorbike accident 1 year prior. She had previously undergone initial fracture reduction and fixation with a lateral proximal tibial plate. Unfortunately, she had continued pain and disability, and the plate and screws were removed 9 months later; intraoperative cultures revealed a chronic indolent infection with MRSE. At the time of hardware removal, she also underwent subtotal resection of a substantially torn lateral meniscus. When referred for further management, radiographs and CT scans demonstrated near complete destruction of the lateral proximal tibial articular surface.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

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Fig. 1 AP radiograph of initial injury. Schatzker 2 left lateral tibial plateau fracture

Fig. 2 AP radiograph of original ORIF of plateau fracture

Fig. 3 AP radiograph 6 weeks after removal of hardware; intraoperative cultures positive for MRSE

3 Preoperative Problem List

- Near complete destruction of the lateral tibial plateau articular surface
- Articular bone loss/defect
- Significant lateral meniscal tear noted when hardware is removed
- Valgus malalignment and dynamic instability related to loss of bone in the lateral compartment
- Established MRSE infection (Cierny-Mader 4A osteomyelitis)

4 Treatment Strategy

The extent of articular cartilage loss and bone destruction in this instance was too large to consider for mosaicplasty using multiple osteochondral autografts; the patient's relative youth and active infection were considered contraindications

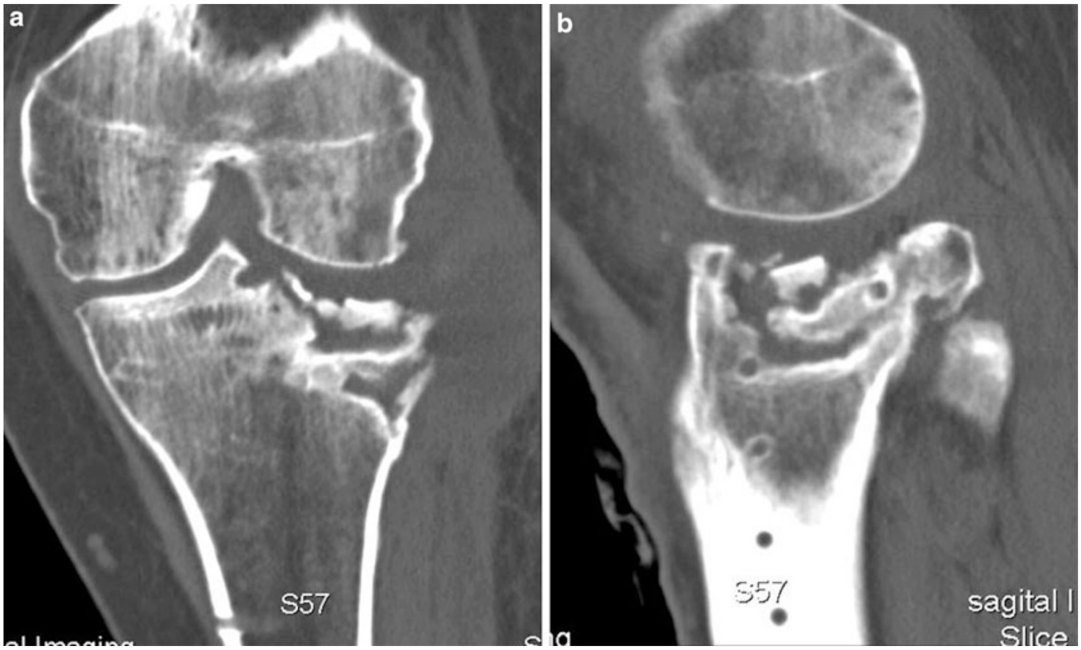

Fig. 4 Coronal (**a**) and sagittal (**b**) CT scans demonstrating extent of bone loss and destruction of articular cartilage, lateral tibial plateau

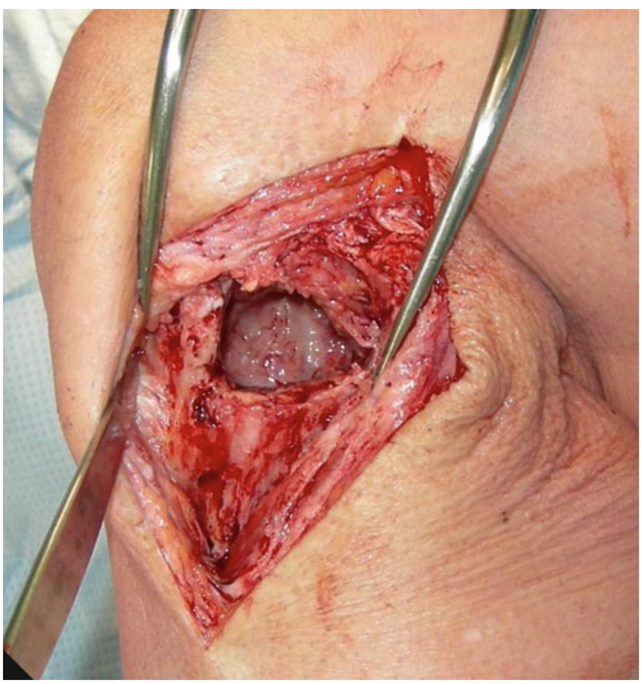

Fig. 5 Debridement defect following resection of involved volume of chronic infected lateral tibial plateau

to single-stage arthroplasty. We chose to reconstruct the lateral tibial plateau with a frozen osteochondral allograft, proceeding in a staged fashion (Heitmann et al. 2003; Tetsworth and Cierny 1999). In the first procedure, complete debridement of the area involved was achieved, and the defect was filled with an antibiotic PMMA spacer. This could not be weight bearing but only allowed her to maintain ROM of the knee. The second stage involved removal of the spacer, with definitive reconstruction using a combined osteochondral and lateral meniscal allograft. Although the long-term durability of the frozen osteochondral graft is uncertain, the allograft will restore significant bone stock; this is expected to considerably simplify later joint arthroplasty, if necessary.

5 Basic Principles

- Meticulous and complete debridement is the key to successful management of chronic adult osteomyelitis (Heitmann et al. 2003; Tetsworth and Cierny 1999).
- Staged reconstruction is preferred for management of musculoskeletal sepsis; this is often facilitated by clever use of antibiotic PMMA spacers (Heitmann et al. 2003; Tetsworth and Cierny 1999). Articulated or functional PMMA spacers are best for maintaining physiologic ROM and facilitating patient mobilization during the interim between stages.
- Frozen osteochondral allograft has been shown to have adequate biomechanical and biological properties, although fresh osteochondral allograft is preferred (Ball et al. 2004; Rozen et al. 2009).

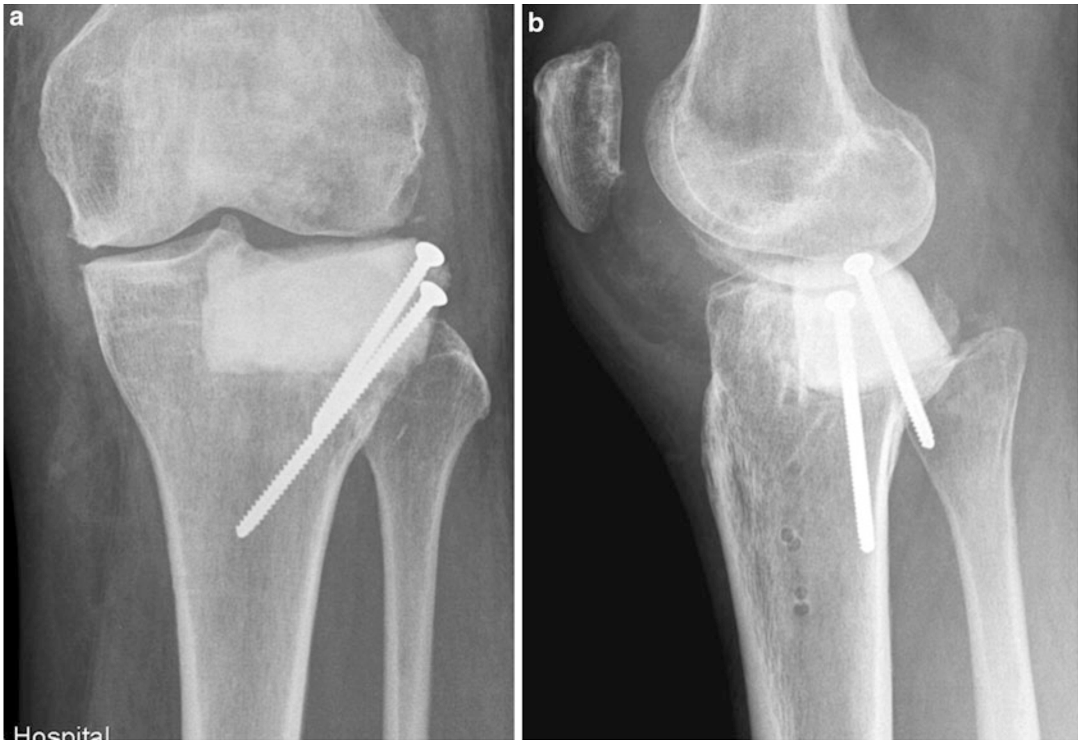

Fig. 6 AP (**a**) and lateral (**b**) radiographs following first stage, debridement and temporary reconstruction with antibiotic PMMA spacer. Two divergent screws provide adaquete stabilization of the PMMA spacer

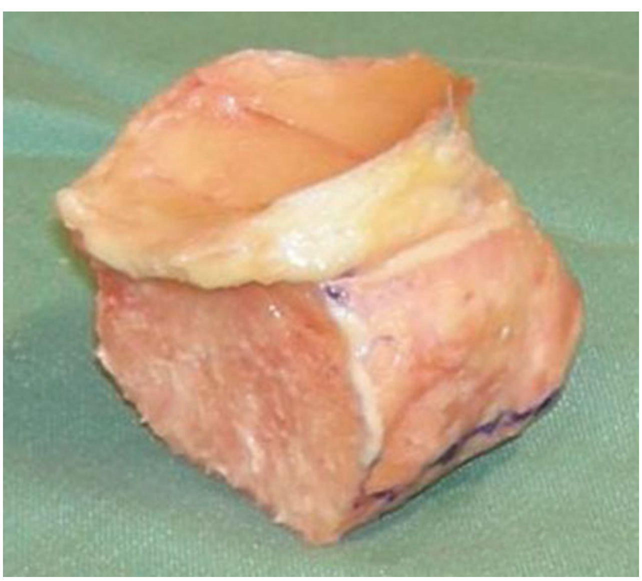

Fig. 7 Meticulously crafted allograft to very closely match the size, shape, and orientation of the osteochondral defect. The associated allograft lateral meniscus is also demonstrated

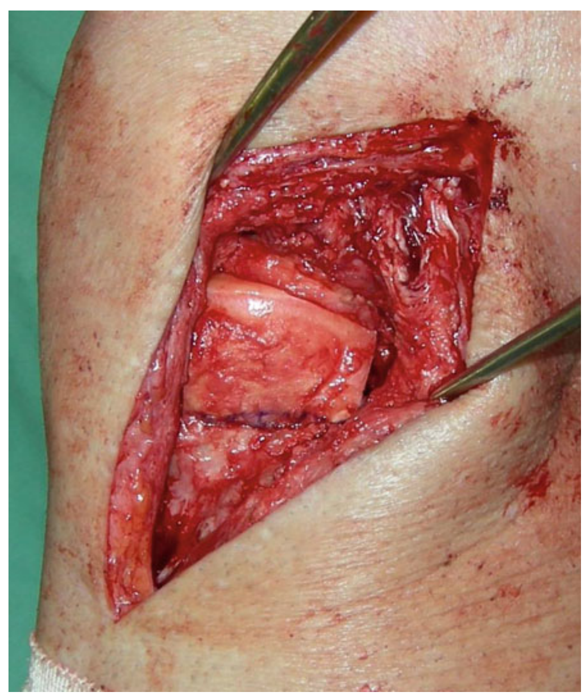

Fig. 8 Initial position of osteochondral allograft prior to stabilization; the intimate fit of the osteotomized surfaces is apparent

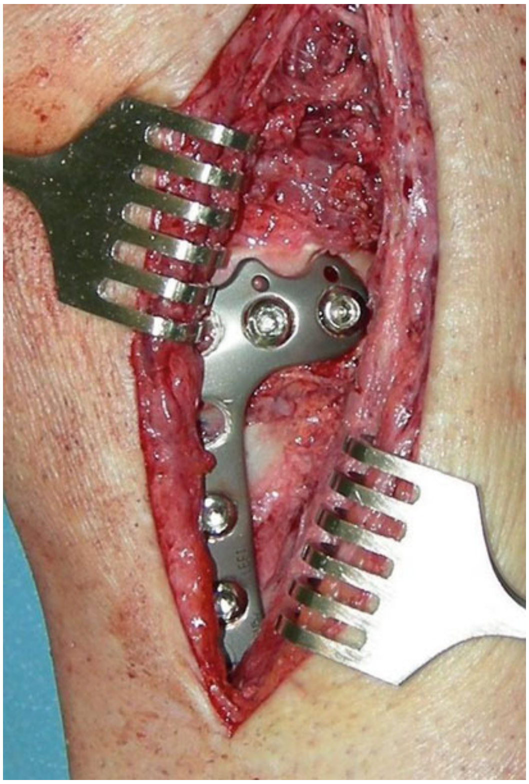

Fig. 9 After ORIF of the osteochondral allograft using an anterolateral plate and screws

- This reconstruction is only possible when joint stability and motion have been preserved, soft tissues remain pliable, and the patient is motivated to succeed.
- Although the second stage was planned for 8–10 weeks after (Heitmann et al. 2003; Tetsworth and Cierny 1999), unavoidable delays occurred and the exchange to allograft was not completed for 28 weeks.

6 Images During Treatment

See Figs. 5, 6, 7, 8, and 9.

7 Technical Pearls

- Preserving host bone where possible, both the temporary and definitive reconstructions will be more stable when at least three orthogonal surfaces are present. In this case, the anterior rim of native bone was preserved, in addition to the medial and inferior surfaces; the insertions of both the ACL and PCL had been maintained.
- The antibiotic PMMA spacer is carefully contoured to very closely match the size, shape, and orientation of the intact lateral plateau. Palacos PMMA elutes better than

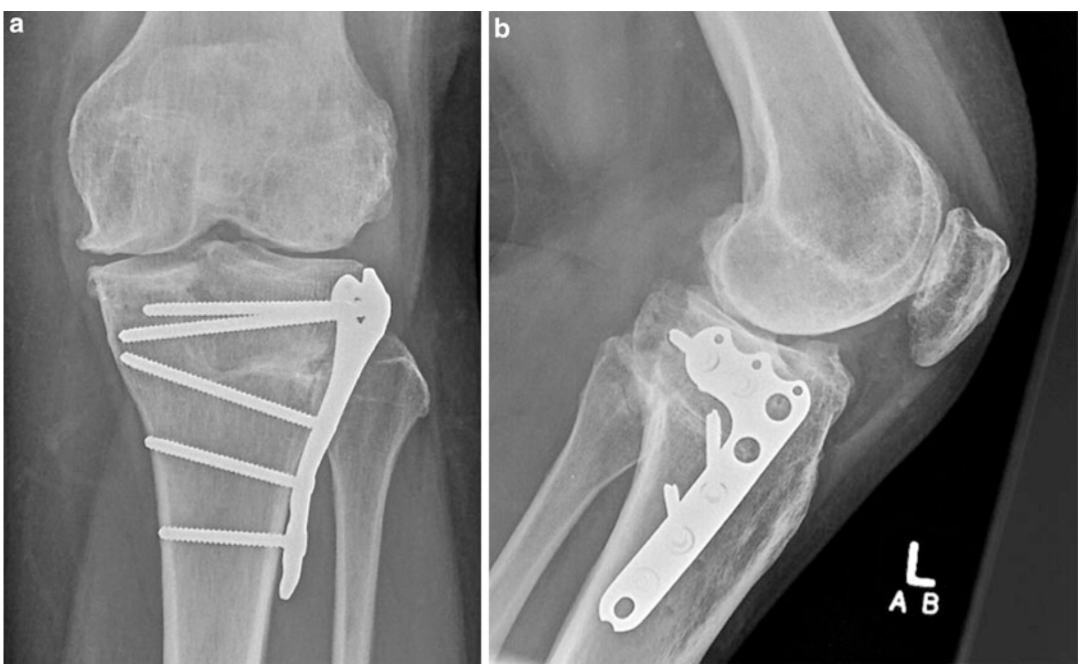

Fig. 10 AP (**a**) and lateral (**b**) radiographs 4 years postoperative

Simplex (Stevens et al. 2005); we add 3 g of powdered vancomycin and 3 g of powdered flucloxacillin per 40 g pack of methacrylate.

- Two divergent 3.5 mm screws are inserted with trajectories that will capture the spacer and hold it rigidly in position, avoiding the expected articulation itself. These screws are positioned before the PMMA is inserted into the defect. Once the PMMA spacer begins to take shape, the screws are reversed several mm; immediately after the PMMA sets, the screws are again tightened, providing maximum compression and mechanical stability.
- After completing a course of parenteral antibiotics and only after confirming the infection has been eliminated, the second stage is conducted with definitive reconstruction (Heitmann et al. 2003; Tetsworth and Cierny 1999).
- Fine blades on an oscillating saw are used to meticulously craft a suitable lateral plateau out of the allograft, closely matching the size and shape of the original host bone. The removed PMMA spacer acts as a convenient template, and it is much more convenient to measure the spacer dimensions rather than attempt to measure the contours of the defect.
- Although fresh osteochondral allograft is preferable, it is not always available. Frozen osteochondral allograft can be used (Ball et al. 2004; Rozen et al. 2009), with better results anticipated in the lateral compartment of the knee.
- This allograft was carefully secured using an anterolateral plate and screws; screws through cortical allografts are not recommended, but we have enjoyed success with limited screw fixation in metaphyseal bone.
- The anterior and posterior roots of the allograft meniscus were retained, and a simultaneous lateral meniscal transplant was performed. This was completed using multiple nonabsorbable sutures directly through the lateral exposure used for ORIF.

8 Outcome Clinical Photos and Radiographs

See Figs. 10, 11, and 12.

Fig. 11 Clinical photograph 4 years postoperative, confirming full extension with no extensor lag

Fig. 12 Clinical photograph 4 years postoperative demonstrating flexion of 115°; she was full weight bearing with no limp

9 Avoiding and Managing Problems

If there is any concern regarding possible recurrence of infection, consider a third stage to either biopsy/culture the spacer or exchange the spacer. The risk of contamination and reinfection of a bulk allograft is higher than normal, and it is critical to confirm the infection has been eradicated before proceeding further.

10 Cross-References

▶ Case 41: Knee Joint Osteochondral Reconstruction Using Fresh Femoral Head Autograft
▶ Case 42: Reconstruction of a Lateral Femoral Condyle Articular Surface Defect with a Fresh Osteochondral Allograft

References and Suggested Reading

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Case 44: Treatment of Severe Knee Joint Stiffness with Soft Tissue Release and External Fixation

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Contents

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Abstract

This case illustrates a treatment of severe post-traumatic knee joint stiffness. The surgery performed in this case was a Judet quadricepsplasty procedure and the adjuvant use of external fixation (computer-assisted hexapod – Ortho-SUV Frame). The use of the hexapod frame gradually improved range of motion (ROM) of the knee.

1 Brief Clinical History

The patient is a 46 year old female who complains of left knee joint stiffness. Seven years earlier she had an open fracture of the left femur. She underwent surgical repair using external and internal fixation. Bony union was achieved, but limitation of the knee ROM occurred. Conservative treatment was not effective.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

(a) Severe knee joint stiffness
(b) Soft tissue scar adherent to the bone
(c) Presence of fragile union of femoral fracture with risk of refracture
(d) Residual neuropathy of the peroneal nerve

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Fig. 1 Left knee joint ROM is 15/0/0 (15°), extension contracture

Fig. 2 Fragile union of femoral fracture

4 Treatment Strategy

(a) Release of soft tissue scar adherent to the femur using the Judet procedure
(b) Protection of the weak bone and improvement of ROM with the help of external fixation

5 Basic Principles

(a) In this case aggressive intraoperative flexion manipulation could not be used because of fragile fracture of the union site. Refracture is a risk.
(b) Initial flexion achieved intraoperatively can be improved gradually with the use of external fixation.
(c) At passive development of ROM (using external frame), articulate diastasis should be done; movements should correspond to the normal mechanics of a knee joint: flexion, sliding, and rotation.
(d) The frame can be removed, when active ROM of the knee is restored.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

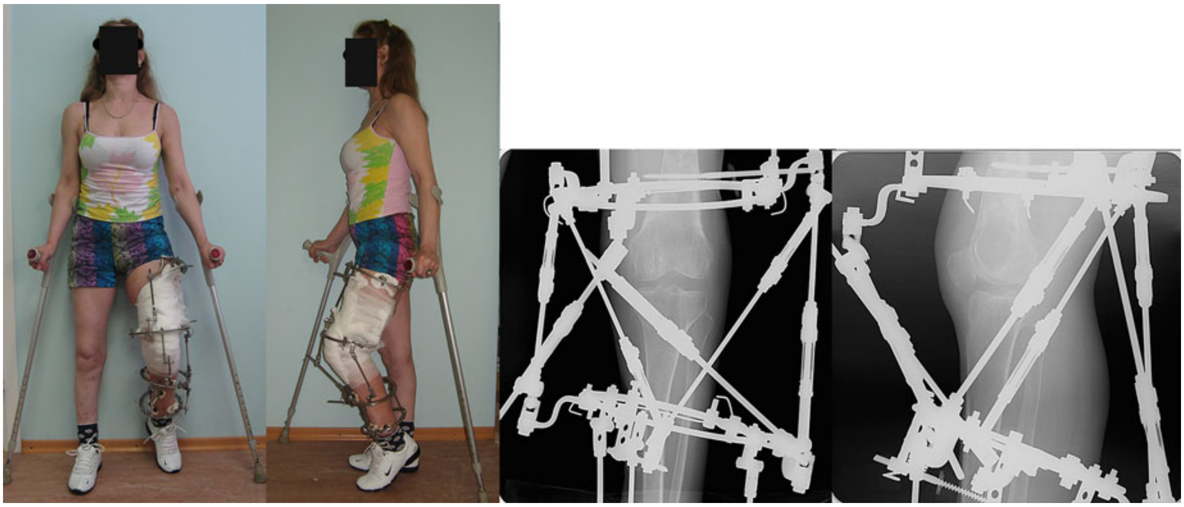

Fig. 3 Photos and radiographs of patient after surgery. Flexion of 30° was achieved in surgery; software-based hexapod (Ortho-SUV Frame) is assembled

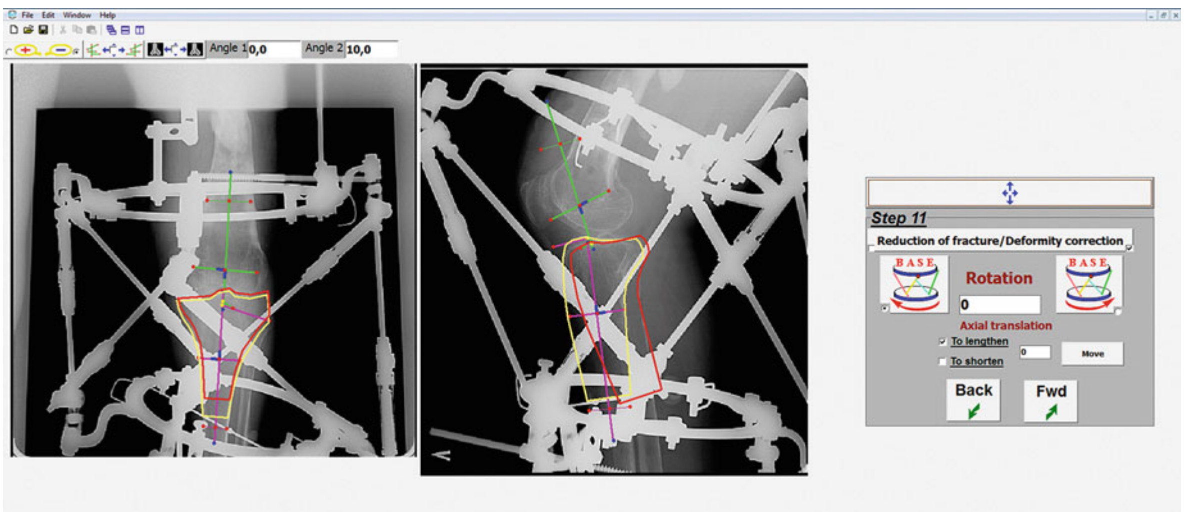

Fig. 4 The Ortho-SUV software window at step 11: planning movement in the knee joint. The *yellow* bone contour indicates the initial tibial bone position. The *red* bone contour indicates the position of the tibia at each increment of 5° flexion increase

7 Technical Pearls

(a) The Ortho-SUV Frame's assembly according to the method of unified designation of external fixation (MUDEF):

$$\frac{\text{II},9,90;\ \text{III},10,90}{1/4\ 220} - \frac{\text{VII},8,90;\ \text{VIII},\mathbf{3}-9}{200} - \text{O}$$

$$-\ \text{SUV} - \frac{\text{III},\mathbf{4}-10;\ \text{IV},1,80}{150}$$

$$-\ \frac{\text{VII},\mathbf{4}-10;\ (\mathbf{8}-2)8-2}{130}$$

Note that the proximal module included two rings, which protected the fragile bone.

(b) Using only "reference positions" (RP) for wires and pins inserting offers the possibility to decrease risk of pin-tract infection and pin-induced joint stiffness.

(c) The use of computer-assisted hexapod gradually improved ROM of the knee in the axis of rotation.

(d) After each of 10° of flexion of the knee was fully achieved, another 10° was programmed.

(e) After passive flexion of 90° was achieved, active knee motion was started.

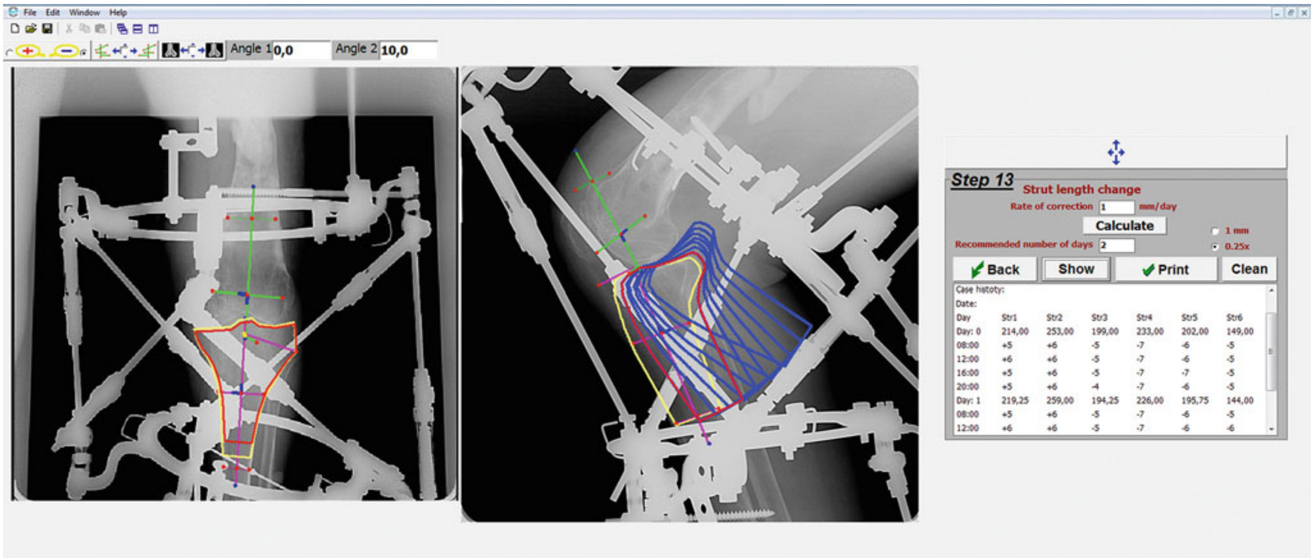

Fig. 5 The Ortho-SUV software window at step 13: software calculation to achieve 90° of flexion

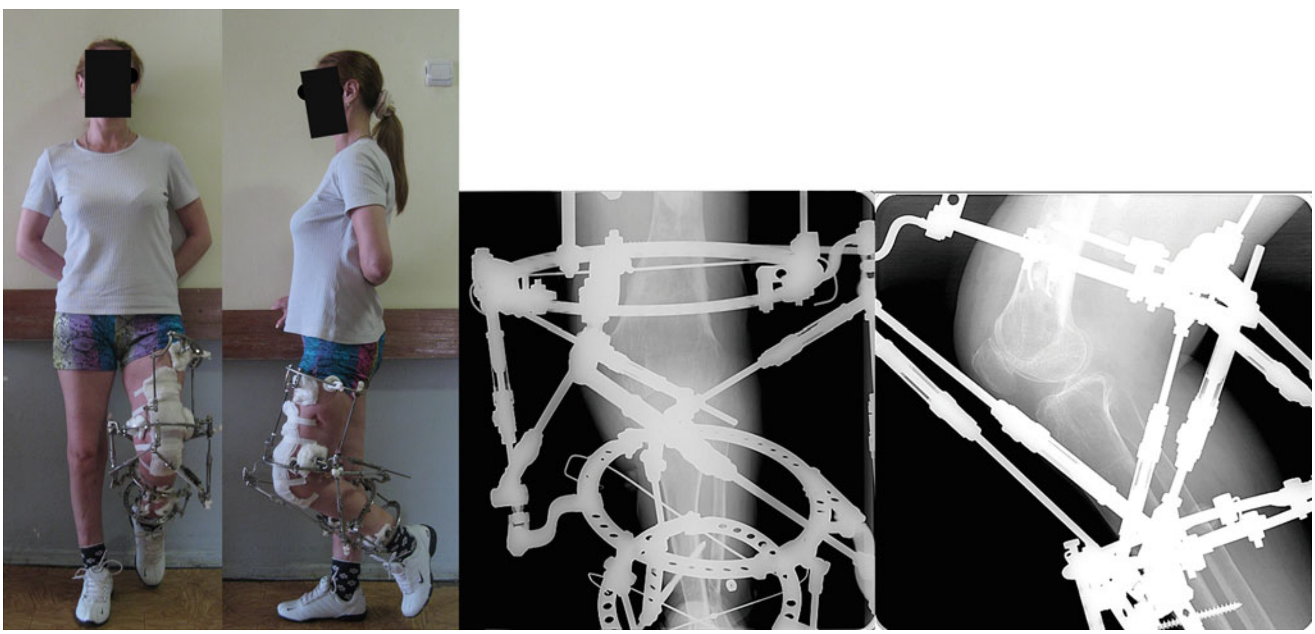

Fig. 6 Photos and radiographs during treatment. ROM is 45/0/0. Note the normal congruency of the knee joint

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

9 Avoiding and Managing Problems

(a) The use of the computer-assisted hexapod prevents damage of the articular cartilage by distracting the joint while gradual flexion is performed.

Fig. 7 Clinical photo 1.5 years after frame removal showing ROM of 110/0/0

(b) Three full cycles of flexion/extension were provided to assure active movement of the knee joint. After 2 months, this was completed and then the frame was removed.

10 See Also in Vol. 2

Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity
Case 5: Computer Assisted External Fixation at Femur Two-Level Posttraumatic Complex Deformity

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Part VIII

Adult Deformity: Knee Fusion

Case 45: Bilateral Congenital Knee Fusions with Lower Limb Deformities and Coxa Vara Treated with Osteotomies

Marie Gdalevitch

Contents

Abstract

This is a case of complex bilateral lower limb deformities including bilateral coxa vara and severe knee flexion deformities through congenital knee fusions. The patient required combined techniques of acute and gradual deformity correction using six-axis external fixation. The patient underwent staged surgery to correct both limbs within a 6-week interval.

1 Brief Clinical History

Patient is a 19 year old male, who is a working car mechanic and has history of congenital knee fusions that have increasingly progressed into flexion over the years. His main complaints are pain in his hips and ankles, and he feels he is progressively losing height due to the increased bend in his knees. He also complains of having difficulty abducting his legs. His past medical history includes Pierre-Robin syndrome and a previous surgery to the right leg to try and correct the knee deformity as a child. The patient smokes a pack of cigarettes daily. On physical exam he is able to walk without difficulties. He has severe knee flexion deformities while standing. Examination of his hips demonstrates flexion to 100° with no hip flexion contractures, but he has limited hip abduction of 5° bilaterally with adduction of over 40°. Patient has good range of motion of both ankles and a normal spine exam.

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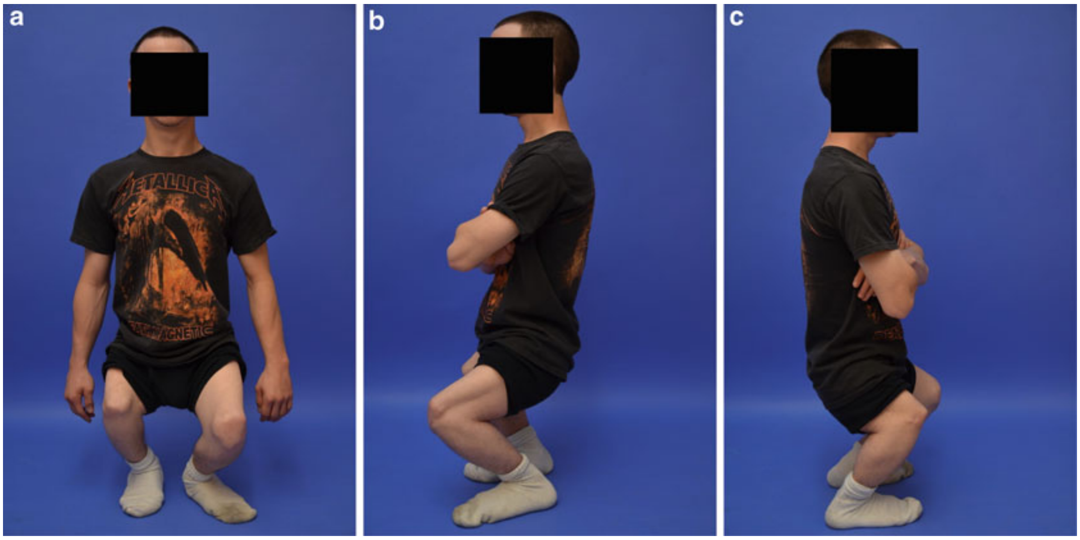

Fig. 1 (**a**–**c**) Clinical photos of the patient standing with bilateral knee fusion deformities

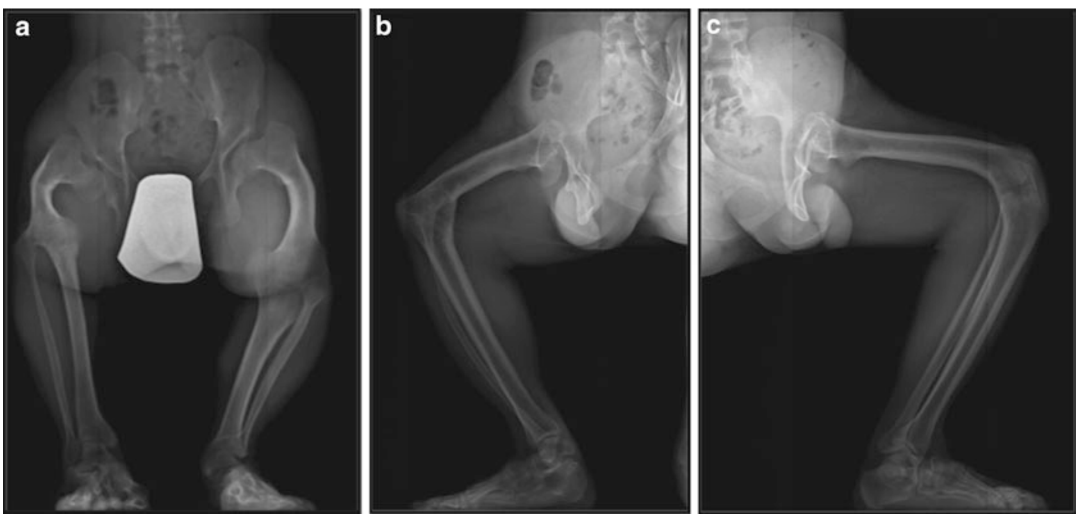

Fig. 2 (**a**–**c**) AP and lateral full-length radiographs demonstrating bilateral coxa vara hip deformities and severe knee flexion deformities

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Bilateral coxa vara with acetabular dysplasia.
2. Bilateral severe knee flexion deformities (through knee fusions).
3. LLD of approximately 7 cm with the right being shorter than the left.

4 Treatment Strategy

The treatment strategy for such a case is to begin with acute correction of the coxa vara hip deformities via subtrochanteric valgus osteotomies. One leg is done at a time, and during the same intervention, the knee fusion deformity is addressed by dissection of the apex of the deformity circumferentially and acute shortening with closing wedge prior to the osteotomy and then utilized ensuring that the posterior soft tissues were not tense. An external fixator was applied to complete the correction gradually and to be able to adjust the sagittal and coronal planes to realign the mechanical axis of the leg. The anatomy in such a case can be variable, and careful

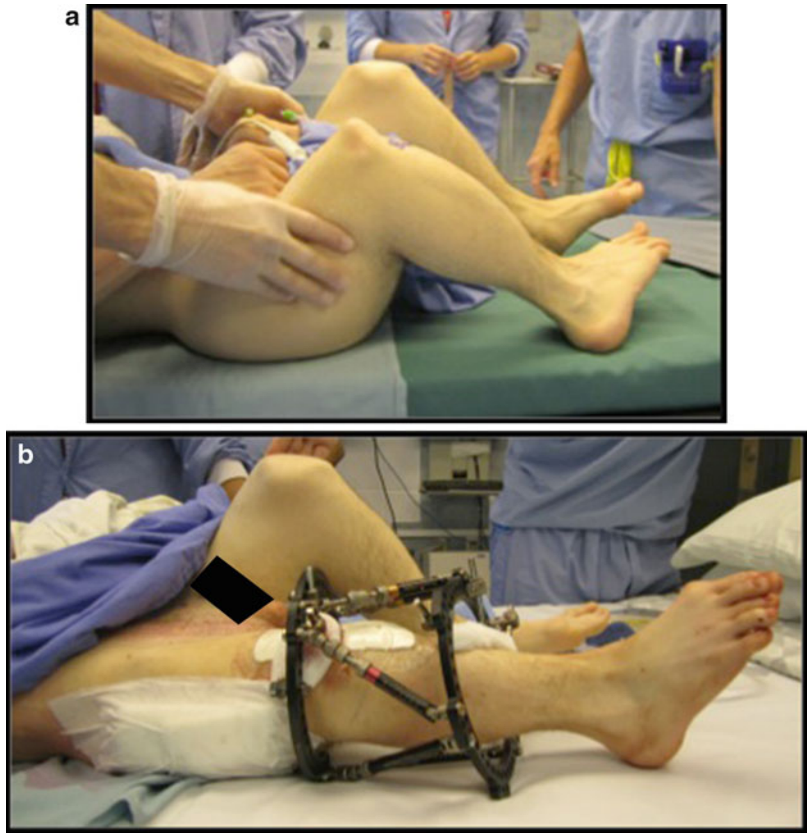

Fig. 3 (**a**, **b**) Intraoperative photographs preoperatively and postoperatively during treatment of the right side

dissection of the soft tissues at the level of the deformity is necessary. Postoperatively, the external fixator is used to realign the limbs and adjust for limb length inequalities. In this case the right femur was significantly shorter than the left, and the patient requested that it be lengthened instead of shortening the left leg. Distraction and lengthening was done through the same osteotomy site. The patient subsequently healed his 8 cm regenerate on the right side after almost a year with the external fixator. A bone stimulator was used to accelerate the process. The patient was unable to quit smoking. The osteotomy on the left side only healed posteriorly, and the patient subsequently returned to the operating room to have a debridement of the nonunion and iliac crest bone grafting.

5 Basic Principles

Combined deformity correction via acute and gradual techniques allows the surgeon to obtain a partial acute correction of the deformities, and then the correction is completed using the external fixator. This is particularly useful in patients where the anatomy is altered or in cases of bilateral deformity correction since the limb lengths and alignment can be adjusted based on postoperative standing radiographs.

6 Images During Treatment

See Figs. 3 and 4.

7 Technical Pearls

- Combined acute and gradual deformity correction is a valuable technique when dealing with patients with both femoral and tibial deformities in the same limb. It allows adjustment of the correction using the external fixator in the postoperative period and can compensate for minor under- or over-corrections of the acutely corrected bone.
- Combined acute and gradual deformity correction is also recommended when the anatomy of the limb is altered or when acute correction of the entire limb would jeopardize the neurovascular structures.

8 Outcome Clinical Photos and Radiographs

See Fig. 5.

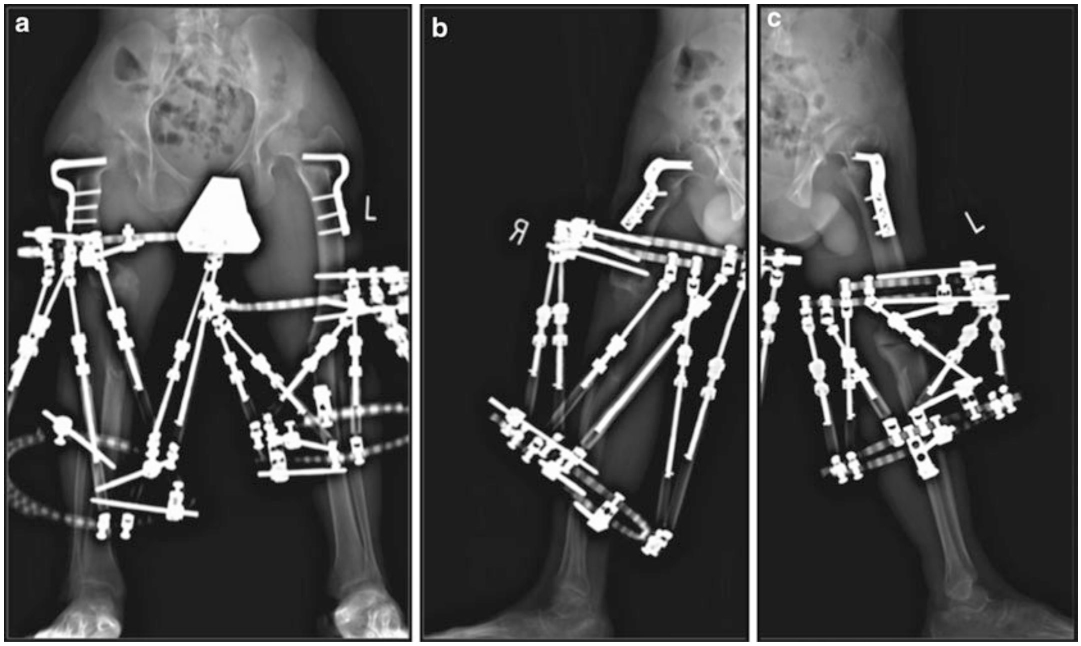

Fig. 4 (**a**–**c**) Full-length weight-bearing anteroposterior and lateral radiographs during treatment. Note the distraction of the right-sided osteotomy

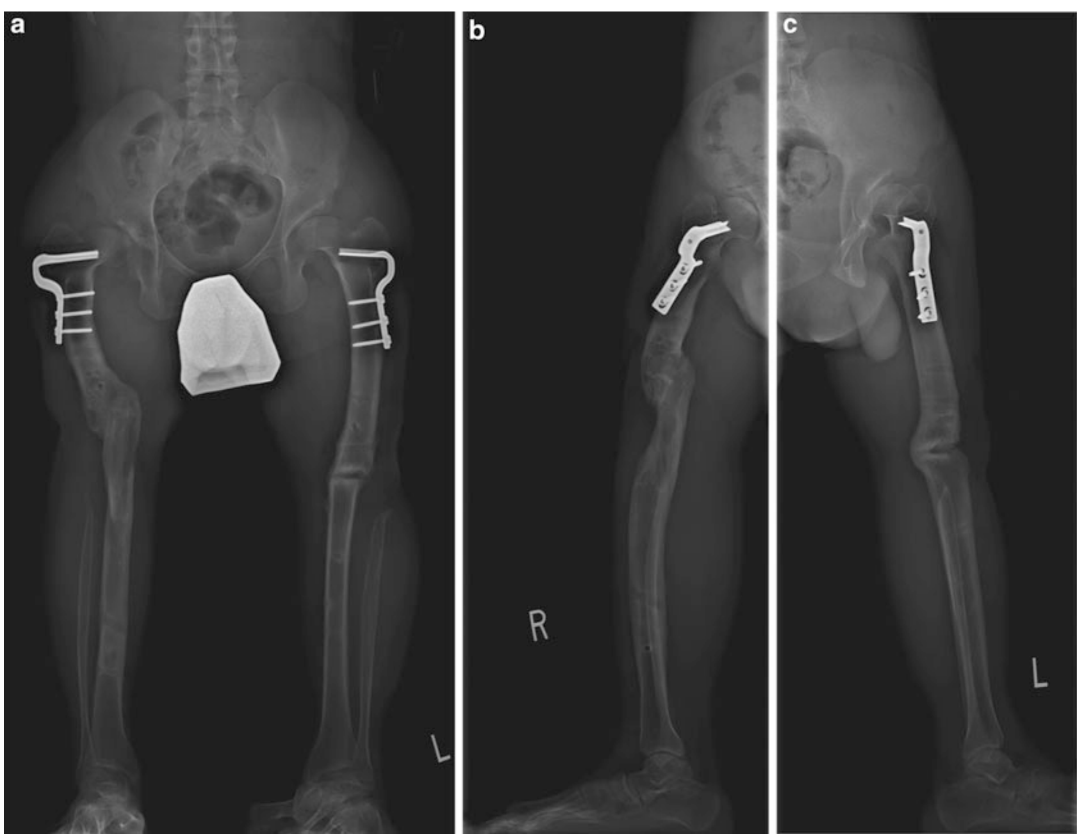

Fig. 5 (**a**–**c**) Full-length weight-bearing AP and lateral radiographs 6 months after removal of the external fixators. Note the left osteotomy has only partially healed

9 Avoiding and Managing Problems

- When dealing with knee flexion deformities (either soft tissue or bony) and procurvatum deformities, the surgeon needs to recognize the need to shorten the bone for acute correction of the deformity, thereby avoiding undue tension on the posterior neurovascular structures.
- When the flexion or procurvatum deformities are very pronounced, the surgeon can combine an acute and gradual correction to avoid over-shortening the bone.

10 See Also in Vol. 1

Case 101: Vitamin D-Resistant Hypophosphatemic Rickets Treated by Double-Level Femoral Osteotomy with Internal Fixation and Proximal Tibial Osteotomy with Gradual Deformity Correction

References and Suggested Reading

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Case 46: Correction of Varus Deformity of the Femur in a Patient with Knee Fusion

Leonid N. Solomin and Petr Skomoroshko

Contents

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Abstract

This is a case of operative treatment of femur deformity associated with knee fusion. In this case, deformity correction was performed gradually using the computer-assisted hexapod – Ortho-SUV Frame. The article shows the advantages of six-axis correction.

1 Brief Clinical History

This is a 44 year old female with right femur deformity and knee joint fusion accompanied with chronic osteomyelitis (phase of remission). She complained of limp, deformity, shortening of the right leg, and backache. Myeloid sarcoma was treated in 1996 with excision and total right knee replacement. In 2003, septic instability of the implant occurred. This was followed by aggressive debridements and resection of the bone. Finally knee fusion was done.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

(a) Right distal femur varus
(b) Right limb shortening
(c) Chronic osteomyelitis of the right femur]

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Fig. 1 Preoperative patient's view and roentgenograms showing varus and LLD: MAD = 32 mm medial, LDFA = 94 °, LDTA = 96 °, LLD = 7.5 cm. Fusion of the right knee in 25 ° flexion

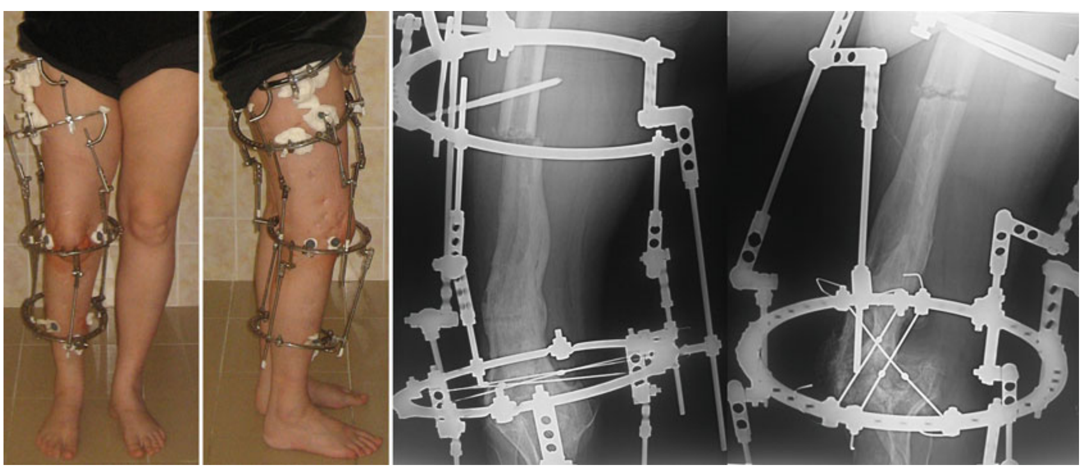

Fig. 2 External fixator applied and osteotomy of the femur in the middle third was performed

4 Treatment Strategy

The strategy we planned was chosen according to the combination of deformities (angulation, torsion, shortening), existence of the focus of chronic osteomyelitis at CORA level. Therefore, we decided to perform the osteotomy away from the apex of the deformity and to use computer-assisted Ortho-SUV Frame (http://ortho-suv.org) for an accurate correction of limb alignment.

5 Basic Principles

(a) The use of external fixation provides possibility of low-trauma surgery, avoiding large incisions at the site of infection.
(b) The use of computer-assisted Ortho-SUV Frame provides precise, gradual deformity correction and lengthening.
(c) Residual LLD of 1.5 cm should be left at knee joint fusion.

6 Images During Treatment

See Figs. 2, 3, 4, and 5.

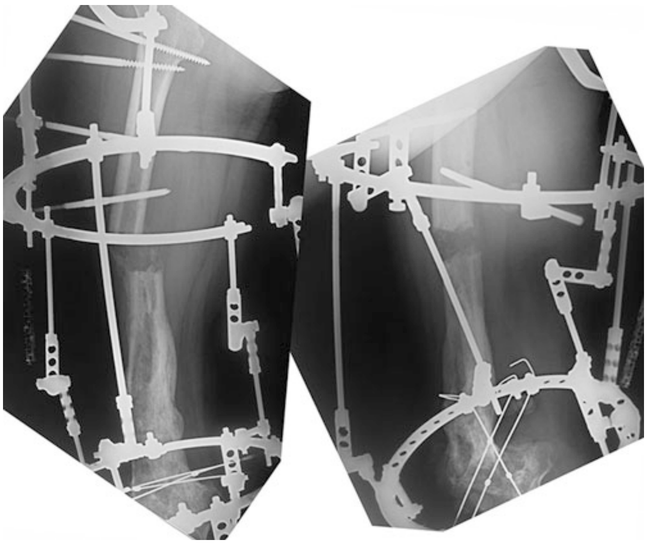

Fig. 3 Lengthening using Ilizarov hinges was performed at first

7 Technical Pearls

(a) The external fixator provided rigid fixation of bone fragments. The constructs used according to the Method of Unified Designation of External Fixation (MUDEF) are the following:

$$\frac{\mathrm{III},10,90;\ \mathrm{III},9,90}{\mathrm{arch}.\,220} - \frac{\mathrm{IV},10,90;\ \mathrm{IV},8,90}{200} - \mathrm{Ortho} - \mathrm{SUV} - \frac{\mathrm{VII},\mathbf{3}-9;\ \mathrm{VII},\mathbf{8}-10}{180} - \mathrm{o} - \frac{\mathrm{IV},\mathbf{4}-10;\ \mathrm{IV},1,90}{160}$$

(b) The precise deformity correction was the result of the calculations and planning made in Ortho-SUV software.

(c) Using only "reference positions" (RP) (safe zones) for wire and pin placement helps to decrease risk of pin-tract infection and pin-induced joint stiffness.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

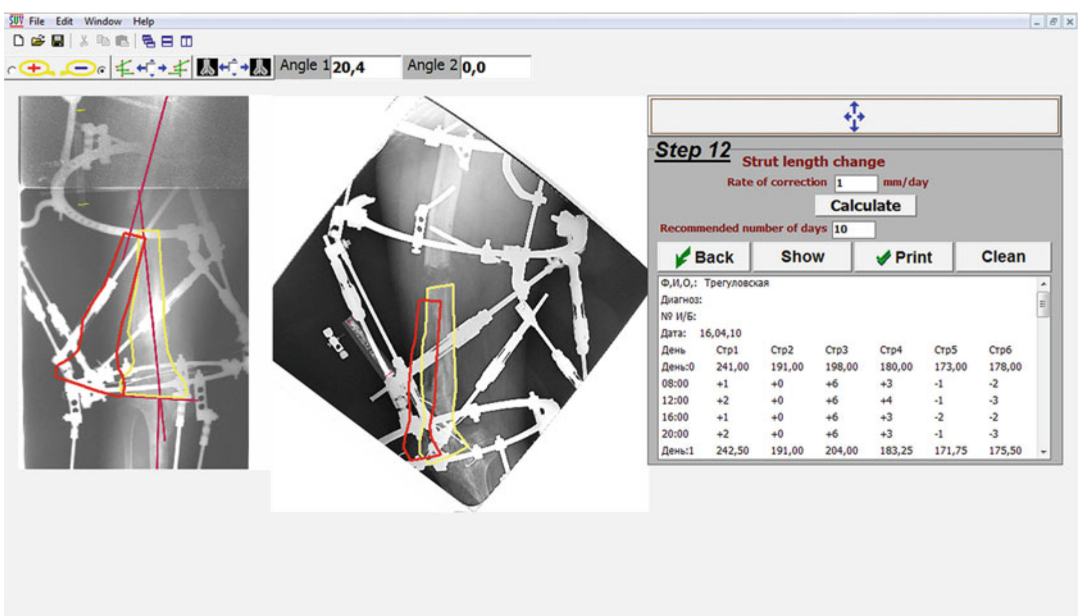

Fig. 4 The Ortho-SUV Frame was applied. The Ortho-SUV software window at step 12: deformity correction planning. The bone fragments' anatomical axes were drawn. *Yellow* bone contour signifies the initial mobile (corresponding) fragment position. *Red* bone contour signifies the final position of mobile bone fragment. The software calculated the number of days needed for deformity correction using a rate of 1 mm/day

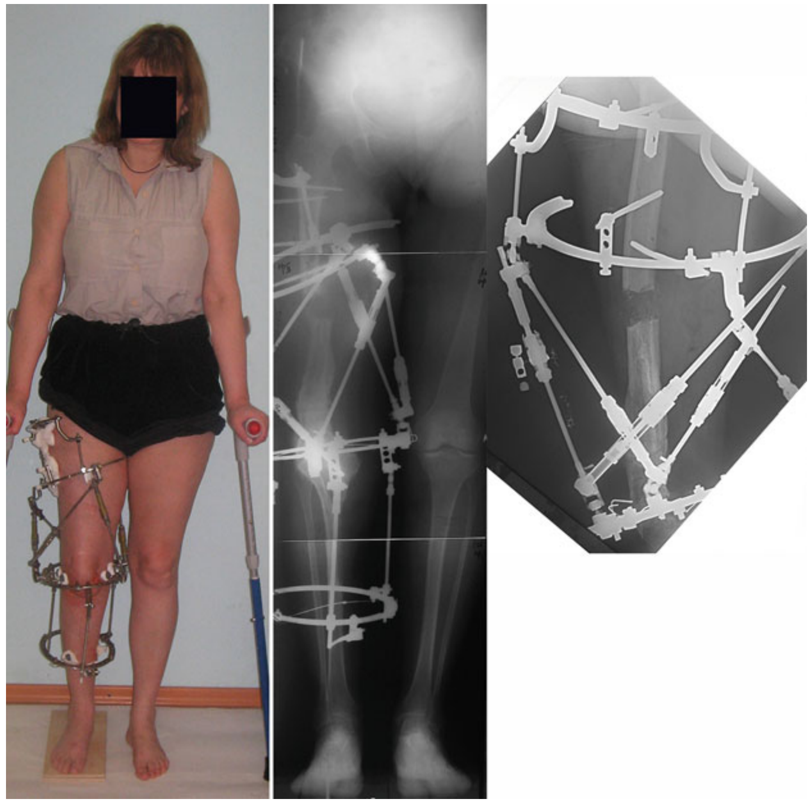

Fig. 5 After deformity correction

Fig. 6 Front and lateral views showing realignment and partial correction of LLD. MAD is normalized. Side view showing full hip joint function

9 Avoiding and Managing Problems

(a) The correction of the deformities was made gradually. The use of the SAR points prevented any nerve or vascular injury and provided a good environment for callus formation.
(b) Active antibiotic therapy and pin-site care were used to prevent infectious complications.
(c) We avoided osteomyelitis exacerbation because the osteotomy was performed away from the apex of the deformity, out of the focus of infection.
(d) The osteotomy away from CORA required translation. The accurate alignment of the limb was achieved with the help of the computer-assisted frame.
(e) The patient lives in region where there is sparse orthopedic care. The use of Ilizarov hinges for lengthening simplified the first step of the project after discharge from the hospital.

10 See Also in Vol. 2

Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity
Case 5: Computer Assisted External Fixation at Femur Two-Level Posttraumatic Complex Deformity
Case 21: Computer Assisted External Fixation and then Nailing at Both Lower Legs Non-unions Accompanied with Complex Deformities

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Case 47: Knee Arthrodesis for Failed Total Knee Arthroplasty

Megan M. Riedel and Janet D. Conway

Contents

Abstract

This is a case of infected total knee replacement in an elderly man who is a compromised host with multiple comorbidities. Successful arthrodesis was accomplished with aggressive debridement and stabilization with two monolateral external fixators placed in a multi-planar (90–90°) fashion. Compression at the fusion site and staged bone grafting enhanced bony union. Bone loss and limb shortening were accepted in this patient, and a shoe lift was used.

1 Brief Clinical History

A 70 year old man had a primary total knee arthroplasty that was complicated by arterial injury and required vascular surgical repair and fasciotomies. Subsequently, the patient developed an infection of the total knee arthroplasty. He was treated with intravenously administered vancomycin, which led to renal failure requiring dialysis. Prior to presentation, he underwent removal of the total knee arthroplasty hardware in an attempt to eradicate the infection. He presented to our clinic with a chronically infected knee, foot drop, and a poor soft tissue envelope with a draining sinus. A knee arthrodesis was planned secondary to his poor medical condition, poor soft tissue envelope, compromised blood flow, and chronic infection. Our treatment plan included a two-stage knee arthrodesis using biplanar monolateral external fixators (Limb Reconstruction System, Orthofix, Lewisville, TX). During the first stage of treatment, the surfaces of the proximal tibia and distal femur were resected to clean, bleeding, and healthy bone. An external fixator was applied to the lateral side of the limb so that it bridged the knee. A V.A.C.Ulta Negative Pressure Wound Therapy System (KCI, San Antonio, TX) was placed on the anterior wound to promote healing of the soft tissue envelope. Intravenously administered antibiotics were given for 6 weeks after the initial surgery. The patient attended

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Fig. 1 Clinical anteroposterior (**a**) and lateral (**b**) view photos show the poor soft tissue envelope and the draining sinus at the knee (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

home physical therapy sessions, and the limb was allowed 50% weight bearing. Four months after the application of the first stage of external fixation, the anterior wound healed and the patient underwent the second stage of the arthrodesis. Bone graft was harvested from the iliac crest and inserted into the knee fusion site. A second monolateral external fixator was applied anteriorly to the femur and tibia. This external fixation was not placed anteriorly during the first stage of treatment secondary to wound access. After surgery, the laboratory results showed no acute infection and the patient did not report any pain. He was allowed weight bearing as tolerated and at-home physical therapy. Two months after the second procedure, the knee arthrodesis was united. The external fixation was removed in the operating room, and a long leg cast was applied. When the patient was discharged, the limb was allowed 50% weight bearing and the patient was given a prescription for at-home physical and occupational therapy. The cast was removed 1 month after application, and the patient began full weight bearing. At long-term follow-up (approximately 2 years), the patient had an infection-free and solidly united knee arthrodesis with weight bearing as tolerated.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- Septic right knee with osteomyelitis
- Chronic wound infection

Fig. 2 Anteroposterior (**a**) and lateral (**b**) view radiographs obtained at the time of initial presentation show retained antibiotic cement and infected total knee arthroplasty site. Note that the total knee arthroplasty hardware had been removed prior to presentation (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

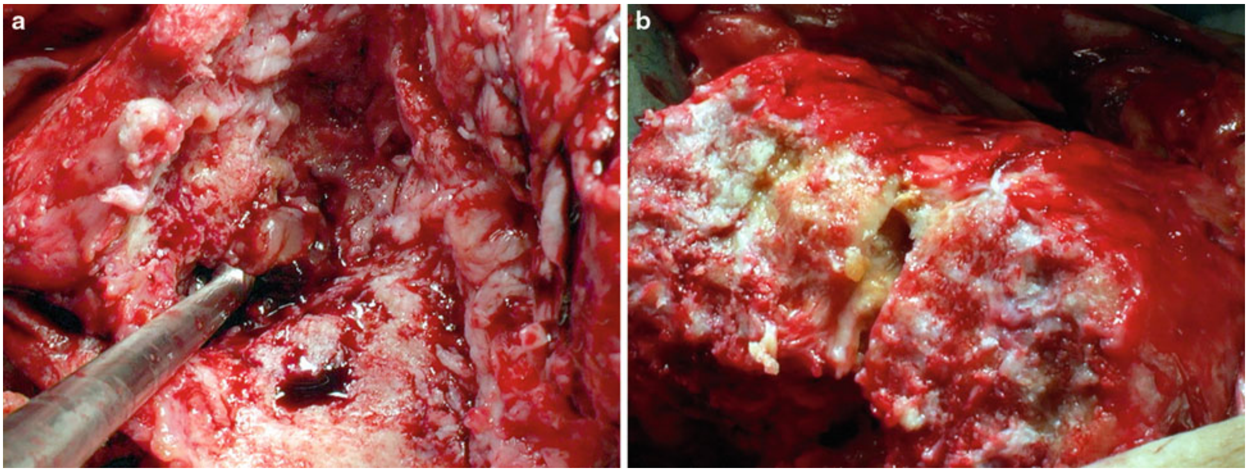

Fig. 3 Intraoperative photos (**a** and **b**) of necrotic tibia and femur with large amounts of reactive granulation tissue (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

Fig. 4 (**a**) Postoperative clinical photo obtained after application of the external fixation during the first stage of treatment. (**b**) Postoperative lateral view clinical photo obtained after application of the external fixation during the first stage of treatment. Note the compression-distraction unit (CD unit) (*blue arrow*) (Orthofix, Lewisville, TX) at the knee that allows for compression at the knee joint postoperatively. Also note the two distal clamps (*red arrow*) that are linked together. (**c**) The incision has a transverse component to allow wound closure after acute compression (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

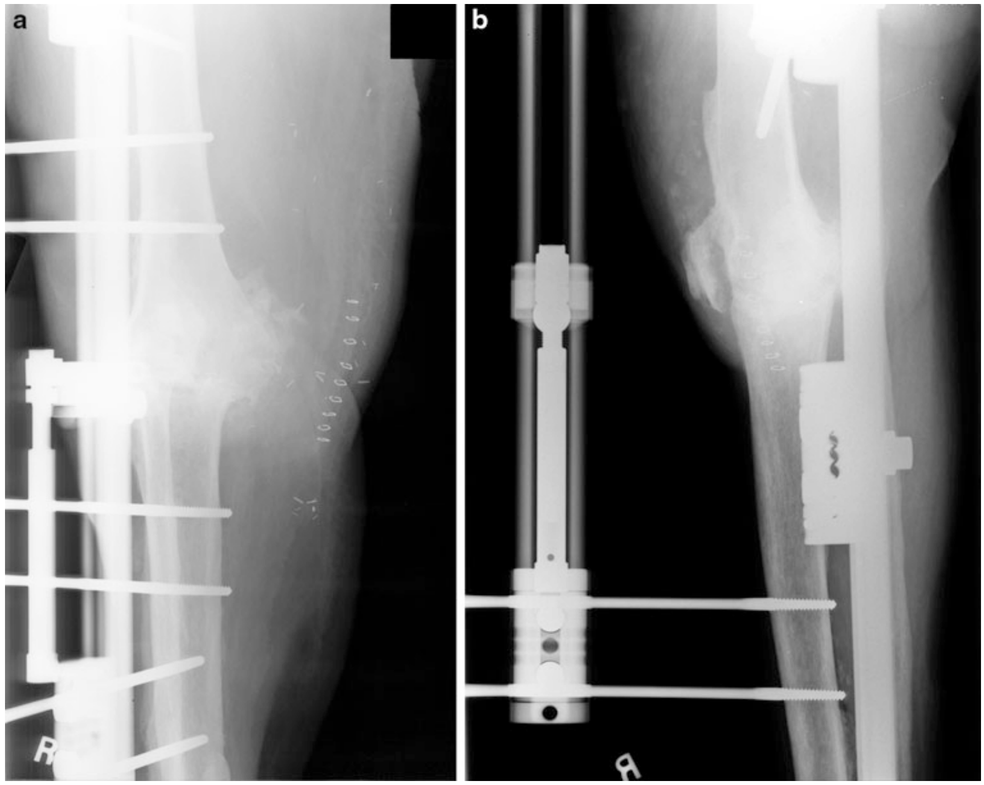

Fig. 5 Anteroposterior (**a**) and lateral (**b**) view radiographs obtained postoperatively show the anterior external fixator application and bone graft. Note that the staple line is placed medially to avoid the poor anterior soft tissue envelope as well as the fixator pins (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

– Multiple medical comorbidities (type II diabetes mellitus, renal failure, vascular insufficiency, hypertension)
– Poor soft tissue envelope with draining sinus
– Foot drop

4 Treatment Strategy

The patient underwent a two-stage treatment. The first stage consisted of irrigation and débridement of the infected knee and resection of the tibial and femoral bone ends to healthy and bleeding bone. A monolateral external fixator was applied laterally for the knee arthrodesis. During the second stage of treatment, a monolateral external fixator was applied anteriorly to the tibia and fibula secondary to the anterior soft tissue envelope issues and the need for the V.A. C.Ulta Negative Pressure Wound Therapy System. Bone grafting was also performed during this second procedure. Bone graft was harvested from the iliac crest and/or femoral intramedullary canal and then placed in the fusion site along with bone morphogenetic protein-2. When harvesting bone graft from the femoral intramedullary canal, the senior author prefers to use the Reamer/Irrigator/Aspirator (RIA) System (DePuy Synthes, West Chester, PA). Both external fixators remained in place until the limb was stable and healed (approximately 6–8 months with weight bearing as tolerated). A long leg cast was applied, and the limb was allowed 50% weight bearing at the time of frame removal.

If a patient has a stable soft tissue envelope and does not need the V.A.C.Ulta Negative Pressure Wound Therapy System, both external fixators could be placed anteriorly and laterally at the initial surgical setting. In all cases, a secondary bone grafting procedure is routinely planned to promote rapid healing.

5 Basic Principles

The infected bone should be resected, and the posterior capsule should be stripped to achieve good acute bone contact. The external fixation needs to provide rigid stability to obtain bone union. A compression-distraction unit (CD unit) (Orthofix, Lewisville, TX) can be used postoperatively to increase compression and stability at the knee arthrodesis site. Pins should be placed to avoid existing wounds.

Bone loss will lead to limb shortening after apposition of the femur and tibia. This can be addressed with either a shoe lift or bone lengthening depending on the individual patient. Optimal limb length of the knee arthrodesis side is about 1.5 cm short. This allows clearance of the foot during the swing phase of gait. Average shortening after fusion for failed TKA is 4 cm.

Fig. 6 Anteroposterior (**a**) and lateral (**b**) view radiographs obtained after frame removal. Note the union at the knee (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

6 Images During Treatment

See Figs. 3, 4, and 5.

7 Technical Pearls

Bone ends should be clean, bleeding, and healthy. The limb should be aligned within 0–5° valgus before the external fixators are applied. The foot should be splinted at 90°. External fixation should be maintained until clinical and radiographic union of the arthrodesis site is observed (10–12 weeks). When applying bone graft, place the incision away from the poor soft tissue envelope (i.e., anterior aspect of the knee). In the majority of cases, this means placing the incision on the medial or lateral aspect of the knee.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

Watch for pin loosening postoperatively. Remove and replace any pins that are loose since this will compromise the fixator stability. Be sure to use hydroxyapatite-coated pins.

10 Cross-References

▶ Case 48: Knee Fusion and Lengthening for Failed Total Knee Replacement and Bone Loss
▶ Case 49: Knee Fusion with Gradual Shortening and Staged Insertion of Antibiotic Coated Intramedullary Nail for Failed Infected Total Knee Arthroplasty

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Case 48: Knee Fusion and Lengthening for Failed Total Knee Replacement and Bone Loss

Vikrant Landge and Janet D. Conway

Contents

Abstract

A 64 year old woman underwent total knee arthroplasty of the right knee. The knee developed a chronic recurrent infection with exposed hardware and no extensor mechanism. The prosthesis and components were removed. The infection was treated, and her knee was fused with the insertion of an antibiotic cement-coated intramedullary rod. She presented to our clinic with persistent pain that was primarily located at the distal interlocking screws. The right limb had a 3-cm limb length discrepancy (LLD). Radiographs showed persistent nonunion of the right knee. At the time of surgery, the patient underwent simultaneous treatment of the nonunion and LLD. The antibiotic cement-coated rod was not removed. She underwent resection of the nonunion and implantation of bone graft harvested from the left femur with the Reamer/Irrigator/Aspirator (RIA) system (Synthes, West Chester, PA). BMP-2 was used to augment healing. The distal tibial interlocking screws were then removed, and proximal tibial and fibular osteotomies were performed. A two-incision technique (anterolateral and posteromedial) was used for the tibial osteotomy to cut around the rod. The knee fusion rod was always locked proximally, and the external fixator controlled the entire tibial segment (proximal and distal) with respect to rotation. An Orthofix external fixator (Lewisville, TX) was applied to the tibia. Distraction began 1 week after surgery (four 1/4 turns per day). The patient received physical therapy for the ankle to prevent equinus contracture. The tibia was distracted 3 cm over a 30-day period. She remained non-weight bearing throughout the distraction phase. After achieving correction, the external fixation was locked in place for 1 month. The patient then returned to surgery for insertion of distal interlocking screws and frame removal. After surgery, the patient attended physical therapy sessions and was partial weight bearing as tolerated. Eight weeks after external fixation removal, the patient achieved full weight-bearing status with a cane.

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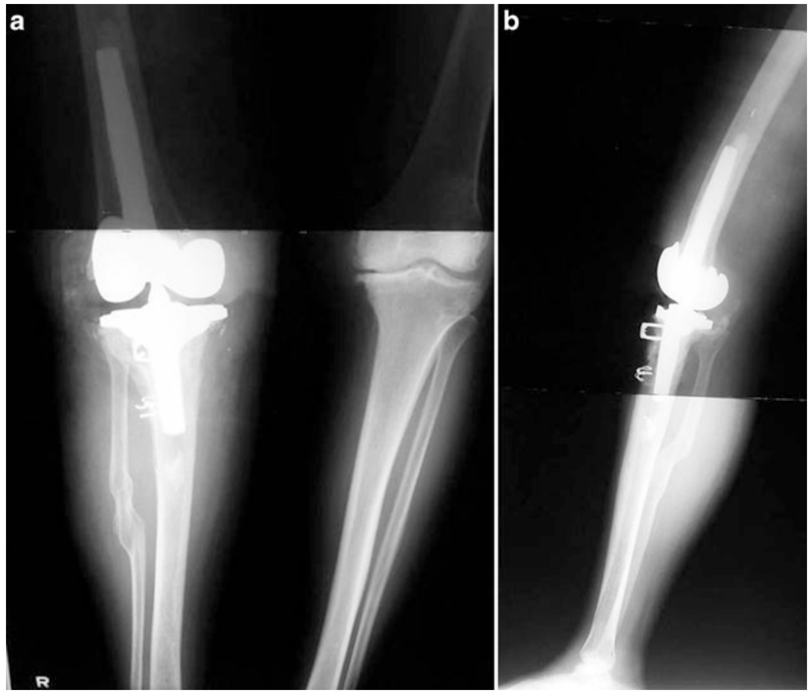

Fig. 1 Preoperative anteroposterior (**a**) and lateral (**b**) view radiographs show revision total knee arthroplasty (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

Fig. 2 (**a**) Clinical photo obtained at initial presentation with extensive anterior soft-tissue loss secondary to infection. (**b**) Photo obtained after removal of total joint arthroplasty and extensive débridement. Anterior soft-tissue defect treated to complete closure with V.A.C. Ulta Negative Pressure Wound Therapy System (KCI, San Antonio, TX) (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

1 Brief Clinical History

A 64 year old woman underwent total knee arthroplasty of the right knee, which developed a chronic recurrent infection with loss of anterior soft tissue. The prosthesis and components were removed. The necrotic soft tissue was débrided, and the knee was fused with the insertion of an antibiotic cement-coated intramedullary rod. Following the eradication of her infection and healing of her soft-tissue envelope, she stated that she had persistent pain that was primarily located at the distal interlocking screws. The right limb had a 3-cm limb length discrepancy (LLD), and radiographic evaluation showed that the knee fusion site was not united.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

Fig. 3 Preoperative anteroposterior view full-length standing radiograph obtained at the time of nonunion of the knee fusion and prior to lengthening (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

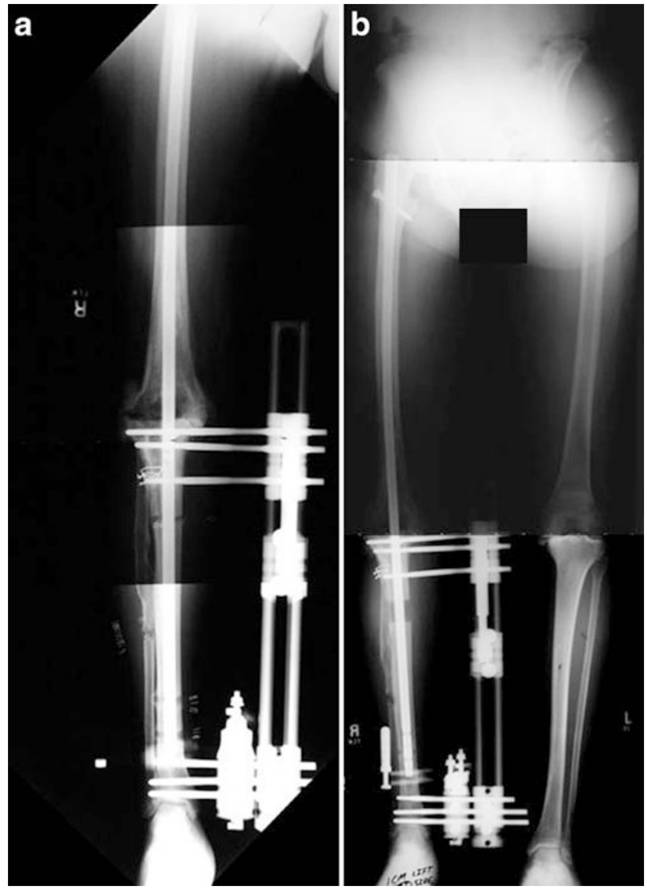

Fig. 4 (**a**) Anteroposterior view radiograph obtained during the distraction stage of treatment. (**b**) Anteroposterior view full-length standing radiograph obtained after the distraction stage of treatment was completed (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

3 Preoperative Problem List

- Nonunion of knee fusion
- Limb length discrepancy
- Bone loss from previous surgical procedures
- Poor soft tissue secondary to multiple surgical procedures

4 Treatment Strategy

The nonunion was resected until clean, bleeding, healthy bone was observed. Bone graft was inserted through a longitudinal incision along the lateral aspect of the knee joint to avoid the damaged anterior soft-tissue envelope. The tibia was gradually lengthened using the lengthening over nail technique, and the fibula was captured.

5 Basic Principles

Determine the patient's vitamin D levels and supplement appropriately. The surgeon should remove all dead bone until reaching bleeding bone surfaces. Surgeons should have a low threshold for decompressing the peroneal nerve prior to lengthening. Be sure to capture the fibula when lengthening the tibia. In tibial lengthening cases, closely monitor the rate of distraction. To prevent ankle equinus, aggressive ankle range of motion and splinting are necessary.

6 Images During Treatment

See Fig. 4.

7 Technical Pearls

Place the fixator pins so that they do not touch the intramedullary rod. To achieve this, use a cannulated wire technique. The fibula can be captured with a wire or with one of the cannulated half-pins.

Fig. 5 Anteroposterior view full-length standing radiograph obtained after external fixation removal and insertion of interlocking screws (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

9 Avoiding and Managing Problems

Be sure not to incise the damaged anterior soft-tissue envelope when bone grafting the nonunion. Always use a longitudinal medial or lateral incision. Prophylactically decompress the peroneal nerve to avoid symptoms during lengthening. When inserting distal interlocking screws, be prepared to correct any residual ankle equinus with a tendo Achillis lengthening.

10 Cross-References

- ▶ Case 47: Knee Arthrodesis for Failed Total Knee Arthroplasty
- ▶ Case 49: Knee Fusion with Gradual Shortening and Staged Insertion of Antibiotic Coated Intramedullary Nail for Failed Infected Total Knee Arthroplasty

Fig. 6 Anteroposterior (**a**) and lateral (**b**) view full-length standing radiographs obtained 12 months after external fixation was removed. Note the complete and total regenerate healing at the level of the proximal tibia (Copyright 2014, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore)

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Case 49: Knee Fusion with Gradual Shortening and Staged Insertion of Antibiotic Coated Intramedullary Nail for Failed Infected Total Knee Arthroplasty

Amgad M. Haleem and S. Robert Rozbruch

Contents

Abstract

This case is about a female patient with multiple failed infected total knee arthroplasties (TKA) associated with persistent active infection and incapacitation with inability to bear weight on the affected knee. Eradication of infection was achieved by removal of infected implants and wide resection of all infected bone. The resultant bone defect across the joint (8 cm) was spanned with a Taylor Spatial Frame (TSF) that was used to gradually shorten the femoral and tibial bone ends across this defect. Once the soft tissue gap was reduced and bony apposition was attained, knee fusion via an antibiotic-coated intramedullary nail (IMN) was performed. This resulted in a solid knee fusion with complete eradication of infection. Residual leg length discrepancy was managed by a shoe lift; limb lengthening was not performed for this elderly patient. At 1 year postoperatively, the patient was completely infection-free, pain-free, and ambulating with a very good functional outcome.

1 Brief Clinical History

A 76 year old female presented 20 years after a primary TKA that was complicated 3 years later by infection of the prosthesis. The patient had undergone a two-stage revision with an antibiotic-coated knee spacer and a course of intravenous (IV) antibiotics for 6 weeks followed by revision TKA. However, the revision TKA was compromised again 2 years later by recurrent infection, and the patient subsequently underwent two additional two-stage revision TKAs with repeat IV antibiotics followed by oral antibiotic chronic suppression for 12 years. After discontinuing oral antibiotics, infection recurred with an actively draining sinus of purulent discharge on the anteromedial aspect of the knee joint with severe knee pain and inability to bear weight on the involved TKA.

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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Fig. 1 (**a**, **b**) Preoperative clinical photograph of the patient showing the draining sinus over the anteromedial aspect of the knee

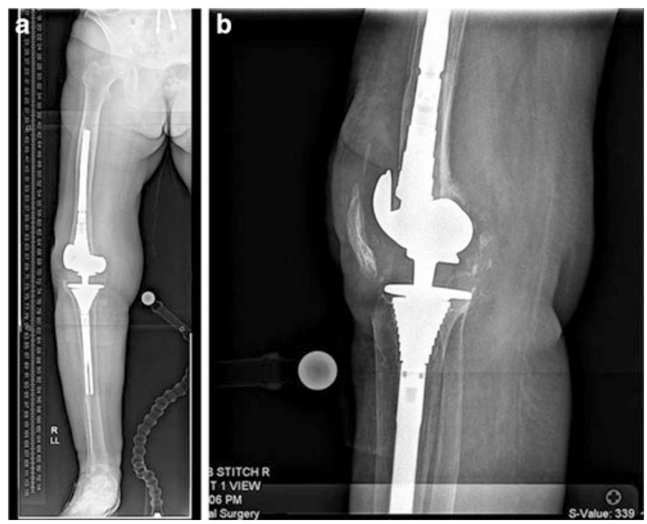

Fig. 2 (**a**, **b**) Preoperative long-standing (hip to ankle) (**a**) anteroposterior (AP) and (**b**) lateral radiographs of the right knee demonstrating a revision TKA with femoral and tibial stemmed components and a highly constrained (rotating hinge) prosthesis. Note the reduced bone stock on both femoral and tibial sides from repeat TKA revision surgeries

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Infected TKA with revision TKA × 3
2. Active draining sinus
3. Compromised soft tissues from recurrent surgeries
4. Anticipated bone defect after prosthesis explantation

4 Treatment Strategy

1. Removal of infected TKA prosthesis and all infected bone with thorough irrigation and debridement with gradual shortening to close the soft tissue gap after bony resection with TSF application
2. Second-stage surgery with removal of TSF and insertion of an antibiotic-coated intramedullary fusion nail for establishing a solid, infection-free, knee fusion
3. Correction of residual limb length discrepancy by shoe lift versus limb lengthening surgery

5 Basic Principles

1. Aggressive debridement with removal of all infected prosthesis components, cement and infected peri-articular soft tissue.
2. Avoid acute shortening of the large bony defect across the knee joint to avoid neurovascular compromise and wound closure problems.
3. Application of TSF with gradual compression at the knee and shortening of the lower extremity to achieve bony contact.
4. Stop antibiotics 2–4 weeks before surgery to obtain reliable intraoperative cultures during the explantation. Then, treat with IV antibiotics (culture specific) for 6 weeks. This is followed by use of oral antibiotics until bony union has been achieved.
5. Antegrade insertion of antibiotic-coated IMN from the hip across the knee with minimal violation of the

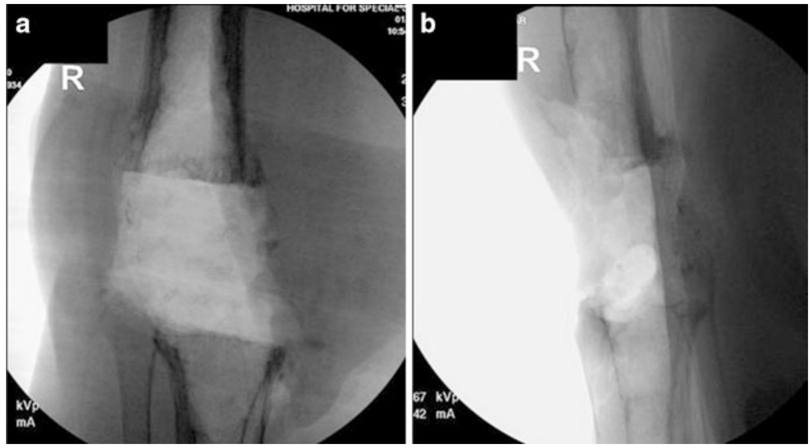

Fig. 3 (**a**, **b**) Intraoperative (**a**) AP and (**b**) lateral radiographs of the right knee demonstrating an 8-cm gap after removal of the infected prosthesis and wide resection of infected femoral and tibial bone ends

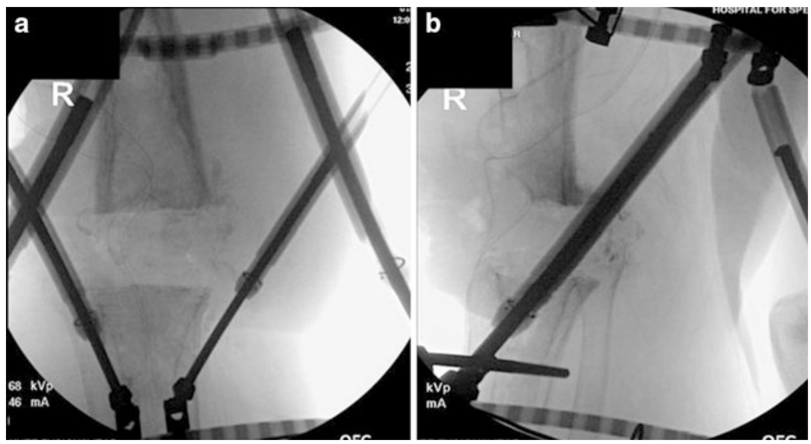

Fig. 4 (**a**, **b**) Intraoperative (**a**) AP and (**b**) lateral radiographs of the right knee after application of the TSF demonstrating intraoperative acute partial reduction of the gap across the knee joint to a 6-cm gap. This was the maximum amount of acute shortening tolerated by the skin still enabling primary closure

compromised soft tissue around the knee joint, allowing optimum soft tissue coverage and healing. This allows removal of the external fixator after about 6 weeks. The cement is mixed with culture-specific antibiotics.

6. The IMN is a 10-mm knee fusion nail with proximal and distal interlocking screw capability.
7. This is an example if optimal use of integrated fixation – using both the external fixation and internal fixation in the most efficient manner.

6 Images During Treatment

See Figs. 3, 4, and 5.

7 Technical Pearls

1. Patient was put on antibiotic holiday prior to the first-stage removal surgery. Removal of all infected prosthetic components with debridement of all infected bone and peri-articular soft tissues is mandatory for eradication of infection as well as copious irrigation with antibiotic-containing normal saline solution. Intraoperative cultures were taken and patient was placed on a 6-week course of intravenous antibiotics based on culture and sensitivity results.
2. Only partial reduction of the soft tissue gap was achieved intraoperatively during the first-stage surgery to avoid compromise to the neurovascular and soft tissue structures around the knee. This was guided intraoperatively by monitoring peripheral pulses and assuring adequate closure of wound edges.
3. Upon apposition of bony ends, insertion of the antegrade antibiotic-coated IMN in a closed fashion was performed to avoid further soft tissue compromise to the prior surgical incision.
4. Over-reaming by 2 mm for the anticipated nail diameter (based on preoperative planning) was performed to accommodate for the antibiotic-coated IMN. Preparation of the coated IMN was performed by pressurizing a silicone tube with antibiotic-impregnated cement, followed by insertion of the IMN into the silicone tube

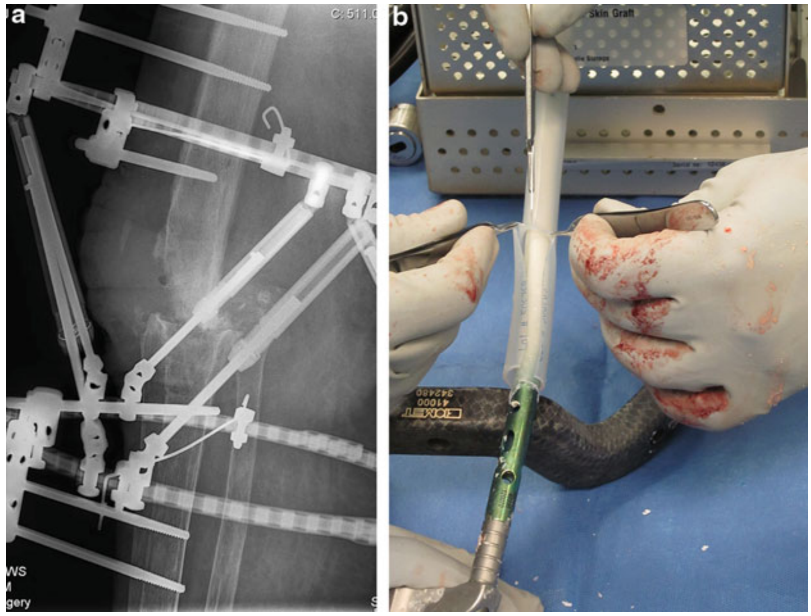

Fig. 5 (**a**) Lateral X-ray at the end of gradual shortening of the defect and prior to insertion of the antibiotic-coated IMN. (**b**) Intraoperative photo showing the silicone tube being removed after the antibiotic-laden cement had hardened around the IMN

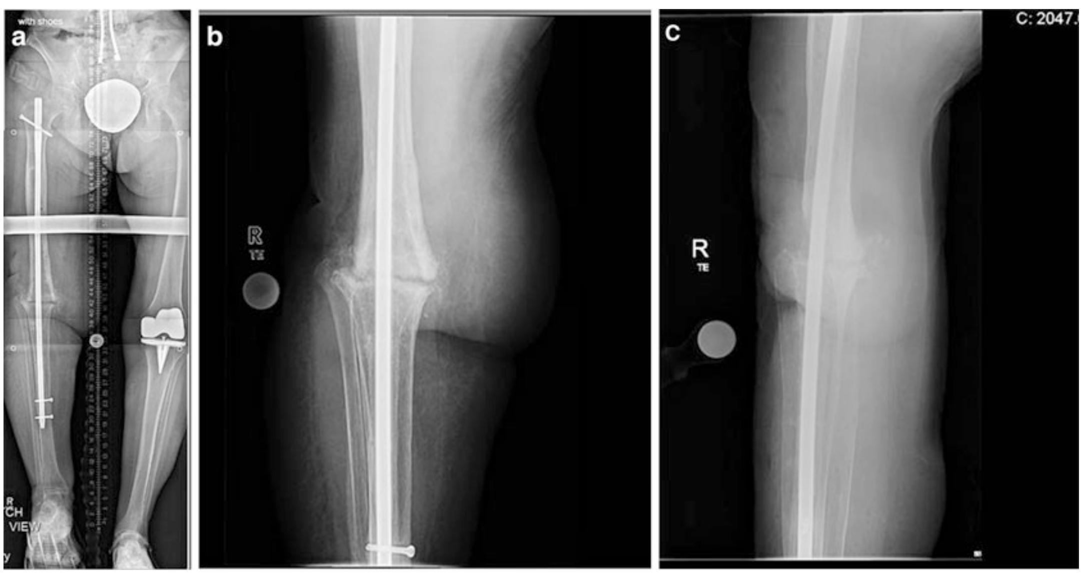

Fig. 6 (**a–c**) Postoperative (**a**) 51-in. erect long-standing hip to ankle radiographs, (**b**) AP and (**c**) lateral radiographs of the right knee 12 months after surgery demonstrating radiographic fusion across the knee joint. Residual limb length discrepancy was managed conservatively as the patient was satisfied with the outcome and functioned well with a shoe lift. All infection markers had normalized without any signs of active infection and excellent soft tissue healing

as the cement sets. After the cement had set, the silicone tube was split longitudinally with a sharp knife, and the antibiotic cement-coated nail was removed.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

1. Prompt management of total knee arthroplasty infection with multiple two-stage revisions results in bone stock compromise. A decision to salvage the knee by a fusion should be judiciously considered if excessive bone stock compromise is anticipated from further revisions.
2. Complete eradication of infection requires aggressive debridement with resection of all infected/necrotic bone

and soft tissue, even if this may lead to excessive shortening of the limb, as this can be subsequently managed.

3. Appropriate IV antibiotics according to intraoperative culture and sensitivity results, under the guidance of an infectious disease specialist, is mandatory.
4. Managing residual limb length discrepancy can be managed conservatively or operatively based upon patient's age, final functional outcome and satisfaction.

10 Cross-References

► Case 48: Knee Fusion and Lengthening for Failed Total Knee Replacement and Bone Loss

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Case 50: Staged Revision of a Chronic Infected Ipsilateral THA and TKA Using an Antibiotic Laden PMMA Functional Spacer Incorporating a Knee Fusion Nail

Stephen Kent and Kevin Tetsworth

Contents

Abstract

This case involved an elderly man with a failed infected total hip replacement (THA), massive acetabular and femoral bone loss, and extension of the infection to involve his native degenerative knee. This ultimately required radical debridement with removal of the entire femur, all the components, and prior polymethyl methacrylate (PMMA). The challenge was to construct a temporizing functional PMMA spacer that would simultaneously replace a completely resected femur, act as a functional articulating device at the hip, and allow immediate weight bearing to restore mobility during the interim between the two stages. Staged reconstruction was made possible using an interim custom antibiotic-impregnated PMMA spacer incorporating a THA stem impaled on a knee fusion intramedullary (IM) nail.

1 Brief Clinical History

The patient was an 83 year old man who presented for review with increasing symptoms 10 years after initial treatment for an infected THA. He had undergone primary left THA in 1997 for age-related joint degeneration, but in 2001 required staged revision after he developed symptomatic loosening related to an established MRSA infection. The acetabular component was grossly loose and associated with extensive osteolysis and a protrusio cup. He already had massive loss of femoral bone stock noted, involving over 50 % of the femoral circumference extending almost 20 cm down the femoral shaft. This was salvaged at that time successfully using a provisional THA impaled on a femoral IM nail to create an extremely long stem to bypass the defects noted. This construct was incorporated into an

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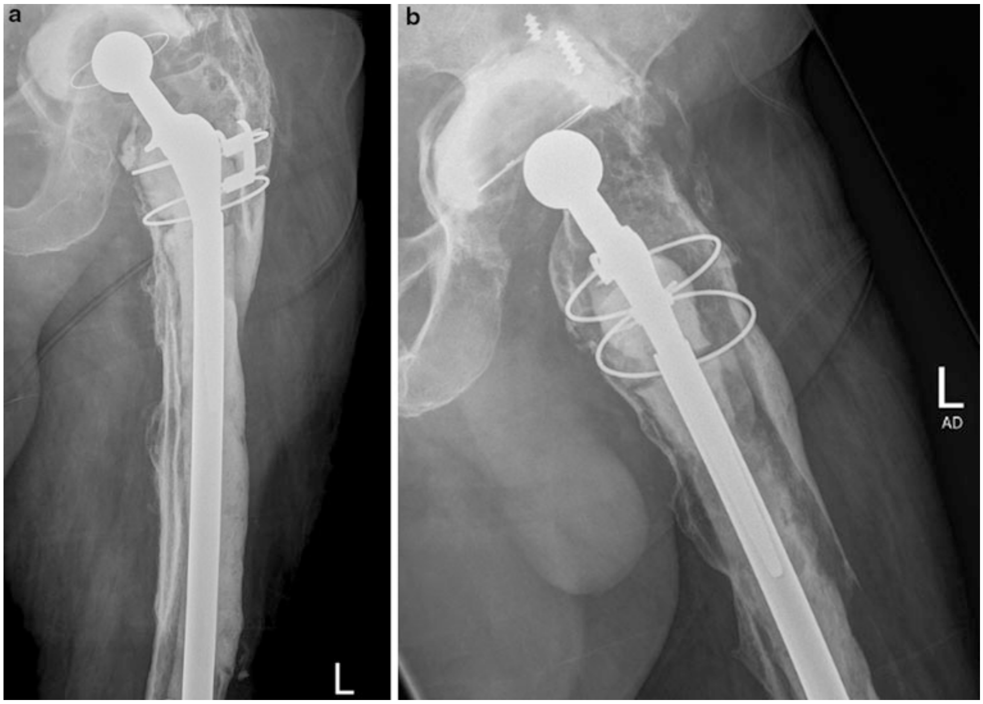

Fig. 1 Temporary PMMA spacer had been used 10 years prior to salvage a total hip chronically infected with MRSA. Even at that time the extent of bone loss was severe, with up to 70 % loss of cortical bone over a 20 cm length of femoral shaft. The construct utilizes an inexpensive THA stem impaled into a femoral nail to create an extremely long stem, as a composite reconstruction incorporating a mass of antibiotic PMMA. This temporary spacer was solid and stable enough for him to remain fully functional with no limitations for almost 10 years. (**a**) AP view and (**b**) lateral view

antibiotic-impregnated PMMA spacer, with bone cement replacing much of the femoral shaft (Fig. 1). The femoral component proximally was used as an articulating spacer, incorporating a polyethylene acetabular component in another mass of antibiotic PMMA. This was extremely well tolerated, and as is often the case, he was reluctant to consider the planned second stage. He was fully functional and weight bearing as tolerated (WBAT) without any walking aides for nearly 10 years; however, at that point the temporary reconstruction began to fail and became increasingly symptomatic. The construct began to subside, and the distal tip of the femoral nail perforated the distal femoral metaphysis, ultimately contaminating the left knee and suprapatellar pouch (Fig. 2). He presented with complaints of increasing hip, thigh, and knee pain associated with the loosening and subsidence of the complex temporary reconstruction of his left femur that had unexpectedly lasted a full 10 years, and he wanted to proceed with definitive reconstruction.

Fig. 2 Over the course of 10 years, the construct became axially unstable and subsided several cm distally, eventually penetrating into the knee and contaminating it as well

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

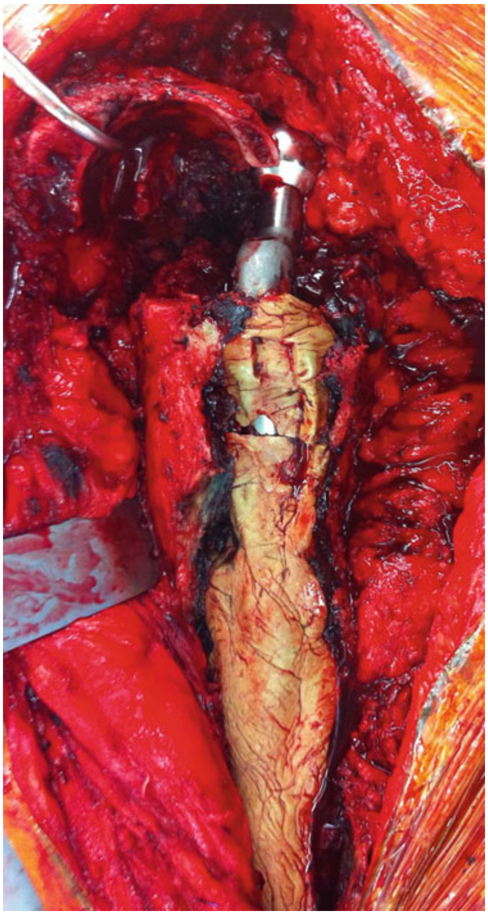

Fig. 3 Exposure of the remaining proximal femur and previously placed PMMA THA spacer. The extent of bone loss is now so severe there is no lateral cortex extending over a distance of 20 cm

Fig. 4 Extensive debridement included removal of the prior implants, all PMMA, and the entire remaining osteoporotic femur

Fig. 5 A temporizing functional antibiotic PMMA spacer with an extremely long stem was created by impaling an inexpensive THA stem into a knee fusion nail

3 Preoperative Problem List

- Recurrent loose/infected left THA with articulated PMMA spacer in situ for the past 10 years; this had functioned well and had been completely asymptomatic for greater than 9 years.
- Probable extension of infection to involve the native left knee, with concomitant advanced degenerative changes present.
- Significant loss of left femoral bone stock, including loss of 70–90 % of the circumference of the femoral shaft extending across 20 cm.
- Significant loss of acetabular bone stock, with marked protrusio.
- Four centimeter leg length discrepancy.
- Assumption of recurrent infection, without a draining sinus or overt systemic signs of active infection.
- Advanced age with anesthetic risk.

Fig. 6 Postoperative radiographs of the interim functional PMMA spacer incorporating a THA stem and a knee fusion nail

Fig. 7 Postoperative radiographs of the interim functional PMMA spacer incorporating a THA stem and a knee fusion nail

4 Treatment Strategy

While single stage revision has a genuine role in managing infected joint arthroplasty, it was felt that staged revision would be better tolerated and safer for this patient. Given the extent of massive femoral bone loss (Fig. 3) and the extension of infection to involve his degenerative native ipsilateral knee, it was clear that the best option would require conversion to a total femoral replacement. Furthermore, the significant acetabular loss would require advanced techniques for reconstruction.

Insertion of a temporizing functional PMMA spacer would simultaneously replace a completely resected femur, act as a functional articulating device at the hip, and allow immediate weight bearing and restore mobility during the interim between the two stages. Treatment with culture-specific intravenous antibiotics is done after stage 1. This would be followed by a staged total femoral replacement.

His postoperative course was complicated by a perioperative myocardial infarction; given the extent of his previously undiagnosed cardiac disease, his planned second stage was delayed for one full year. He remained mobile and independent throughout that year, weight bearing as tolerated on the involved limb (Fig. 8).

5 Basic Principles

This ultimately required radical debridement with removal of the entire femur and his native knee, including all prior components and PMMA (Fig. 4). Cultures obtained during this stage grew *Pseudomonas*, *Serratia*, and *Klebsiella*. The challenge was to construct a temporizing functional PMMA spacer that would simultaneously replace a completely resected femur, act as a functional articulating device at the hip, and allow immediate weight bearing and restore mobility during the interim between the two stages.

Fig. 8 Patient able to fully weight bear with comfort on the temporizing antibiotic PMMA spacer incorporating a THA stem and a knee fusion nail

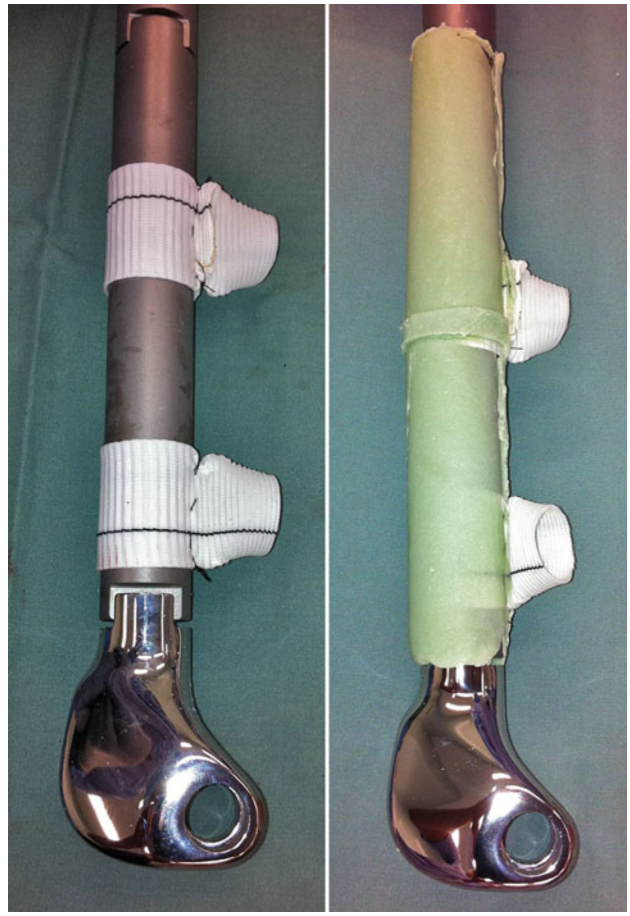

Fig. 9 Dacron vascular grafts incorporated into the antibiotic PMMA surrounding the diaphyseal component of the total femoral mega-prosthesis. These are used to facilitate reattachment of the posterior muscles back to the equivalent of the linea aspera. Elderly patients with a total femur replacement are otherwise at risk of developing large effusions in the huge potential dead space distally

The problem was solved in a fashion analogous to the first temporizing spacer that had worked so well previously. A provisional THA stem was again impaled on an IM nail to create an extremely long construct to bypass the defect, now constituting the entire femur (Fig. 5). We prefer to use a stainless steel nail when available, as it is easier to fully seat the THA stem into these nails, which deform more easily. Using a knee fusion nail provided adequate length to gain excellent stability and to correct the preoperative LLD acutely. This construct was again incorporated into an antibiotic-impregnated PMMA spacer, with bone cement now replacing the entire femoral shaft. The femoral component proximally was again used as an articulating spacer, incorporating a polyethylene acetabular component in another mass of antibiotic PMMA (Figs. 6 and 7).

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, 8 and 9.

7 Technical Pearls

Total femur replacement was undertaken at that point, together with impaction grafting for his acetabular reconstruction, and the mega-prosthesis was coated with antibiotic-laden PMMA. Soft tissue reconstruction was facilitated by incorporating Dacron vascular grafts into the PMMA to provide solid anchors for reattachment of the linea aspera (Fig. 9). The use of a dual mobility (tripolar) cup provided greater stability with the loss of the greater trochanter and abductors. After a year immobilized in extension, patellar tracking required an extensive yet anatomic subvastus lateral release; his postoperative course was this time uneventful.

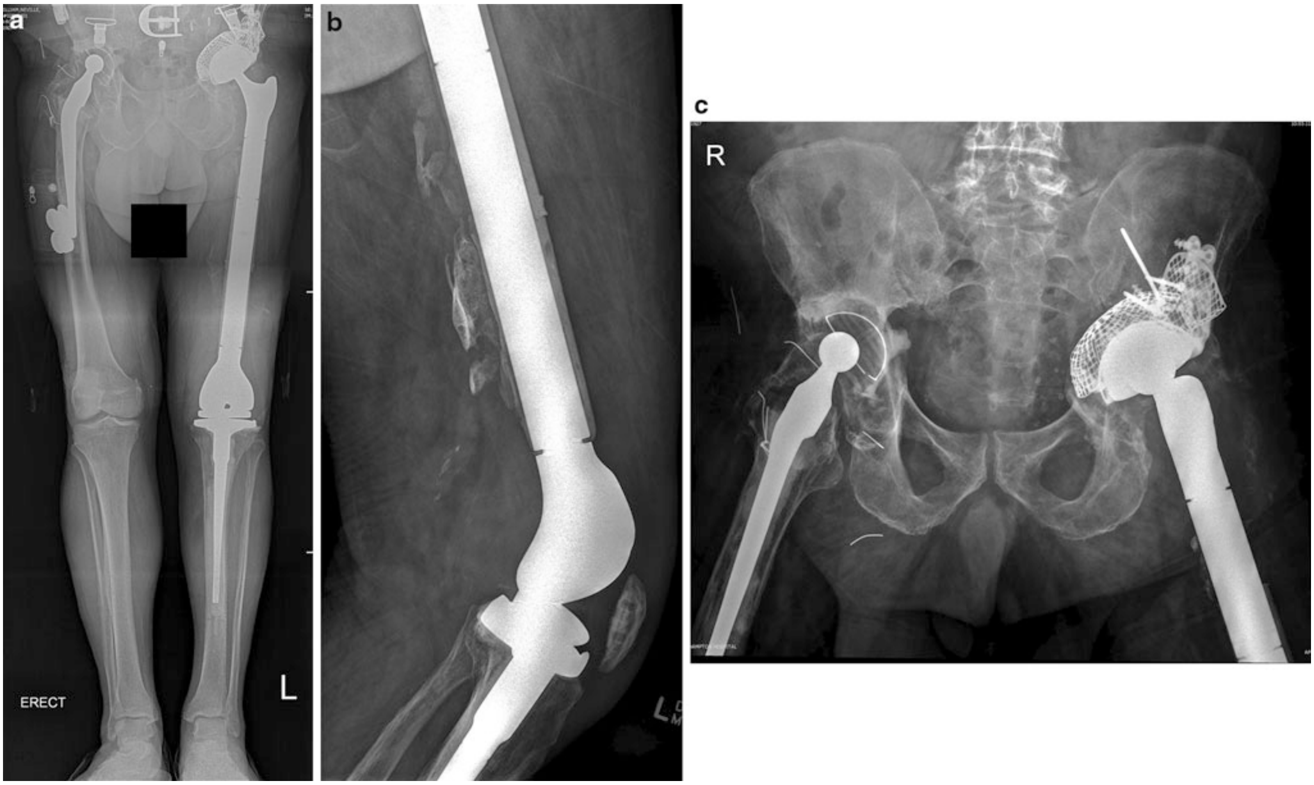

Fig. 10 (**a**, **b** and **c**) Postoperative radiographs after the second stage, conversion to a total femur mega-prosthesis

8 Outcome Clinical Photos and Radiographs

See Figs. 10 and 11.

9 Avoiding and Managing Problems

This form of temporary reconstruction relies on an interference fit of the total hip stem and the long knee fusion nail. This works best with a stainless steel nail because it deforms to match the stem as it is impacted. Titanium nails have thicker walls and are less compliant, and a small burr must be used to increase the internal diameter of the proximal portion of the nail.

Obtain intraoperative cultures and treat with culture-specific antibiotics.

Dacron vascular grafts are incorporated into the antibiotic PMMA surrounding the diaphyseal component of the total femoral mega-prosthesis. These are used to facilitate reattachment of the posterior muscles back to the equivalent of the linea aspera. Elderly patients with a total femur replacement are otherwise at risk of developing large effusions in the huge potential dead space distally (Fig. 9).

10 Cross-References

- ▶ Case 47: Knee Arthrodesis for Failed Total Knee Arthroplasty
- ▶ Case 48: Knee Fusion and Lengthening for Failed Total Knee Replacement and Bone Loss
- ▶ Case 49: Knee Fusion with Gradual Shortening and Staged Insertion of Antibiotic Coated Intramedullary Nail for Failed Infected Total Knee Arthroplasty
- ▶ Case 76: Staged Reconstruction of a Failed Modular Knee Tumor Prosthesis

Fig. 11 (**a**, **b** and **c**) Clinical photographs 2 years after the conversion to a total femur mega-prosthesis demonstrate knee ROM from full extension with no extensor lag to 110° of flexion. He remains infection-free and full weight bearing, using a walker for community ambulation

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Part IX

Adult Deformity: Bone Defects

Case 51: Acute Shortening and Re-lengthening to Bridge Bone Defects

Mahmoud A. El-Rosasy

Contents

Abstract

Combined bone and soft tissue loss of the leg is a challenging orthopedic problem due to paucity of soft tissue mass and the frequent need for staged reconstruction. Bone transport, as described by Ilizarov, has been successful in the management of such cases; however, the difficulties and problems encountered during bone transport made it a tedious work for both the surgeon and the patient. Acute limb shortening and re-lengthening (ASRL) was described to avoid the problems met with during bone transport. However, ASRL has its limits based on the size of soft tissue defect and the vascularity of the limb. Careful attention to the details of the technique is necessary to avoid acute ischemia of the limb. Overzealous acute shortening can be dangerous.

1 Brief Clinical History

This is a case of a 22 year old male patient, otherwise healthy, who had a closed fracture of his left leg. The fracture was treated by open reduction and internal fixation using plate and screws 8 months earlier. It was complicated by deep infection, failure of fixation, and nonunion.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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Fig. 1 (**a**) Preoperative radiographs show an ununited fracture of the middle third of the tibia fixed with plate and screws with implant failure. (**b**) Preoperative clinical photos show the soft tissue condition of the leg with an actively infected nonunion of the tibia. A skin sinus surrounded by unhealthy skin is seen on the anterior aspect of the middle third of the leg (Reproduced from El-Rosasy 2008)

Fig. 2 (**a**) Intraoperative photos show the planned skin incision to be Z-shaped and the horizontal limb was converted into ellipse to allow excision of the sinus together with the unhealthy skin. (**b**) The implants were removed and square osteotomy was performed to the level of healthy bone using Gigli saw. (**c**) After soft tissue and bone debridement, a combined defect of 6 cm has resulted. (**d**) Acute leg shortening was performed to allow closure of the wound and approximation of bone ends

3 Preoperative Problem List

1. Nonunited fracture of the tibia
2. Active deep infection
3. Significant soft tissue and bone defect as a result of debridement

4 Treatment Strategy

The plan was to simultaneously reconstruct the soft tissue and bone defects by distraction histogenesis without the use of flaps or grafts, using the Ilizarov external fixator.

5 Basic Principles

Eradication of the infection entails extraction of all retained hardware and debridement of all infected bones and soft tissue. Planning the surgical approach to allow excision of the unhealthy skin and acute limb shortening and facilitate wound closure.

6 Images During Treatment

See Figs. 2, 3, and 4

7 Technical Pearls

The amount of acute limb shortening should be kept within the safe limits which allow a good distal blood flow. The distal circulation is checked during surgery with Doppler ultrasonography, palpation of the dorsalis pedis and posterior tibial arteries, and observation of capillary refilling as compared to the healthy side. If the distal blood flow is compromised, then compression is reversed. If the bone defect is greater than the safe limit for acute limb shortening, then the limb is shortened to the safe limit and the remaining gap is gradually closed at a rate of 2–3 mm per day (El-Rosasy 2007). If the required shortening was >5 cm, or in the presence of unhealthy skin, a Z-shaped incision is very helpful. The horizontal limb of this incision is made elliptical to allow excision of infected skin sinuses or the major part of a previous skin graft. During closure, the limbs of the Z-shaped incision are either replaced or transposed to increase the width at the expense of length in order to allow more shortening and to facilitate closure. Longitudinal skin incisions should be avoided in such cases (Simpson et al. 2001).

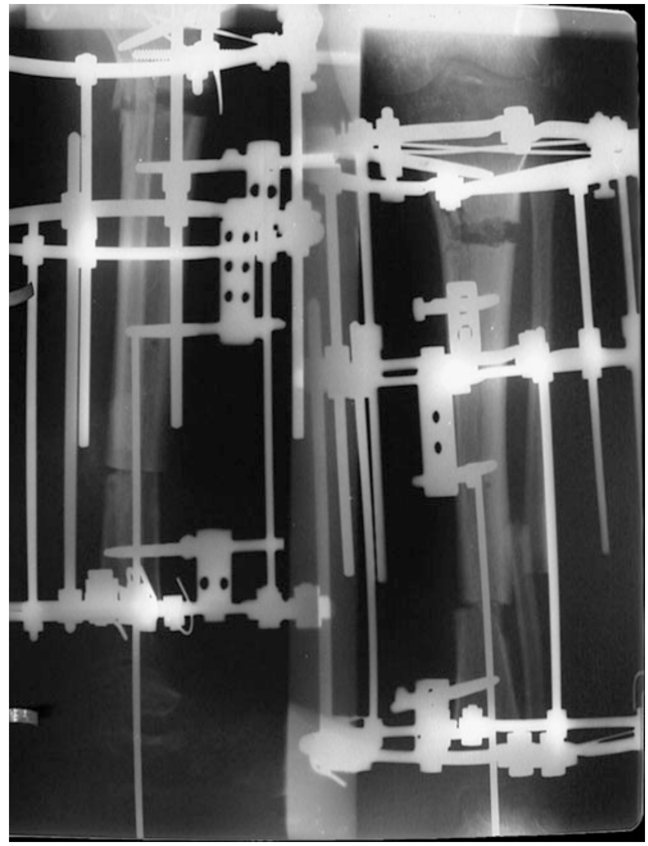

Fig. 3 Postoperative radiographs show the fibular osteotomy and overlap of fibular bone ends to allow leg shortening. A temporarily inserted Kirschner wire guides the acute shortening and prevents deflection of bone ends due to laxity of soft tissues. Proximal tibial osteotomy is performed for re-lengthening of the tibia

8 Outcome Clinical Photos and Radiographs

See Fig. 5

9 Avoiding and Managing Problems

No absolutely safe limits for acute shortening are established, and every case should be monitored intraoperatively. Postoperative monitoring is mandatory

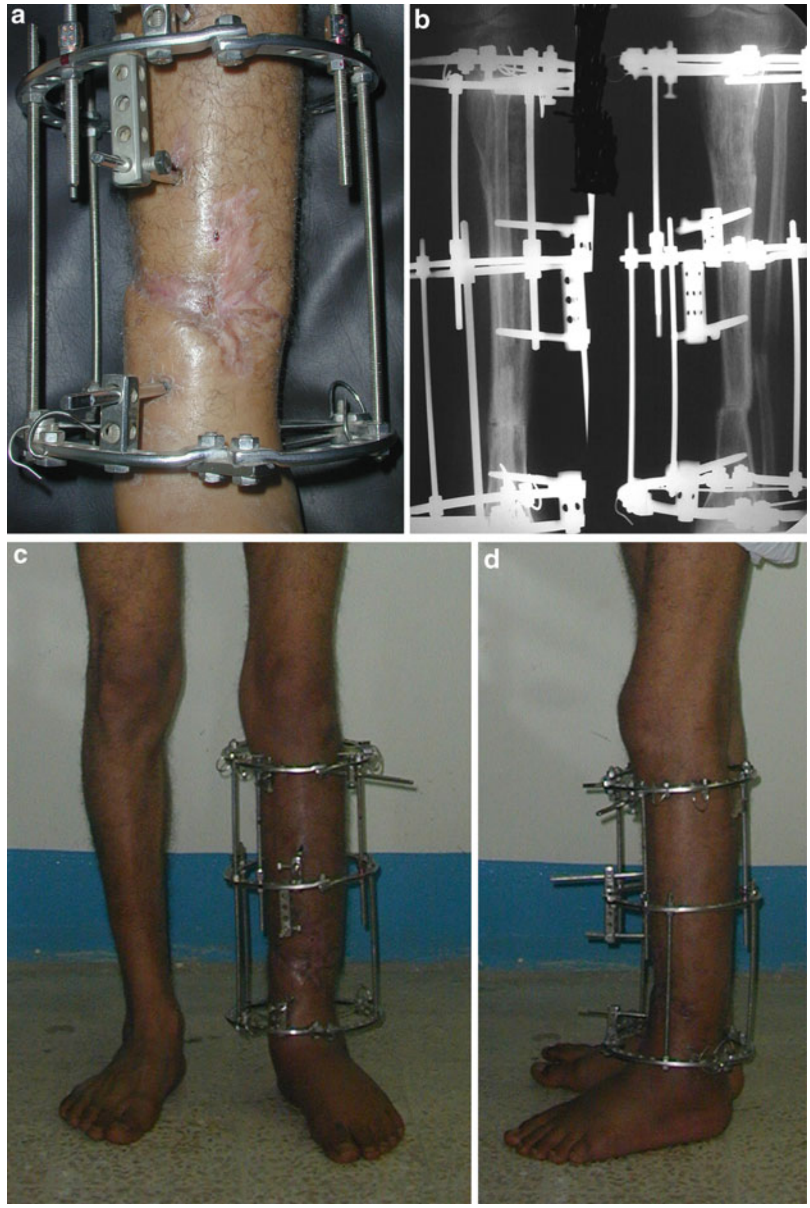

Fig. 4 (**a**) Clinical photos during treatment show good healing of the soft tissues and the regain of soft tissue tension as a result of lengthening. (**b**) Radiographs during treatment show the distraction gap in the proximal tibia and regenerate formation, the overlapped fibular osteotomy ends are pulled apart and consolidation of the nonunion. (**c** and **d**) Clinical photos during treatment show full weight bearing and restoration of leg length

because soft tissue edema can result in late neurovascular compromise, which would require a reversal of part of the acute shortening. The suggested limits for limb shortening should be considered during preoperative planning. For a bone defect of 3 cm, a transverse skin incision would be adequate, but a Z-shaped incision should be used for a defect greater than 5 cm. Acute shortening of defects in the upper third of the leg may be more challenging because of vascular problems. In the vicinity of the ankle, overzealous shortening may cause the skin to buckle, leading to ischemia and skin loss – a particularly challenging problem in this location (Saleh and Rees (J Bone Jt Surg [Br] 77-B:429-434, 1995); Sen et al. (J Orthop Trauma 18:150-157, 2004); El-Rosasy (J Bone Jt Surg Br 89:80-88, 2007 & Indian J Orthop 42(4):420-425, 2008)).

Fig. 5 (**a**) Follow-up radiographs show good consolidation of the nonunion and lengthening sites and restoration of the normal mechanical axis. (**b–d**) Follow-up photographs show equal leg length with good alignment and full range of motion of the ankle and knee joints

10 See Also in Vol. 2

Case 16: Acute Shortening and Then Lengthening
Case 29: Infected Nonunion Tibia with Bone and Soft-Tissue Defect: Treatment with TSF, Intentional Temporary Deformation and Bone Transport

References and Suggested Reading

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Case 52: Bifocal Staged Bone Transport of a 30 cm Defect Including the Knee Joint

Leonid N. Solomin, Elena Shchepkina, Pavel Kulesh, and Konstantin L. Korchagin

Contents

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Abstract

This chapter details a case of operative reconstruction of a 30 cm defect including the knee joint. The original bone defect was caused by sarcoma resection and subsequent removal of the failed knee joint prosthesis. Subsequently, there was a failed vascularized fibula graft. Bifocal bone transport was used across the femur, tibia, and knee to achieve a stable knee fusion and optimal limb length. The entire period of treatment, excluding breaks, took 43 months. Realignment of right lower extremity using software-based Ortho-SUV Frame was utilized. Equinovarus foot deformity caused by neuropathy of right peroneal nerve was addressed with gradual correction.

1 Brief Clinical History

A 44 year old female most recently experienced shortening and deformity of the lower right extremity and was unable to bear weight. In 1985, sarcoma resection of the distal right femur and knee replacement were done. In 1993 and 2002, revision arthroplasties were performed. In 2003, as a result of a deep infection, radical surgical debridement and removal of the prosthesis were needed. In 2004, attempted reconstruction with a vascularized fibular graft, external fixation, and the lengthening of the tibia was done. Bony union of the fibular graft to the femur and tibia was not accomplished. In the middle third of the tibia, hypoplastic regenerate formed. The frame was removed because of a pin-tract infection, and it led to regenerate fracture and deformity.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_214

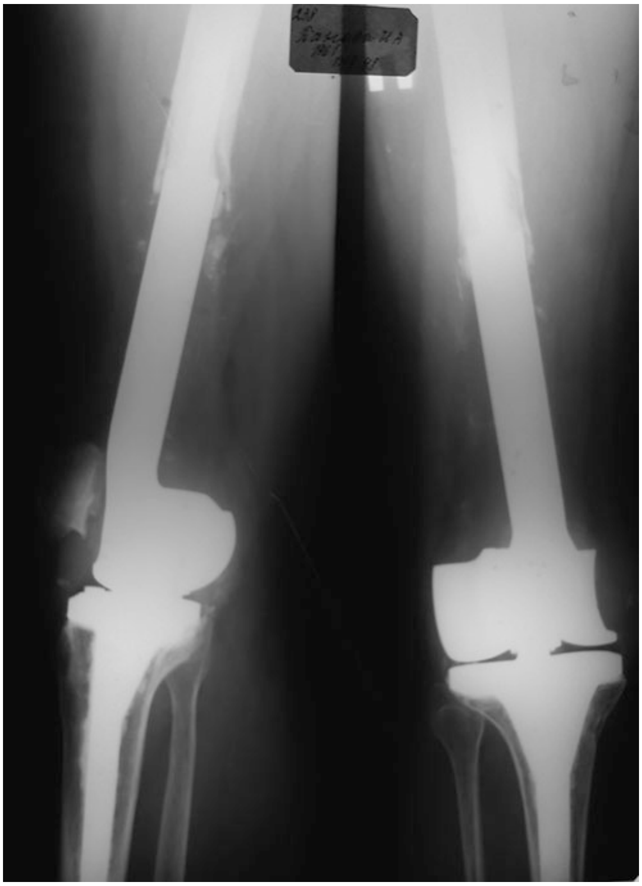

Fig. 1 AP/lateral X-rays after sarcoma resection of the distal *right* femur and knee replacement

Fig. 2 AP/lateral X-rays after radical surgical debridement and removal of the prosthesis

Fig. 3 AP/lateral X-rays after attempt to replace bone defect using vascularized fibular graft and lengthening of the tibia. Note deformation of the tibia regenerate

3 Preoperative Problem List

(a) Shortening of the right lower extremity 12 cm
(b) Bone defect forming the knee joint 12 cm
(c) Chronic osteomyelitis of the right low extremity
(d) Multiple scars
(e) Neuropathy of right peroneal nerve and secondary equinovarus deformity of the foot
(f) Hypoplastic regenerate of tibia, 6 cm, with angular deformation
(g) Nonunion of the fibular graft with femur and tibia bones

4 Treatment Strategy

In view of the complex problems of preoperative, treatment was carried out at several stages:

Stage 1: External fixation with acute tibia (regenerate) deformity correction. Tibial osteotomy followed by

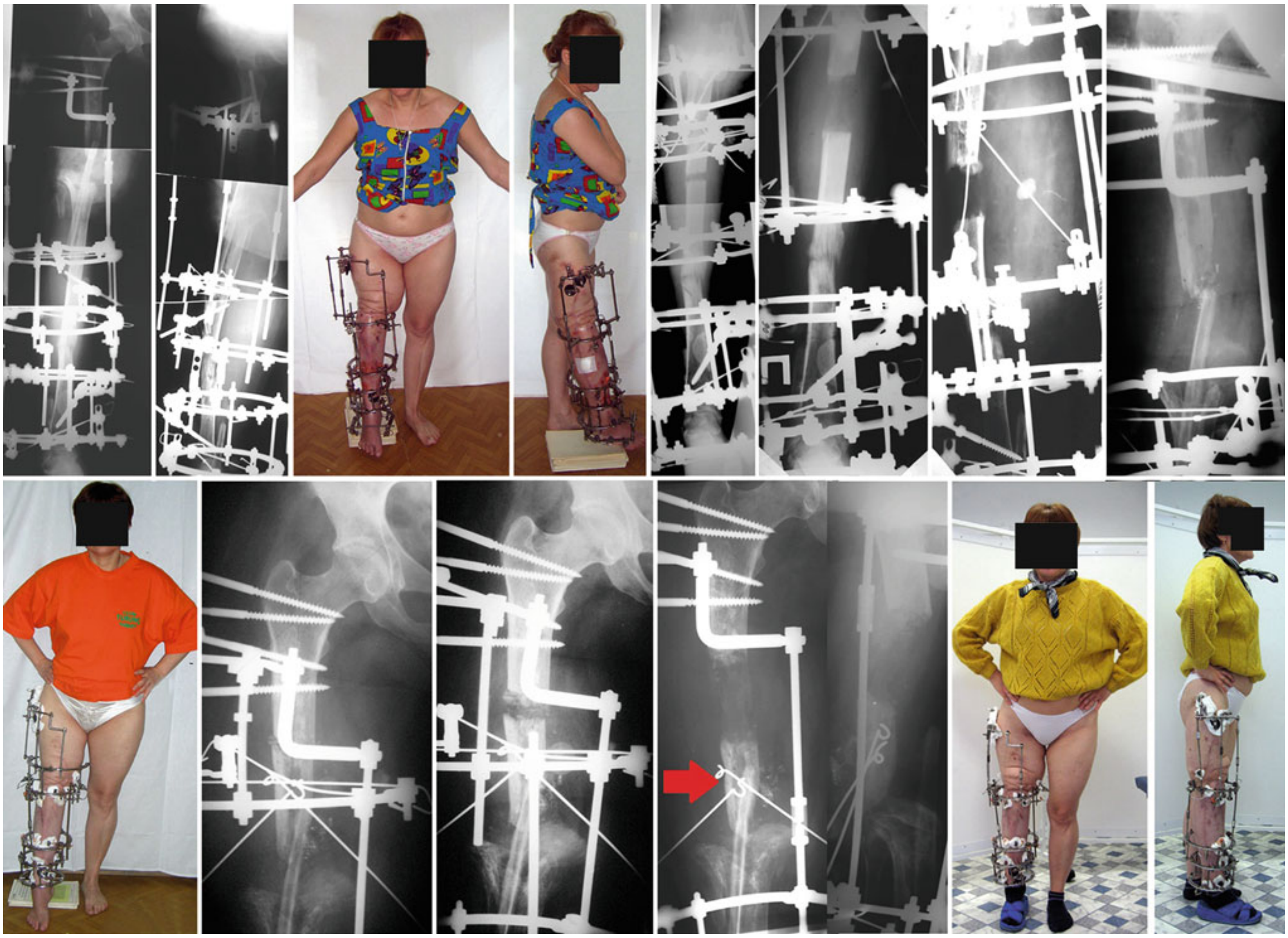

Fig. 4 Multi-level bone transport for elimination of the large bone defect. *Top row* illustrates tibial transport. *Bottom row* illustrates femur transport. Note the cross wires (*red arrow*)

distraction at the osteotomy level and compression at the level of hypoplastic regenerate (bone transport into the hypoplastic regenerate) using first cross-wire and then oblique-wire technique. The period of distraction was 120 days (rate 0.5–0.75 mm/day) leading to 9 cm of regenerate. This was followed by partial frame reassembly and bone transport of the femur. The period of distraction was 120 days leading to 7 cm of regenerate (Fig. 4).

Stage 2: (Without a break) Open grafting of the docking site. Application of hinged foot ring, Achilles tendon lengthening, and gradual foot deformity correction over a period of 30 days. Residual shortening at the end of this stage was 8 cm (Fig. 5).

The timing is now at 30 months from the start of treatment to removal of this frame.

Stage 3: (Two years after end of stage 2) Lengthening of the femur (7 cm) over a period of 110 days (Fig. 7).

Stage 4: Realignment of right lower extremity using a software-based Ortho-SUV Frame over a period of 16 days. The time in the frame was 260 days (Fig. 8).

The total duration of stages 3 and 4 was 13 months.

The entire period of treatment (stages 1–4), excluding breaks, was 43 months.

5 Basic Principles

(a) Replacement of a large bone defect using multi-level distraction osteosynthesis can be done in several stages. When dealing with compromised bone, the rate of distraction should be 0.5–0.75 mm/day.

(b) In long bone transport, cross-wire technique should be used first, then oblique-wire technique should follow. The oblique-wire technique leads to less soft tissue trauma during distraction.

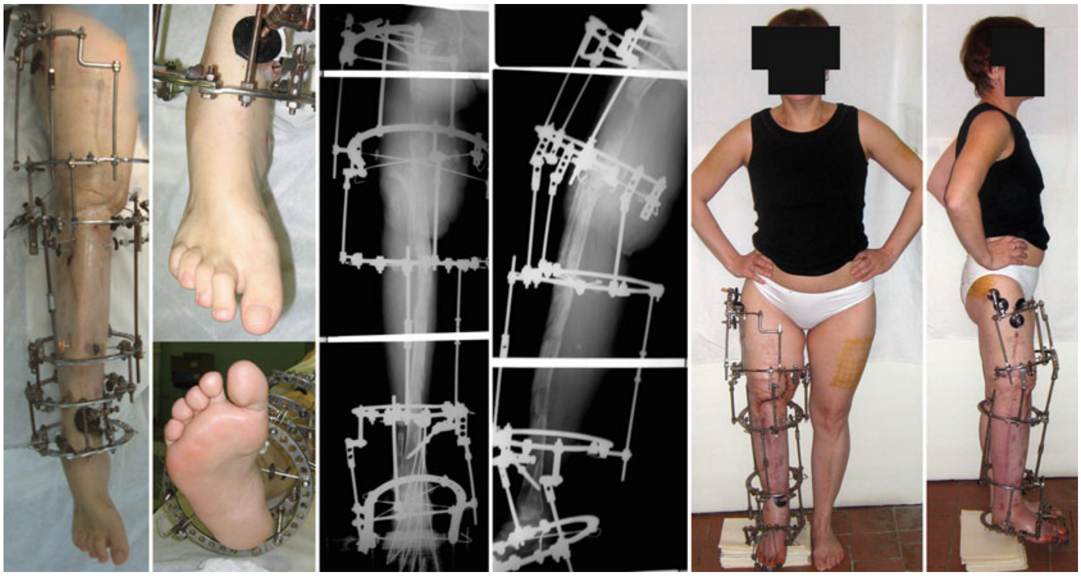

Fig. 5 After docking site procedure, foot deformity correction with additional frame across the ankle; note hinges for gradual deformity correction and wires in toes to prevent contracture

Fig. 6 Result of the second stage with residual lower extremity shortening of 8 cm; note the oblique wires (*red arrow*)

(c) Simultaneous gradual foot deformity correction.
(d) Open docking site procedure utilizing bone graft.
(e) Lengthening with the Ilizarov can be used for residual elimination of the lower limb discrepancy. Final limb realignment (MAD, residual angulation, translation, rotation) can be accomplished by means of a software-based hexapod frame (Ortho-SUV Frame).

6 Images During Treatment

See Figs. 4, 5, 6, 7, and 8.

7 Technical Pearls

(a) The use of an additional osteotomy for bone transport into hypoplastic regenerate provided improvement of the regenerate structure and partial replacement of the defect.
(b) Bone transport: cross-wire technique first, then oblique-wire technique.
(c) Lengthening with the Ilizarov apparatus led to immature distraction regenerate with deformity in this case. This soft regenerate was then realigned with the software-based hexapod frame.

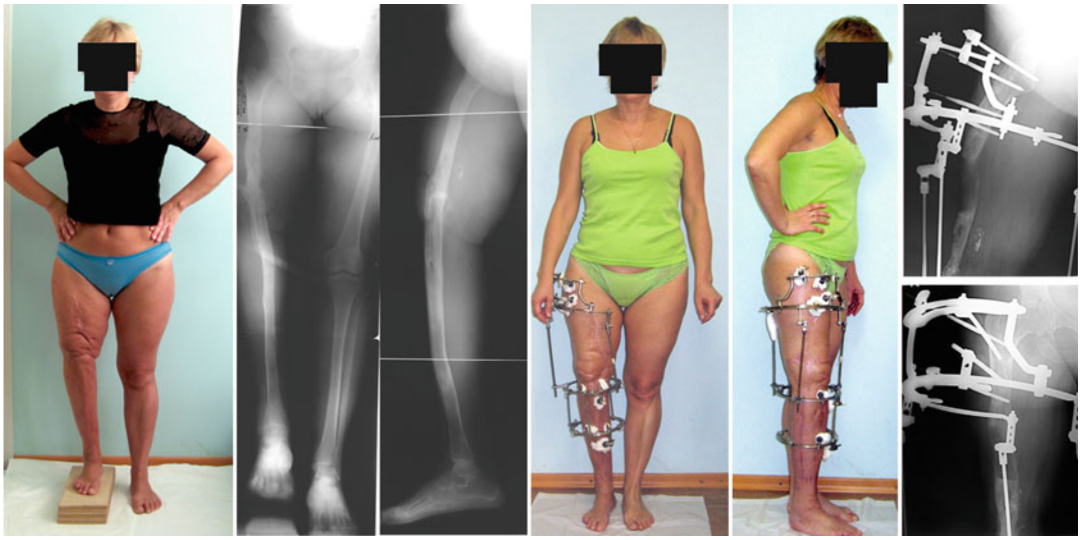

Fig. 7 Femur lengthening (7 cm) with the Ilizarov apparatus

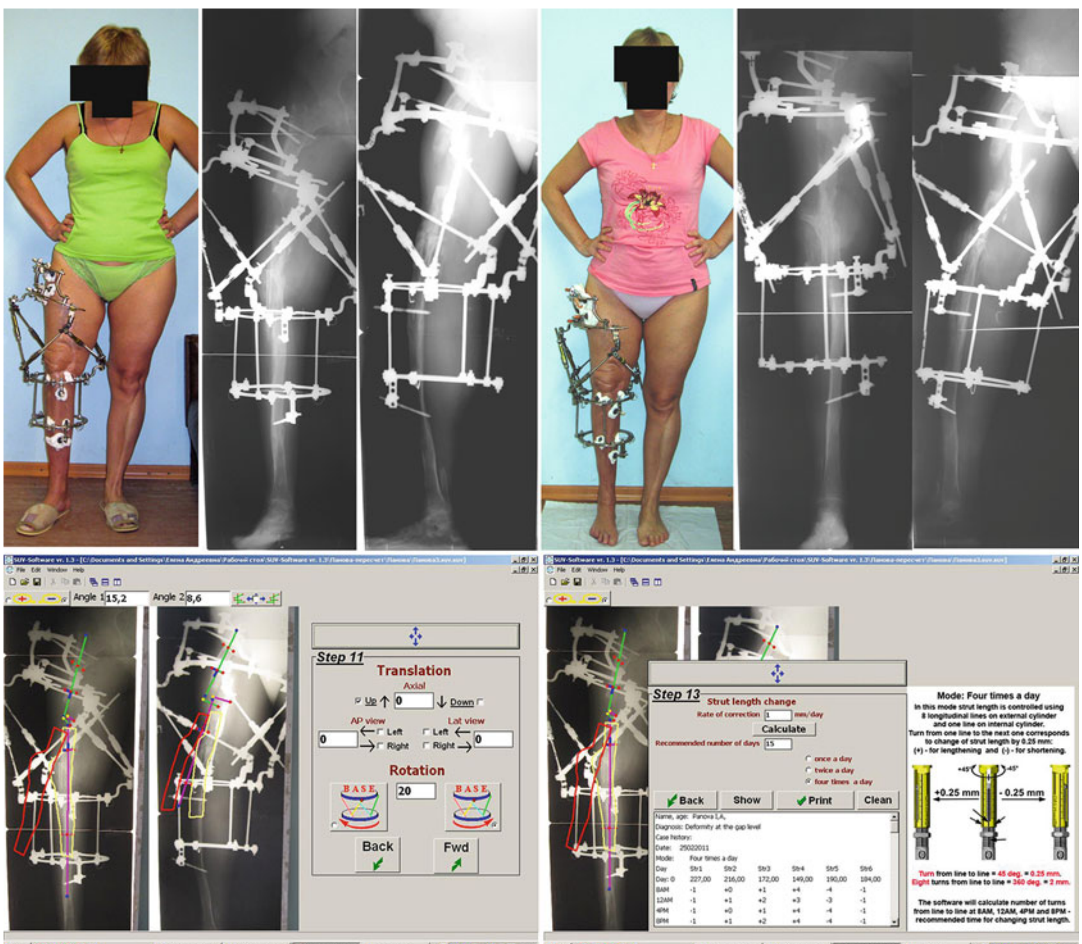

Fig. 8 Limb realignment using the hexapod frame (Ortho-SUV Frame)

Fig. 9 Six months after frame removal

8 Outcome Clinical Photos and Radiographs

See Fig. 9.

9 Avoiding and Managing Problems

(a) Bone transport and lengthening were gradually done at the rate of distraction 0.5–0.75, maximum of 1 mm/day.
(b) For a long bone defect, the cross-wire technique of bone transport was used first; then oblique-wire technique provided reduced trauma to the soft tissues and diminished the dangers of pin-tract infection.
(c) The secondary complex deformity that appeared as a result of the bone transport and lengthening of the extremity was corrected with the use of the hexapod frame.
(d) Active antibiotic therapy and meticulous pin-site management were used to prevent exacerbation of osteomyelitis.

10 Cross-References

- ▶ Case 14: Femoral Shaft Varus Above a Total Knee Replacement Treated With a Circular Hexapod Fixator
- ▶ Case 17: Computer Assisted External Fixation for Aesthetic Changing Lower Limb Shape
- ▶ Case 47: Knee Arthrodesis for Failed Total Knee Arthroplasty
- ▶ Case 48: Knee Fusion and Lengthening for Failed Total Knee Replacement and Bone Loss
- ▶ Case 49: Knee Fusion with Gradual Shortening and Staged Insertion of Antibiotic Coated Intramedullary Nail for Failed Infected Total Knee Arthroplasty
- ▶ Case 76: Staged Reconstruction of a Failed Modular Knee Tumor Prosthesis

11 See Also in Vol. 2

Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity

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Case 53: Cable Technique with a Medial Monorail for Bone Transport and Extended Soft Tissue Access for Reconstruction of More Than 16 cm of Tibial Bone

Peter Helmut Thaller and Julian Fuermetz

Contents

Abstract

The presented patient suffered a subtotal amputation of the lower leg with severe soft tissue trauma and a monovascular blood supply (peroneal artery). After primary stabilization and multiple debridements, a tibial bone defect of 14 cm and additional leg length discrepancy of 2.5 cm resulted. Bone transport of the tibia was achieved by a medial monorail external fixation and a single cable wire bone transport. Additional bone lengthening after docking was provided by a minor conversion of the frame. Bone transport and lengthening of 16.3 cm tibial bone was successfully accomplished.

1 Brief Clinical History

After a bomb blast, the 27 year old female patient sustained an open segmental fracture of the lower left leg (Fig. 1). First treatment at the local hospital was external fracture stabilization and soft tissue debridement (Fig. 2). Due to deep infections with multiresistant bacterial contamination, extensive bone resection was necessary in the following two debridements (Fig. 3). Forty-five days after the trauma, we began treatment of the patient in our department. With final debridement, the tibial bone defect was 14 cm, and the leg length discrepancy was 2.5 cm.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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Fig. 1 Intraoperative arteriography demonstrating monovascular blood supply by the peroneal artery after external fracture stabilization

Fig. 2 Radiograph after primary external stabilization and the first bone resection at the local hospital

Fig. 3 Clinical appearance after partial soft tissue coverage (mesh graft) and multiple bone resections before starting reconstructive surgery at our department

3 Preoperative Problem List

(a) Extensive tibial bone loss
(b) Leg length discrepancy
(c) Soft tissue infection with multiresistant organisms
(d) Further need for multiple Vacuseal revisions
(e) Monovascular blood supply

4 Treatment Strategy

Bone transport was achieved with a medial monorail external fixation and a single cable wire bone transport, similar to the solution described by Kucukkaya et al. (2009). This allows soft tissue preservation of the lateral lower leg where the only remaining artery is endangered. In addition, free access for multiple debridements during the bone transport was possible (Figs. 5 and 6).

Due to the novel design with a custom-made clamp and mounted pulleys for the cable, soft tissue preservation and free access for multiple debridements and Vacuseal changes during the bone transport were possible. Other custom-made

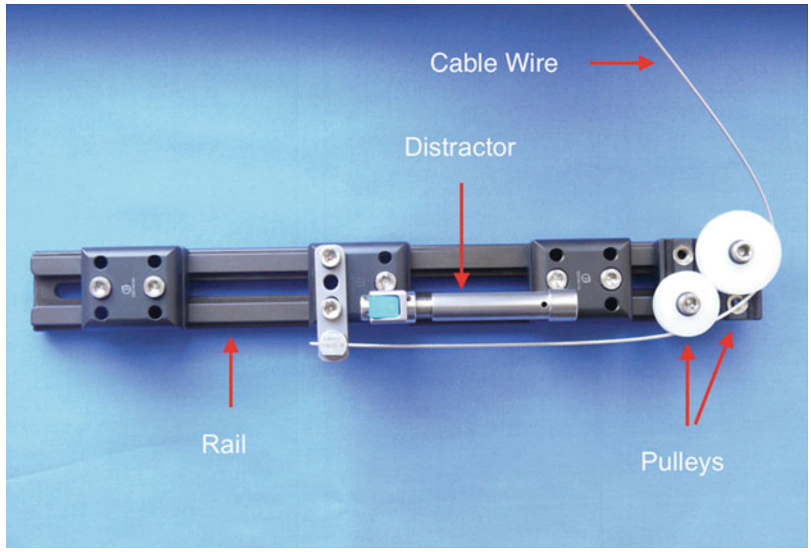

Fig. 4 Assembling of *LRS* (Limb Reconstruction System, Orthofix, Verona, Italy) external fixation with pulleys on a custom-made clamp and cable wire

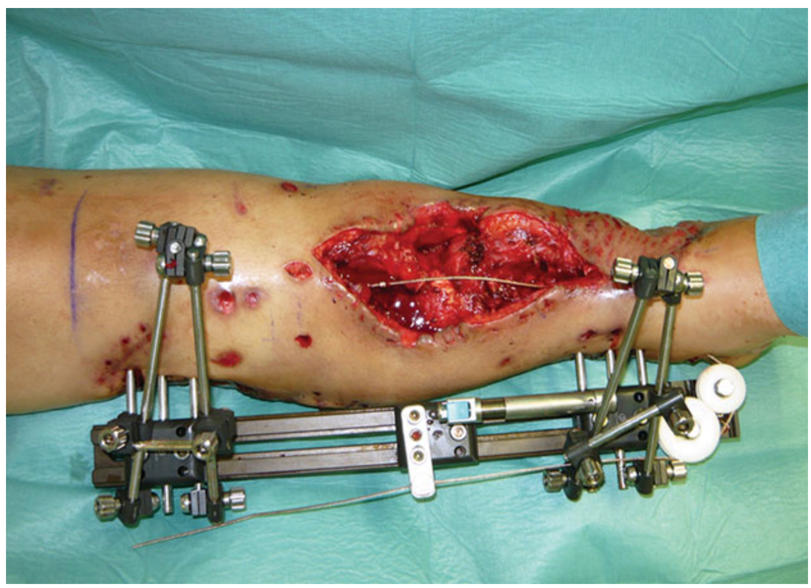

Fig. 5 Intraoperative mounting of the system after debridement

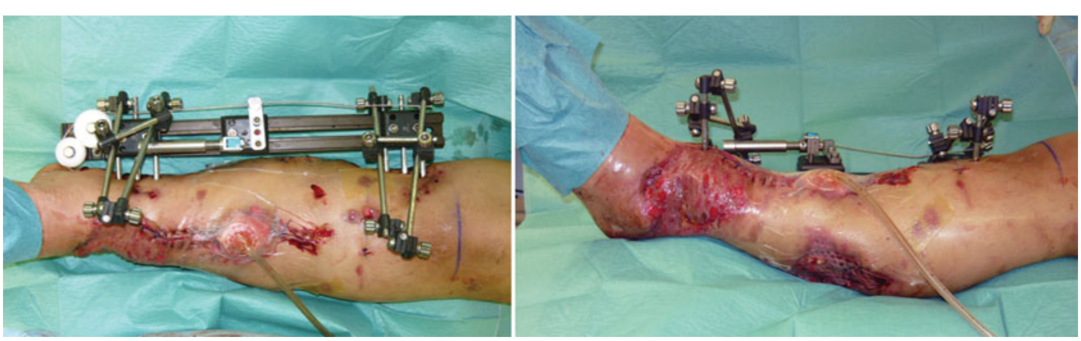

Fig. 6 Free access for multiple wound dressings and Vacuseal changes

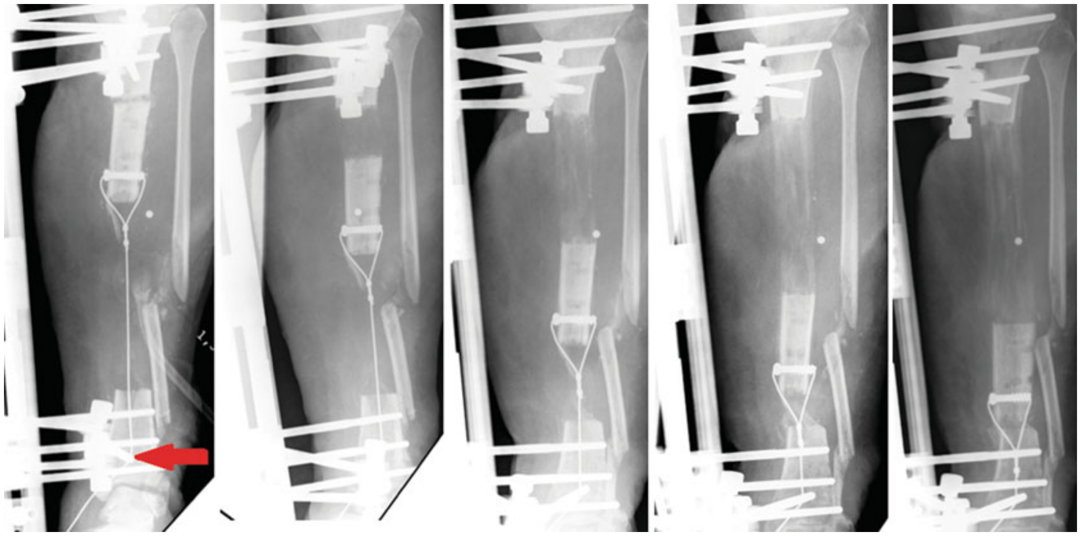

Fig. 7 Frontal radiographs of the bone transport, distraction index was 0.75 mm/day

clamps allowed compression of the docking site and further distraction osteogenesis (Figs. 9 and 10).

5 Basic Principles

The cable wire technique was first described in 1998 (Weber 1998). A bilateral cable wire and pulleys mounted on an Ilizarov frame serve for bone transportation (Weber 1998; Weber et al. 1999). In 2009, Kucukkaya et al. (2009) presented a median, monolateral system for a single wire, coaxial bone transport.

Compared to other external bone transport systems such as the Ilizarov ring fixator, monolateral systems, or hybrid systems, the cable technique reduces soft tissue invagination at the docking site, malalignment, and skin problems due to the excursion of K-wires or Schanz pins.

6 Images During Treatment

See Figs. 4, 5, 6, 7, 8, 9, and 10.

7 Technical Pearls

The central cable is fixed over a cannulated screw and is moved around a Schanz pin inserted centrally (in an anterior to posterior direction) (Fig. 7, red arrow) in the distal segment, serving as an internal pulley. This provides coaxial traction and transportation avoiding malalignment. Additionally, the anterior-posterior-placed Schanz pins increase the stability of the system. The cable wire is guided through the medial malleolus to the external pulley on a modified clamp with minimal friction to bone and soft tissue. After finishing bone transport, stabilization of the transported bone segment and further compression of the docking site are possible with the addition of a modified pin clamp and half-pins (Figs. 9 and 10). Additional lengthening distraction osteogenesis is accomplished by

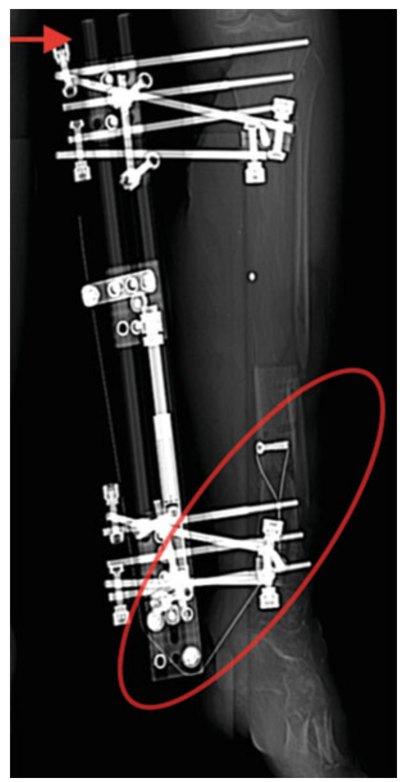

Fig. 8 CT scout of the lower leg shows the docking site (*red circle*), remaining leg length discrepancy for final distraction osteogenesis (*red arrow*)

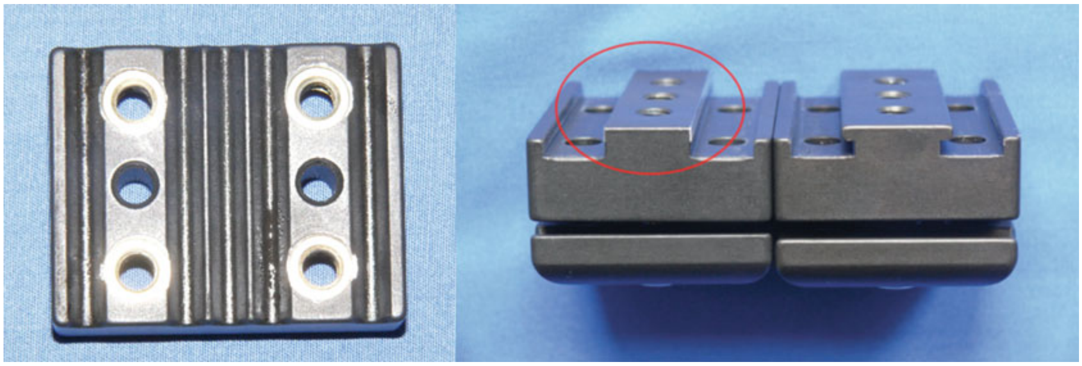

Fig. 9 Modified clamp for mounting the pulleys (*left side*) and modified clamp for stabilization of the docking site and (*right side*)

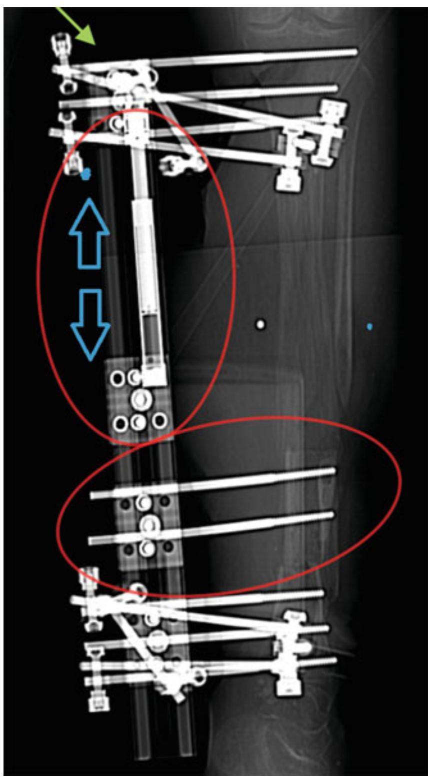

Fig. 10 Easy conversion of the system from bone transport to lengthening: The new, modified clamp compressing the docking site with two added half-pins after bone transport (*lower red circle*), while the two proximal clamps provide the gradual lengthening (*blue arrows* in *upper red circle*). The *green arrow* represents the final destination of the proximal clamp at the end of lengthening

converting the system in a "classic" monorail system with addition of another modified pin clamp (Fig. 10).

8 Outcome Clinical Photos and Radiographs

See Figs. 11 and 12.

Fig. 11 Frontal and lateral radiographs after 2.5 years of treatment, excellent bone result according to the ASAMI criteria (Paley et al. 1989; Song et al. 1998)

9 Avoiding and Managing Problems

During the whole procedure, no unplanned revision was necessary. After initial accurate debridements, no further deep infections occurred. The continuous distally directed

Fig. 12 Clinical outcome after 2 years of treatment, good functional result according to the ASAMI criteria (Paley et al. 1989; Song et al. 1998)

motion of the cable wire out of the leg reduces the risk of developing an ascending infection. The cable technique decreases skin and soft tissue trauma compared to that seen from transport segment pins and wires cutting through the skin. Finally, plating of the tibia using a minimally invasive percutaneous technique reduces the frame wearing time (Fig. 11).

10 Cross-References

▶ Case 71: Reconstruction of a 22 cm Femur Bone Defect with Transport Over Nail and Cable Technique

11 See Also in Vols. 1 and 2

Case 7: Cable Bone Transport for Segmental Bone Loss Secondary to Grade IIIB Open Tibial Fracture (Vol. 1)
Case 6: A 10 cm Traumatic Femoral Defect Treated with a Transport Technique Followed by a Lengthening Procedure. Sequential Use of a Monotube External Fixator and an Intramedullary Rod (Vol. 2)
Case 26: Plating After Lengthening (Vol. 2)

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Case 54: Deformity Correction (Tibial Bone Defect due to Osteomyelitis) in Lower Limb Using Taylor Spatial Frame

Hiroyuki Tsuchiya

Contents

Abstract

Here we present a case of a massive bone defect of tibia and limb length discrepancy due to a long-standing osteomyelitis, which was successfully treated using Taylor spatial frame.

1 Brief Clinical History

A 65 year old female suffered from osteomyelitis of the right tibia. She underwent 10 operations at 12 years of age, following which she did not have any complaints. At 65 years, she experienced severe right knee pain while walking without any prior event and was referred to our hospital for radical treatment.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

(a) Massive bone defect
(b) Limb length discrepancy
(c) Deformity

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Fig. 1 Preoperative clinical photo

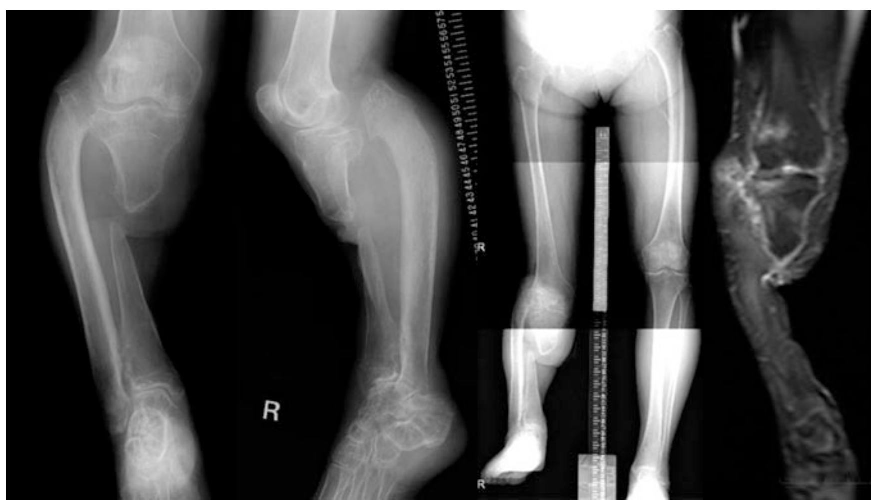

Fig. 2 Preoperative radiographs and MRI

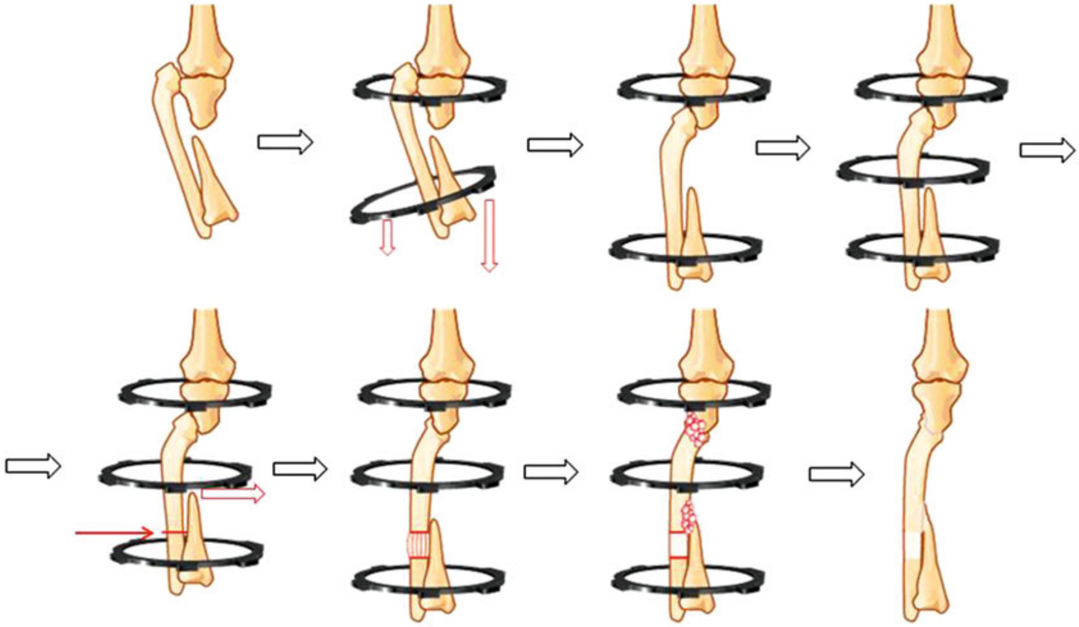

Fig. 3 Images during treatment

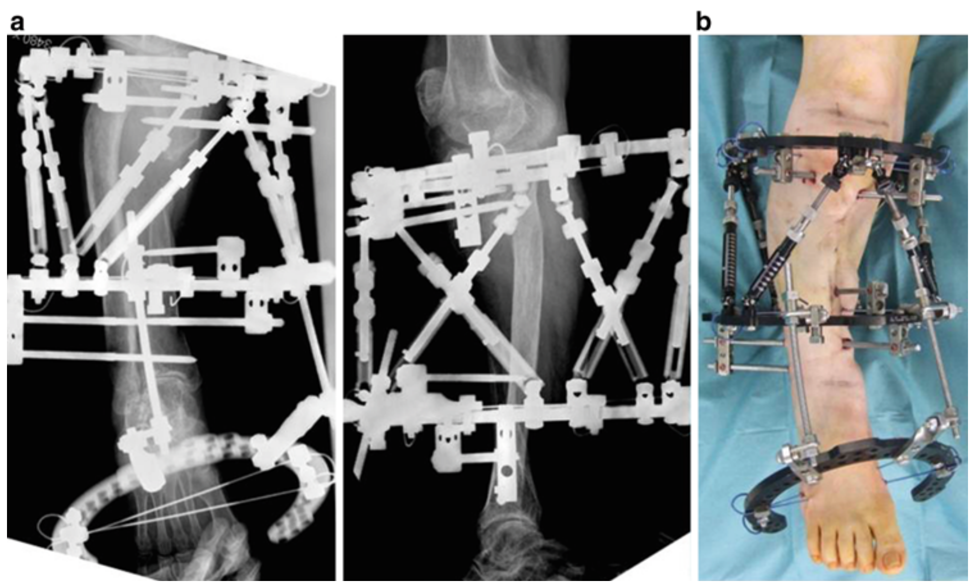

Fig. 4 (**a**, **b**) Placement of the Taylor spatial frame

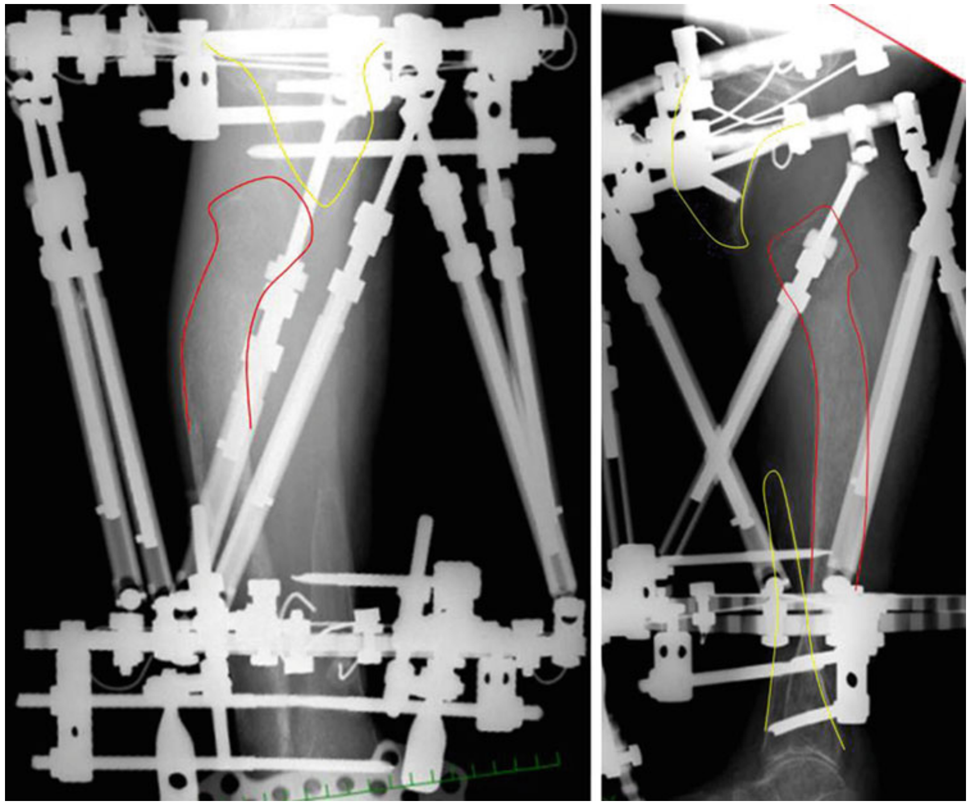

Fig. 5 After deformity correction and lengthening of the soft tissue

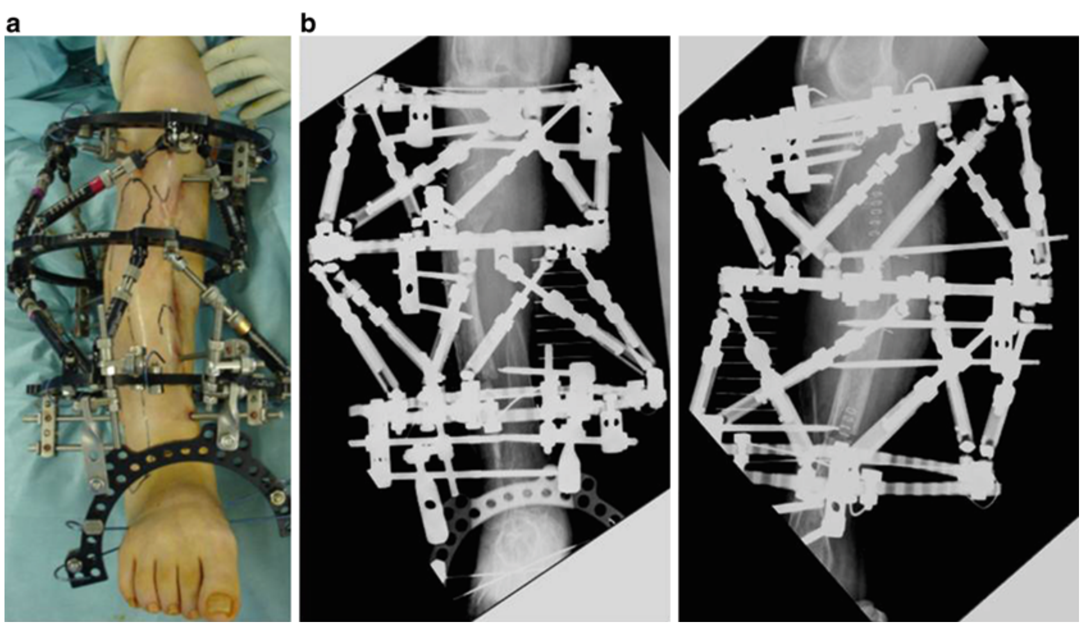

Fig. 6 (**a**, **b**) After the second operation (for fibula transport)

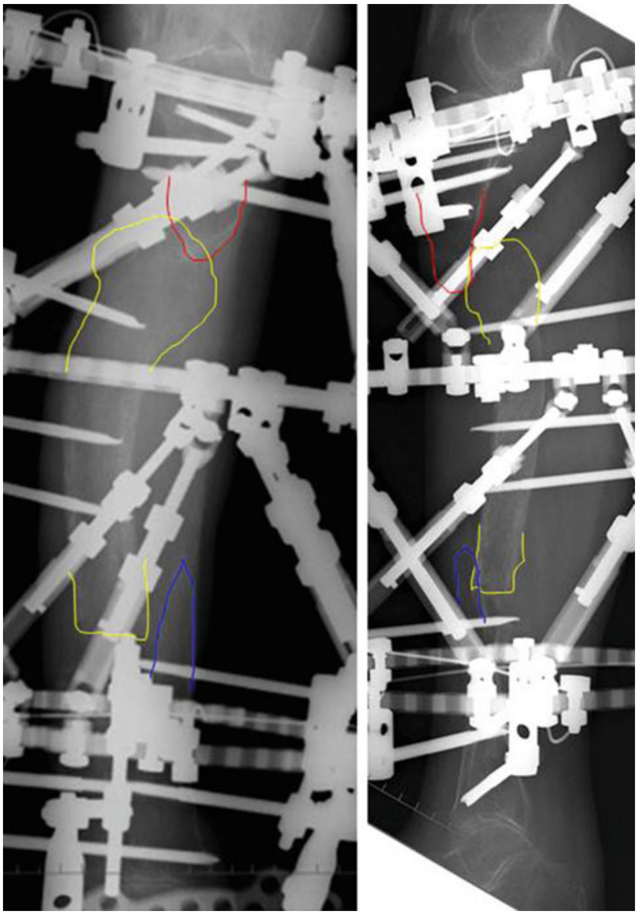

Fig. 7 After fibula transport

4 Treatment Strategy

Multiple steps for deformity correction and limb lengthening using Taylor spatial frame.

Step 1: Deformity correction and limb lengthening (TSF) using distraction histogenesis
Step 2: Fibula transport (TSF)
Step 3: Bone graft

5 Basic Principles

Basic principles of these operations are the use of hypertrophic fibula to reconstruct the massive tibial defect using an external fixator.

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

Fig. 8 Radiographs 5 years after the first operation

7 Technical Pearls

After the operation, two programs of deformity correction will be created using the web application. This case needs bifocal treatment at the proximal and distal sites using three rings. The programs will be designed to obtain good bone contact and alignment. Radiographs will be taken every week until the correction is completed. Additional reprogramming of correction will be necessary for severe deformity such as that observed in this case.

8 Outcome Clinical Photos and Radiographs

See Fig. 8.

9 Avoiding and Managing Problems

Fibula transport using a ring external fixator is difficult because of the possibility of peroneal nerve entrapment and interference with the ring and skin. To avoid these problems, ring construction should be planned elaborately before performing the operation and the peroneal nerve should be released before fibula transport.

10 See also Vols. 1 and 2

Case 117: Chronic Osteomyelitis and 5 cm Bone Defect Treated with Masquelet Technique followed by Ilizarov (Vol. 1)
Case 8: Femoral Bone Defect (Vol. 2)

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Case 55: Motorized Intramedullary Transport and Lengthening Nail Used to Reconstruct a Nonunion/Bone Defect of the Tibia

Søren Kold

Contents

Abstract

A 53 year old male presented with a tibial nonunion with a varus deformity of 16° and 2.2 cm shortening of the tibia. The nonunion site (3.1 cm bone segment) was resected until vital bone was reached. The proximal tibia and the fibula were osteotomized. A custom-made tibial nail with the ability to do initial bone transport and subsequent bone lengthening was inserted. At 4 weeks after surgery, bone morphogenetic protein (BMP-7) was administered to the docking site. At the latest follow-up, 18 months after nail insertion and 3 months after nail removal, the patient did not have any pain or restrictions in daily activities. There was no leg length discrepancy and the tibia had a 3° varus deformity.

1 Brief Clinical History

A 53 year old male sustained a closed fracture of the distal tibia and fibula. Both the tibia and the fibula fractures were treated with open reduction and fixation with locking plates. The patient developed a nonunion with loosening of the osteosynthesis, and the patient was reoperated with bone allograft and exchange of the plates and screws (Fig. 1). The nonunion did not heal. At the time of referral to our institution, the tibial plate was loose with broken screws (Fig. 2). Long-standing anterior to posterior (AP) radiograph showed that the tibia had a varus deformity of 16° and was 2.2 cm shortened (Fig. 3). Lateral radiograph did not show any sagittal plane deformities (Fig. 4).

2 Preoperative Clinical Photos and Radiographs

See Fig. 5.

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Fig. 1 AP X-ray taken after reoperation of tibial nonunion

Fig. 3 Long-standing X-ray demonstrating a *left-sided* limb length discrepancy of 22 mm

Fig. 2 Preoperative X-ray showing loosening of osteosynthesis and tibial varus deformity

Fig. 4 Preoperative lateral X-ray

Fig. 5 The combined bone transport and lengthening nail with 2 proximal and 2 distal locking screws. The middle screw inserted in the sliding hole allows for bone transport

Fig. 6 Resection of the tibial nonunion until vital bone

Fig. 7 X-ray taken immediately after bone resection and prior to bone transport

3 Preoperative Problem List

1. Atrophic nonunion
2. Anticipated bone defect of 3.1 cm
3. Leg length discrepancy of 2.2 cm
4. Retained failed hardware
5. Possible infection

4 Treatment Strategy

1. Removal of all previously inserted implants and screws, except a distal AP screw.
2. The atrophic nonunion site (3.1 cm bone segment) is resected until vital bone is reached (Fig. 6). The fibula is osteotomized at the level of the tibia resection.
3. A proximal percutaneous tibial osteotomy is performed 9 cm from the knee joint line. The nail (FITBONE ®, WITTENSTEIN Intens GmbH, Igersheim, Germany) is inserted and locked with 2 proximal and 2 distal locking

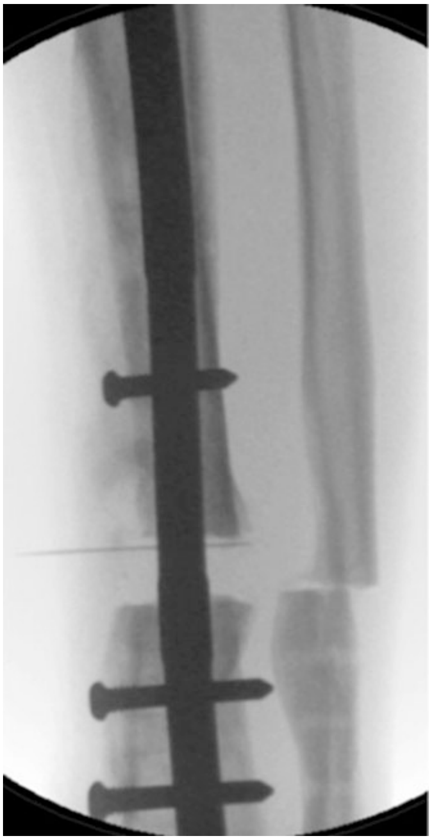

Fig. 8 Intraoperative X-ray showing the space at the docking site at the time of BMP implantation

Fig. 9 Percutaneous implantation of BMP-7 at the docking site

screws. In addition a screw is inserted into a sliding hole in the middle part of the tibia, allowing for bone transport of the middle tibial segment. A tibiofibular screw is inserted distally to protect the distal tibiofibular joint (Fig. 7).

4. Bone transport is initiated 10 days postoperative at a rate of 1 mm daily. The patient will hold a transducer over the subcutaneously placed receiver to activate the motor unit inside the lengthening nail (Fig. 5).
5. Staged bone grafting of the docking site. At 4 weeks postoperative, 3.3 mg of recombinant BMP-7 (eptotermin alfa, Osigraft, Stryker) is administered to the docking site.
6. Continue lengthening until the proximal tibia had been lengthened 5 cm (3 cm bone transport plus 2 cm leg lengthening). The docking site is continuously compressed during the last 2 cm of lengthening.

Fig. 10 X-ray taken just after the docking procedure had been performed

5 Basic Principles

1. The rate of lengthening is adjusted based on the quality of the bone regenerate. This is checked with X-ray every other week during the lengthening.
2. The patient obtains early full joint motion as the skin and muscles are not transfixed by external wires (Fig. 11).
3. The bone transport IM nail is a novel implant that allows bone transport without the use of external fixation. The transport segment is pushed by an internal mechanism in the nail and moves along a slotted section of the nail.

6 Images During Treatment

See Figs. 6, 7, 8, 9, 10, and 11.

Fig. 11 External wires did not restrict joint motion of the ankle and knee during treatment. Note the subcutaneously receiver placed proximal and lateral in the lower leg

Fig. 12 AP and lateral X-rays taken 13 months after implantation of bone transport and lengthening nail

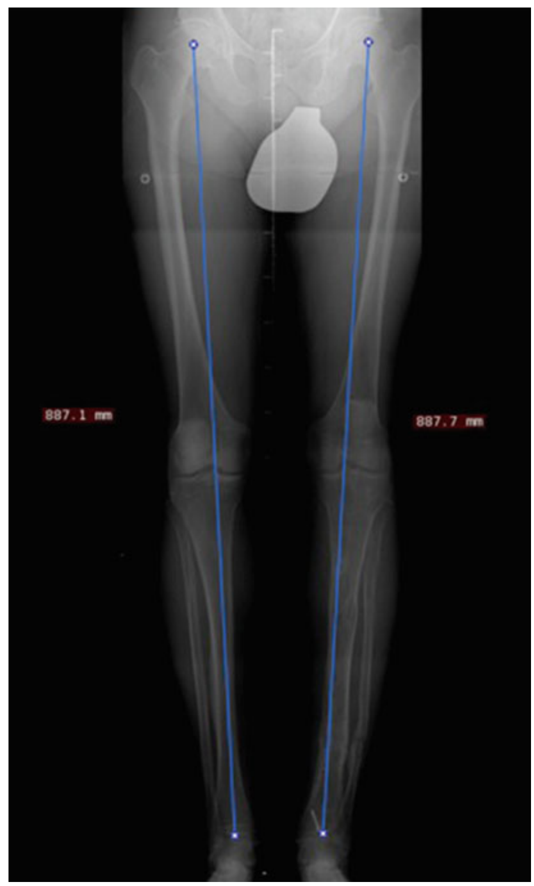

Fig. 13 Long-standing AP X-ray 3 months after nail removal

7 Technical Pearls

- All axis correction must be done at the time of surgery.
- The custom-made bone transport and lengthening nail (Fig. 5) should have the ability to provide 4 cm of bone transport and then 2 cm of bone lengthening.
- The resection site must be distal. With the current used nail, the bone defect should start at a minimum of 20 cm from the proximal tip of the 35 cm long nail.
- The tibia should be able to take a nail with a diameter of 11 mm.

- The proximal osteotomy should be at least 7 cm from the tip of the nail to provide a sufficient stable locking condition.
- The docking site is percutaneous curetted prior to installation of BMP-7 (Fig. 9). Acute distraction at the docking site is not an option. Therefore, the procedure is performed when there still was sufficient space at the docking site (Fig. 8).

8 Outcome Clinical Photos and Radiographs

See Figs. 12 and 13.

9 Avoiding and Managing Problems

1. With the nail technique, all axis correction must be done at the time of surgery. In our case the 3° varus deformity occurring at surgery also resulted in a final varus deformity of 3°.
2. There were no clinical signs of infection and the white blood cell and C-reactive peptide levels were normal before surgery. However, biopsies of the resected bone were cultured and showed growth of coagulase-negative staphylococci sensitive to dicloxacillin. Therefore, dicloxacillin was administered orally for 3 months postoperative. There have not been any clinical signs of infection.

10 Cross-References

► Case 3: Tibial Lengthening Using a PRECICE Nail

11 See Also in Vols. 1 and 2

Case 7: Cable Bone Transport for Segmental Bone Loss Secondary to Grade IIIB Open Tibial Fracture (Vol. 1)
Case 8: Three Year Old Female with Segmental Bone Defect due to Grade IIIB Open Tibial Fracture Treated by Oblique Wire Bone Transport (Vol. 1)
Case 9: Adolescent with Segmental Bone Defect Secondary to Grade IIIB Open Tibial Fracture Treated by Oblique Wire Bone Transport (Vol. 1)
Case 6: A 10 cm Traumatic Femoral Defect Treated with a Transport Technique Followed by a Lengthening Procedure. Sequential Use of a Monotube External Fixator and an Intramedullary Rod (Vol. 2)
Case 7: A 12 cm Traumatic Femoral Defect Treated with a Long Oblique Diaphyseal Femoral Osteotomy and Lengthening Over a Nail (Vol. 2)
Case 10: Infected Nonunion of the Tibia (Vol. 2)
Case 11: Bone Transport Over a Nail for Infected Tibial Nonunion and Bone Defect (Vol. 2)
Case 14: Double Level Bone Transport for Severe Bone Loss (Vol. 2)
Case 15: Bifocal Tibial Transport with the TSF (Vol. 2)
Case 18: Tibial Nonunion with Angular Deformity Treated with Taylor Spatial Frame to Gradually Correct and Lengthen (Vol. 2)
Case 28: Proximal Tibial Bone Defect Treated with Intentional Deformity and Bone Transport (Vol. 2)
Case 29: Infected Nonunion Tibia with Bone and Soft-Tissue Defect: Treatment with TSF, Intentional Temporary Deformation and Bone Transport (Vol. 2)
Case 34: Spatial Frame Correction of an Infected Distal Metaphyseal Tibial Nonunion/Malunion (Vol. 2)
Case 36: Distal Tibial Bone Defect Treated with Bone Transport Using Two Proximal Osteotomy Sites (Vol. 2)

Reference and Suggested Reading

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Part X

Adult Deformity: Amputation Reconstruction

Case 56: Lengthening of a Very Short Below Knee Amputation Residual Limb to Enhance Prosthetic Wear

S. Robert Rozbruch

Contents

Abstract

This is a case illustrating an 8 cm lengthening of a dysfunctional very short below-knee amputation (BKA) residual limb that was initially 7 cm in length. The lengthening was greater than 100 % and resulted in a BKA residual limb of 15 cm. The external fixation index was 1.5 months/cm. A prosthesis was attached to the circular external fixator allowing the patient to bear weight and walk during the treatment.

1 Brief Clinical History

The patient is a 27 year old male who developed compartment syndrome after trauma 2 years earlier. This led to a BKA done at an outside medical center. The length of the tibial remnant was 7 cm. Although he was able to wear a prosthesis, he had difficulties related to the short residual limb.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2

3 Preoperative Problem List

1. Excessively short BKA residual limb
2. Poor control of BKA prosthesis

4 Treatment Strategy

1. Lengthen residual tibia with goal to achieve length of 15 cm. This calls for an 8 cm lengthening which more than double the starting tibial length.

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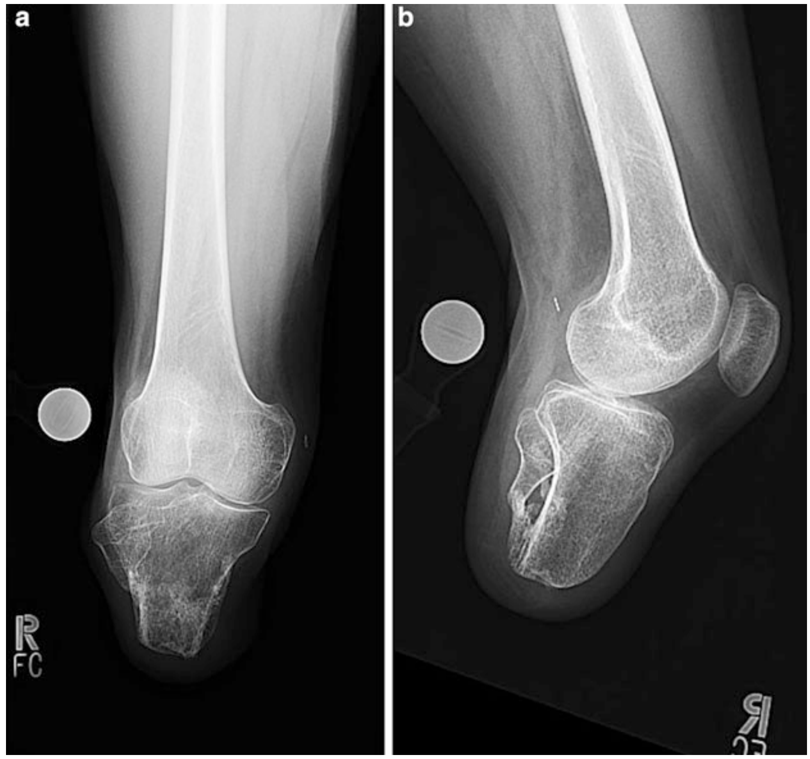

Fig. 1 (**a, b**) X-rays showing a 7 cm residual tibia and fibula

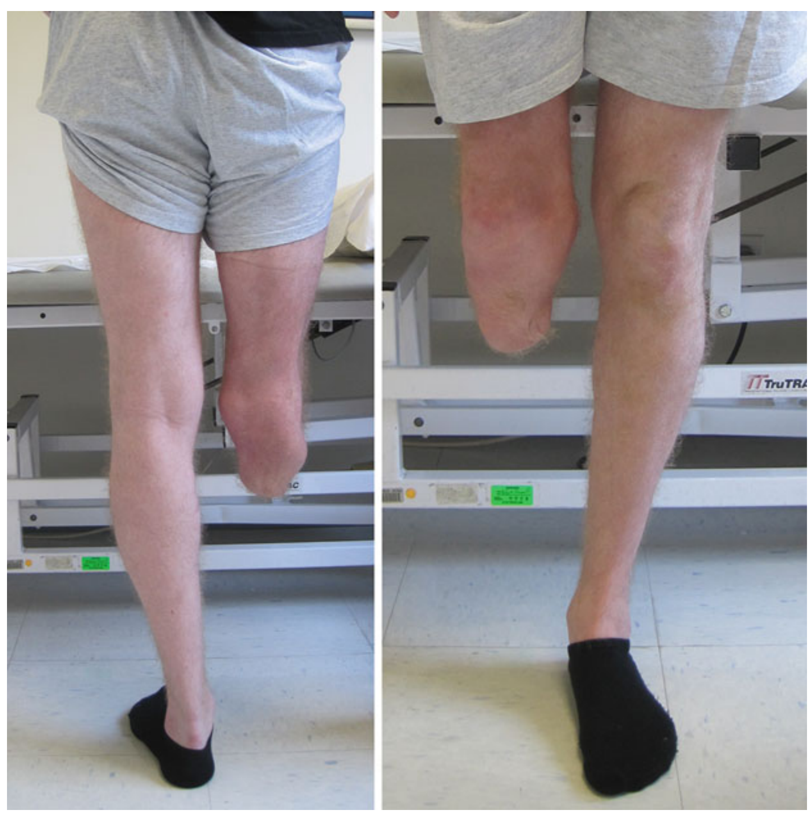

Fig. 2 (**a, b**) (**b**) Front and (**a**) back views showing short residual BKA residual limb

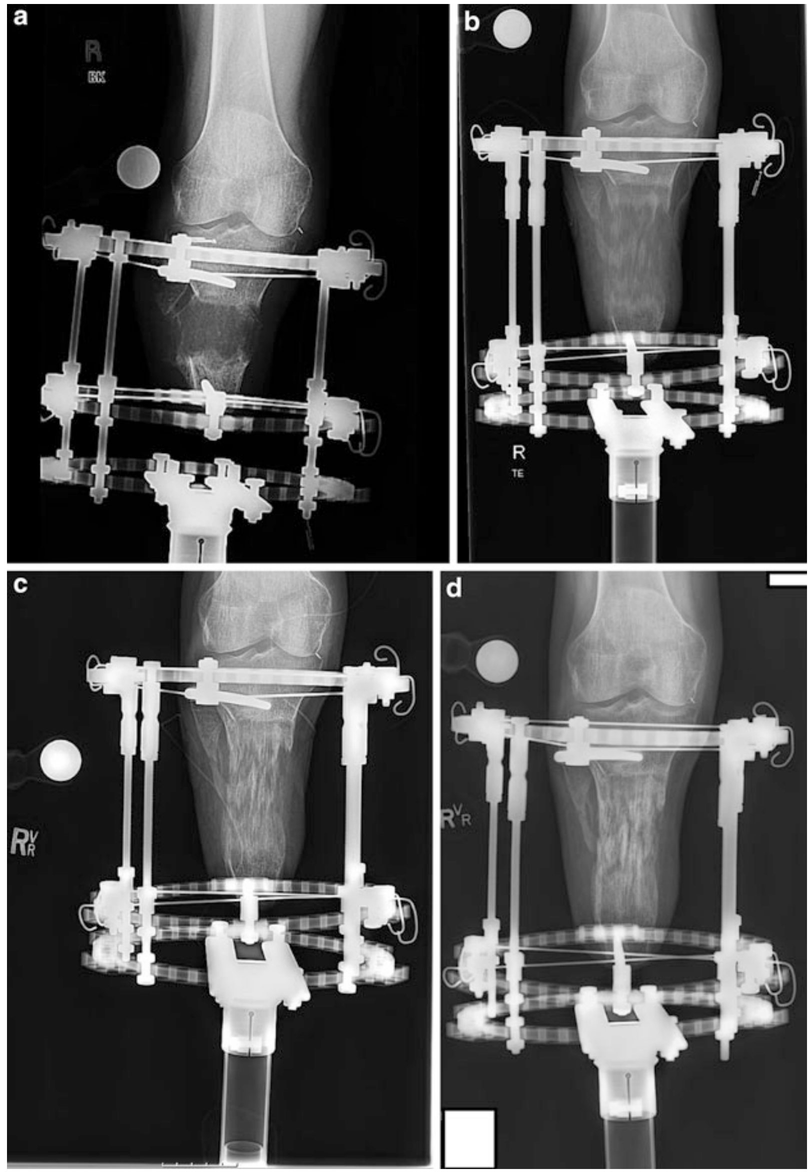

Fig. 3 (**a–d**) (**a**) AP X-ray at 2 months after surgery showing distraction gap. (**b**) AP X-ray at 6 months after surgery. (**c**) AP X-ray 8 months after surgery showing progression of union. (**d**) AP X-ray 11 months after surgery

2. Attach prosthesis to external fixator to enable the patient to bear weight. This was done right after surgery. The length was modified by changing the distance between the two blue rings.

5 Basic Principles

1. Optimal length of BKA residual limb is 15 cm.
2. Although a lengthening goal of 8 cm is greater than a 100 % lengthening, the concerns about soft tissue tension are not as relevant given the context of BKA.
3. Weight bearing during treatment is desirable.

6 Images During Treatment

See Figs. 3, 4, 5, and 6

7 Technical Pearls

1. Perform osteotomy just below the tibial tubercle
2. Distraction done at slow rate of 0.5–0.75 mm per day
3. Use Ilizarov distraction rods as the immediate postoperative distance between the rings was small and the space was tight.
4. Use a distal ring for the connection point of the walking prosthesis.

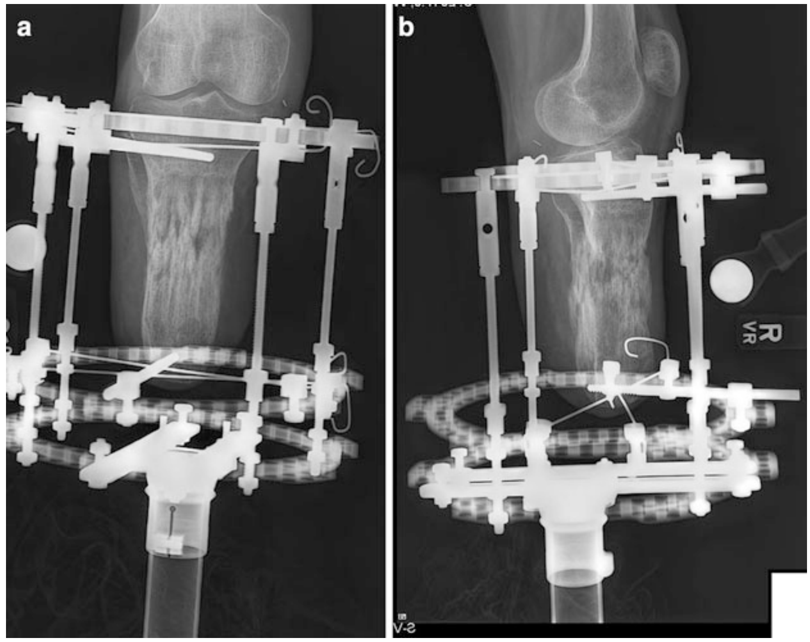

Fig. 4 (**a, b**) AP and lateral X-rays 12 months after surgery showing union of the 8 cm regenerate. Frame removal was done shortly after this. The external fixation index (*EFI*) was 1.5 months/ cm

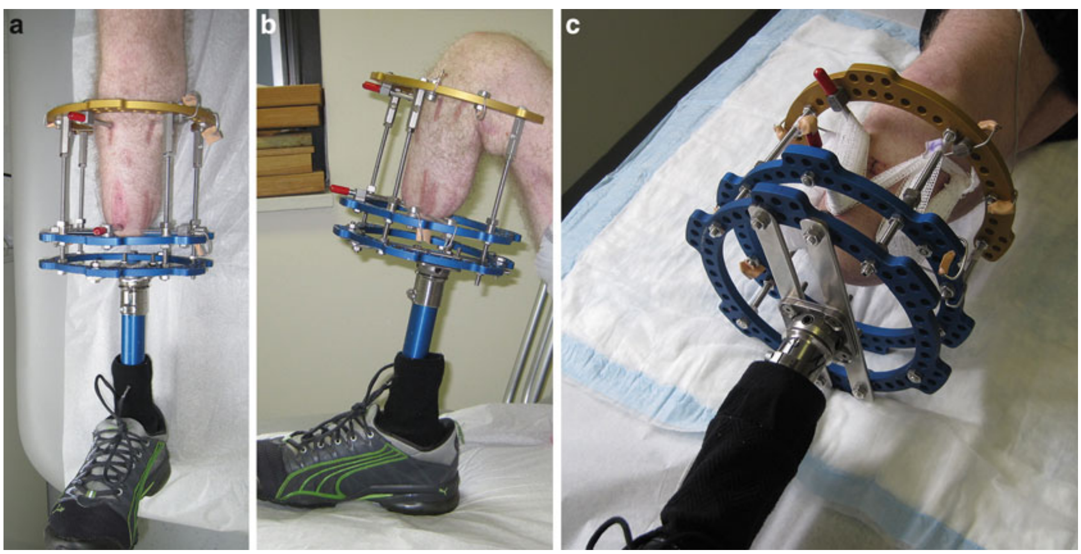

Fig. 5 (**a–c**) Multiple views showing the frame and the prosthetic connection at the end of distraction

5. During distraction, the distance between the proximal gold ring and the middle blue ring increased gradually. At the same time, the distance between the middle and distal blue rings decreased keeping the overall length with the lower extremity with prosthesis stable.

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8

9 Avoiding and Managing Problems

1. Use a slow distraction rate as one can anticipate slow bone healing in the setting of trauma and compromised soft tissue envelope.
2. To prevent the distal tibia from eroding through the distal skin, soft tissue recruitment is used. The distal skin was pulled distally, and the distal wires served to push that skin distal during the lengthening.
3. An anterior to posterior half pin was used to prevent procurvatum deformity during the lengthening.

Fig. 6 (**a–d**) Multiple standing views showing patient function while wearing the external fixator/prosthesis construct. Note the weight bearing and the active knee motion

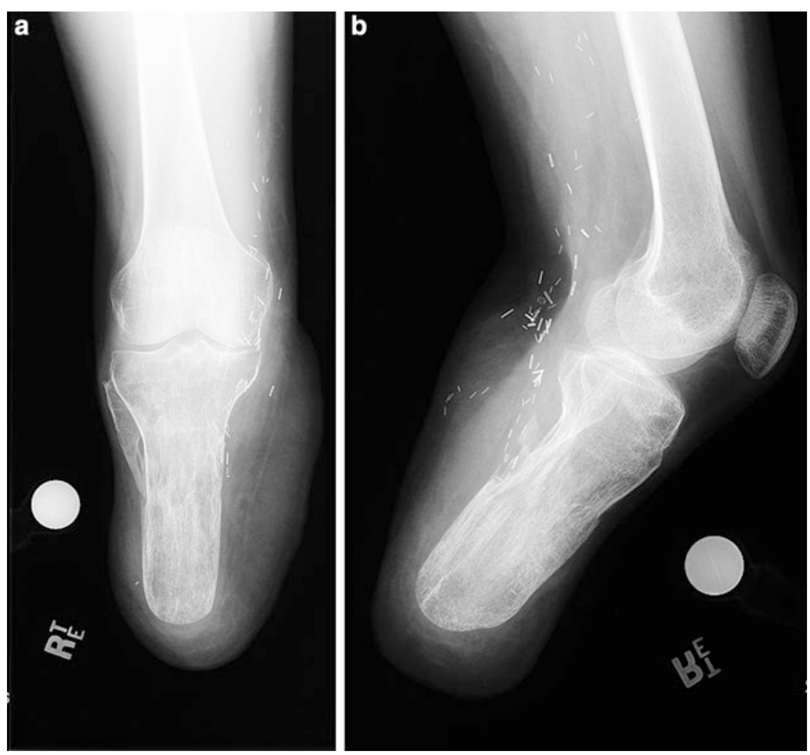

Fig. 7 (**a, b**) AP and lateral X-rays 2 years after surgery. Note the well-healed bone 15 cm in length without deformity. Flap coverage was performed by plastic surgeon to improve soft-tissue coverage of the residual limb

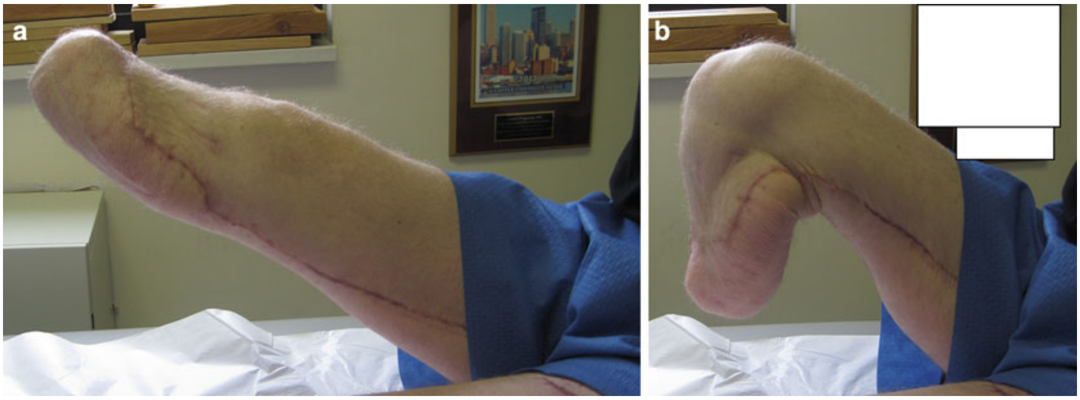

Fig. 8 (**a, b**) Clinical photos showing appearance and length of the residual limb. Prosthetic wear was improved

4. Weight bearing using the prosthesis attached to the frame helped prevent disuse osteopenia and helped advance bony union.

10 Cross-References

- ▶ Case 57: An Initially Successful Lengthening of a Traumatic Below Knee Amputation Stump by Ilizarov Technique with Subsequent Failure due to Soft Tissue Conditions
- ▶ Case 58: Below Knee Amputation Stump Lengthening
- ▶ Case 59: Femoral Stump (Residual Limb) Lengthening with a Motorized Intramedullary Lengthening Rod

References and Suggested Reading

Tellisi N, Ilizarov S, Fragomen A, Rozbruch SR (2008) Lengthening and reconstruction of congenital Leg deficiencies for enhanced prosthetic wear. Clin Orthop Relat Res 466:495–499

Case 57: An Initially Successful Lengthening of a Traumatic Below Knee Amputation Stump by Ilizarov Technique with Subsequent Failure due to Soft Tissue Conditions

Peter M. van Roermund

Contents

Abstract

A traumatic below-knee amputation resulted into a too short stump allowing a conventional below-knee prosthesis which decreased gait efficiency. The Ilizarov technique was used on the 24 year old girl to increase tibial length with 5 cm (= + 62 %) at the age of 25 which gave a 13.5 cm stump length, sufficient for a prosthesis. Bony consolidation was successful, but several problems were encountered with the soft tissues. The scarred skin over the distal end of the bony stump ruptured at the end of the distraction period. A free latissimus dorsi flap transfer failed by inadequate blood flow probably by the dystrophic vessels of the stump. Finally a through-knee amputation was needed. This outcome of the stump lengthening might have been avoided by a preparatory plastic surgery including controlled mechanical overstretching of the scarred skin. Soft tissue quality is the most determining factor in the outcome of a below-knee amputation stump lengthening.

1 Brief Clinical History

Due to a traffic accident, a traumatic below-knee amputation had to be performed in a 12 year old girl. The resulting stump was too short to allow a proper conventional below-knee prosthesis, decreasing gait efficiency. The patient initially refused through-knee amputation for cosmetic reasons and asked for surgical stump lengthening.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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Fig. 1 Clinical view of a traumatic amputation stump in a 24 year old female, being too short for a proper below-knee prosthesis

Fig. 2 An AP X-ray view of the amputation stump

3 Preoperative Problem List

The 8 cm stump length was too short for a proper fitting of a below-knee prosthesis. The skin over the stump was scarred due to traumatic amputation. The active extension of the knee joint was relatively weak. A tibial frame having only two rings may mechanically be too unstable for successful lengthening.

4 Treatment Strategy

The frame was made up of two rings over the stump and two rings over the distal femur. Just below the knee joint, a Kirschner wire with olive was drilled from posterolateral to anteromedial and a similar one in the opposite direction. These wires were fixed to the ring after being tensioned with 130 kg.

This procedure was repeated distally. The two rings on the distal femur were fixed by four transosseous Kirschner wires inserted from different directions and similarly fastened to the rings. The femur rings were intended to increase the stability of the frame. The distal fibers of the

Fig. 3 A lateral X-ray view of the amputation stump

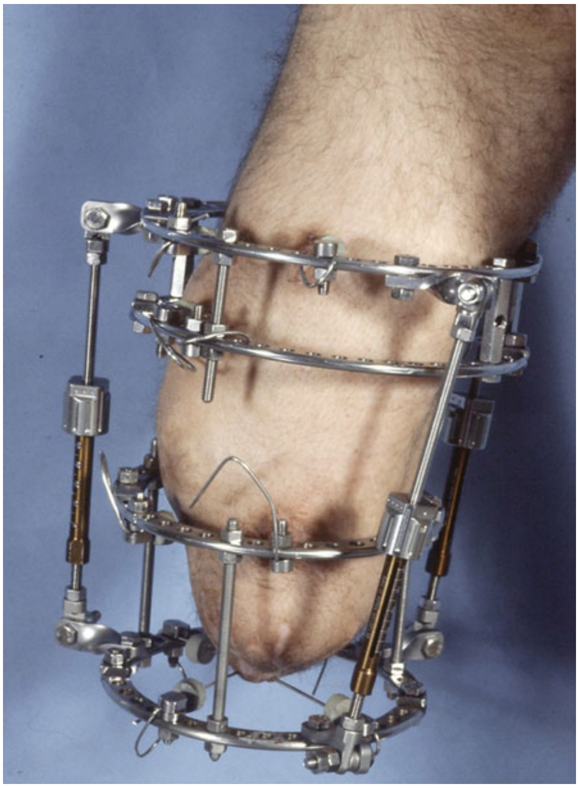

Fig. 4 Oblique view of the leg showing the mounting of the frame

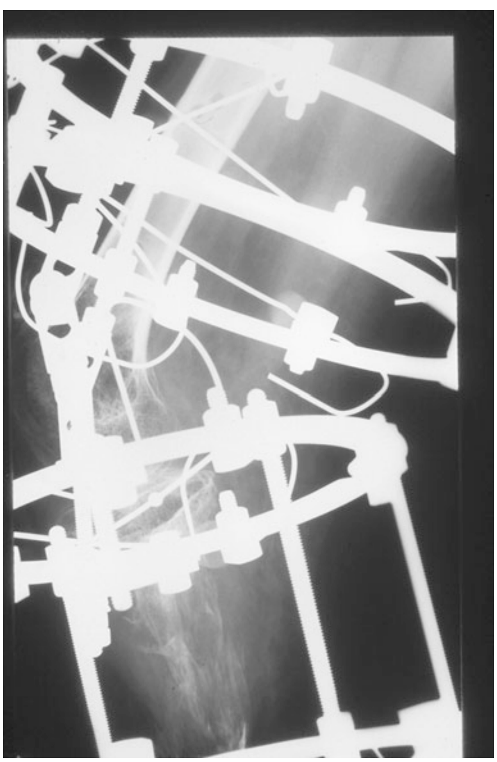

Fig. 5 Lateral X-ray of the tibial stump demonstrating the beginning of bone formation in the lengthened zone showing hinges to permit some active function in the knee

Fig. 6 Caudal view of the amputation stump at the end of the distraction period showing a rupture of the scarred tissue

patellar tendon appeared to be reattached more proximally following a previous tibial tubercle avulsion fracture.

Just below the proximal tibial ring, a percutaneous tibial corticotomy could be made by using a 5 mm osteotome. Five days later, 0.5 mm distraction was started, three times per day by turning nuts on the connecting rods between both tibial rings and turning the three lengthening devices at similar rate. This distraction procedure was continued until a total lengthening of 5 cm (meaning a 62 % increase of stump length) could be achieved. At the end of the lengthening, the scarred skin at the distal end of the stump ruptured. After achievement of the desired lengthening, rods were replaced by threaded rods including two hinges in the sagittal plane allowing some active flexion and extension in the knee joint. Six months after surgery, bony consolidation permitted removal of the ring fixator. To close the skin defect at the distal end of the stump, a free latissimus dorsi flap transfer was performed. Unfortunately this procedure failed by inadequate blood flow probably by the dystrophic vessels of the stump. Finally a through-knee amputation was needed.

Fig. 7 An AP X-ray view of the lengthened amputation stump

Fig. 9 Lateral X-ray view of the lengthened amputation stump

Fig. 8 Side view of the lengthened amputation stump

5 Basic Principles

This technique of stump reconstruction holds promise only if the soft tissue problems are anticipated. The suggestions for future stump-lengthening procedures are preparatory plastic surgery for skin requirements.

6 Images During Treatment

See Figs. 4 and 5.

7 Technical Pearls

Evaluate soft tissue coverage and its ability for being stretched prior to bony lengthening procedure.

Provide sufficient mechanical stability during lengthening by bridging the knee joint with the ring fixator if needed.

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7, 8, and 9.

9 Avoiding and Managing Problems

The Ilizarov technique is an effective method of lengthening the traumatic amputation stump, but sufficient soft tissue coverage is the most important factor for a good outcome. If necessary, soft tissue surgery should be considered prior to bony stump lengthening.

References and Suggested Reading

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Case 58: Below Knee Amputation Stump Lengthening

Prism S. Schneider and Mark R. Brinker

Contents

Abstract

Below-knee amputation (BKA) *See* Below knee amputation (BKA) requires 40 % less energy expenditure when compared with above-knee amputation (AKA) (Waters RL, Perry J, Antonelli D, Hislop H, J Bone Jt Surg 58(1):42–46, 1976), and compliance with prosthesis use is twice as likely with a BKA when compared with an AKA (Hagberg E, Berlin OK, Renström P, Prosthet Orthot Int 16(3):168–173, 1992). However, despite the advantages, when a residual BKA stump is foreshortened, patients exhibit inefficient gait and significant functional loss, and prosthesis fit becomes difficult (Bowen RE, Struble SG, Setoguchi Y, Watts HG, J Pediatr Orthop 25(4):543–547, 2005). BKA stump lengthening with an Ilizarov is an option in patients with short residual BKA stumps, who have a healthy, well-perfused soft tissue envelope and who understand the risks and benefits of Ilizarov application.

1 Brief Clinical History

A 27 year old male sustained a traumatic crush injury to his left lower extremity in an offshore pipe elevator. As a result of the profound nature of his tibia and fibula fractures, in combination with a grossly contaminated wound and prolonged ischemic time, the patient underwent a below-knee amputation, followed by two additional irrigation and debridements prior to presenting to our institution for definitive management. The patient presented with some erythema surrounding the stump, so repeat irrigation and debridement and further shortening of the stump were performed to allow firsthand assessment of the bony integrity and to decrease the risk of infection prior to proceeding with definitive lengthening. The patient was assessed by a plastic surgeon with experience in traumatic wounds who performed several repeat irrigation and debridements, followed by a latissimus dorsi free flap prior

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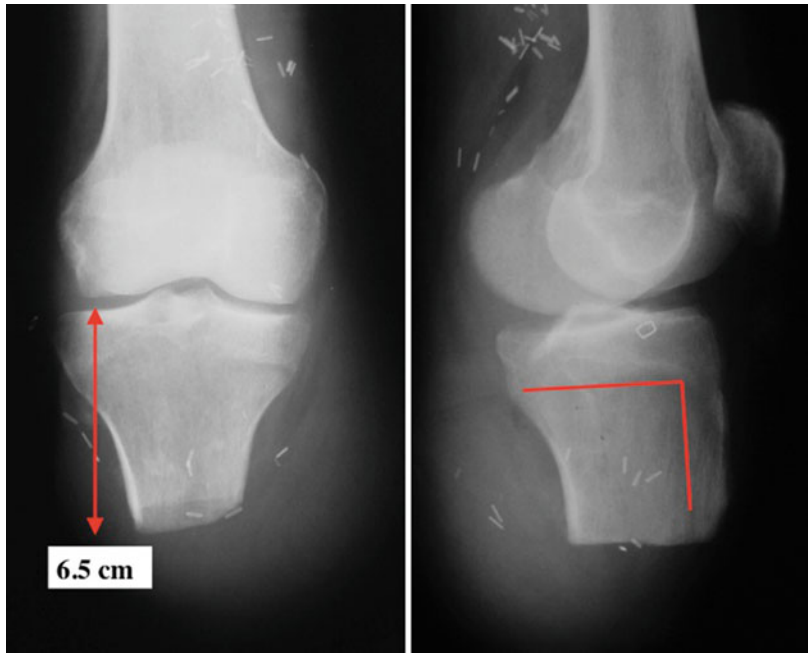

Fig. 1 Residual *left* below-knee amputation stump with fibular resection. *Left* – stump length measured 6.5 cm in length medially from the joint line. *Right* – preoperative templating for L-shaped corticotomy, given short bony end segment

to proceeding with stump lengthening. The time between flap coverage and lengthening was 2 months, in order to allow sufficient time for soft tissue healing. The patient and his wife attended numerous preoperative clinic consultations to ensure their understanding of the treatment plan.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

(a) Short bony segment – Application of an Ilizarov on short bony segment may necessitate the use of fine wires alone, without half pins.
(b) Soft tissue considerations – These include adherence and coverage but also joint contracture and motion. The patient underwent free flap coverage prior to stump lengthening. The soft tissues are the limiting factor on the amount of lengthening that can be achieved.
(c) Tendon insertions – Tendon insertions need to be maintained but may make ring fixator application more difficult, with fine wire placement away from the insertion sites.
(d) Preoperative stump assessment – Stump assessment should include bone length; bone viability; adjacent joint range of motion; soft tissue envelope assessment including contracture assessment, evaluation of adhesions, range of motion, quality of soft tissues for lengthening and coverage, and vascularity; muscular attachments and function; neurologic assessment; and exclusion of underlying infection.
(e) Corticotomy – The corticotomy required may be oblique or L shaped in order to avoid disruption of the insertion of the patellar tendon on the short bony segment (Fig. 1).

4 Treatment Strategy

Two preconstructed Ilizarov frames were built and the best fit was determined intraoperatively. The first frame was preconstructed using 180 mm full spatial frame rings. Ring 1 was connected to ring 2 using 200 mm threaded rods at a gap distance of 27.0 mm. Ring 2 had a square nut-regular nut setup so as to allow for slow lengthening across the corticotomy for tibial stump lengthening. The entire frame was tightened down and templated from preoperative X-rays accounting for X-ray magnification. A total of six threaded rods were used circumferentially for maximum stability. An exact duplicate frame was preconstructed using 155 mm rings so that the best sized frame would be applied in surgery. A 10-day period was observed between application of the Ilizarov and distraction across the corticotomy site. Distraction rate was begun at ¼ turn, three times daily. At day 27 in the Ilizarov, the lengthening rate was increased to ¼ turn, five times daily based on the radiographic appearance of the regenerate. Day 51, the patient was fit with a custom prosthesis to allow weightbearing in chest-deep water in a pool (Fig. 4).

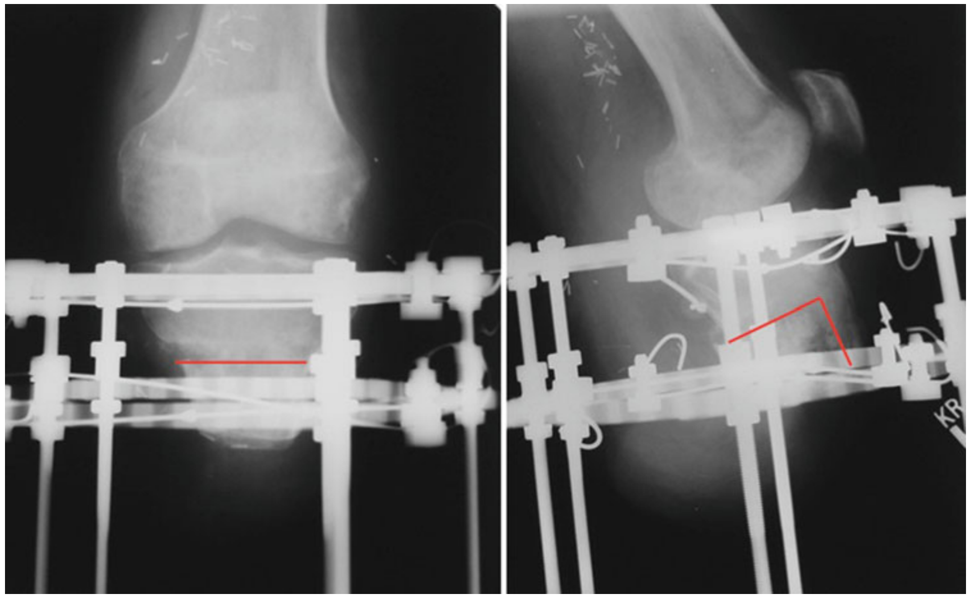

Fig. 2 Postoperative AP and lateral views of the L-shaped corticotomy and Ilizarov frame application

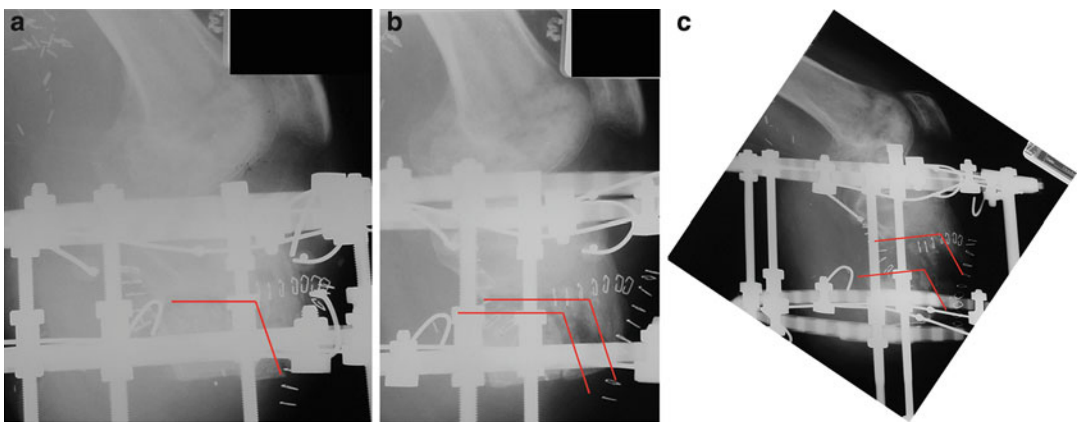

Fig. 3 Residual tibial osteogenesis in progress. (**a**) Prior to distraction. (**b**) Day 7 of distraction. (**c**) Day 21 of distraction

5 Basic Principles

Lengthening following a BKA is indicated for a short stump following traumatic amputation, tumor, or infection resection. Patients who sustain a traumatic amputation are often young and otherwise healthy; therefore, a high level of function following stump lengthening is possible. The goals of lengthening are to improve function and improve prosthesis fit and cosmesis by increasing the stump lever arm (Waters et al.1976; Bowen et al. 2006; Hagberg et al.1992). Lengthening is not indicated in vascular injury or disease, as the compromised blood supply can result in lengthening failure, wound complications, and delayed healing. A stump length of 12–17 cm is required for proper prosthetic fit. A stump length of less than 9 cm presents significant problems with prosthesis fit. A residual stump length of less than 5 cm significantly compromises function, especially if the biceps femoris insertion has been resected. It can be very difficult to assess the regenerate in a short bony segment with an Ilizarov in place; therefore, a CT scan may be used if the patient complains of increasing pain during distraction, or if there is radiographic concern, or if the overlying frame precludes adequate regenerate assessment. If deformity of the bone occurs, residual correction may be done with frame modification.

6 Images During Treatment

See Figs. 2, 3, and 4.

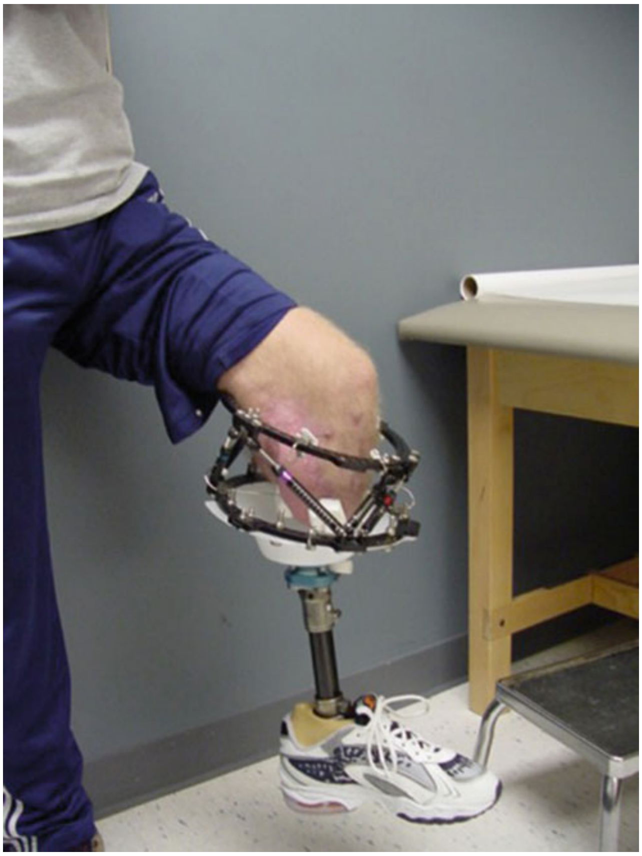

Fig. 4 Custom prosthesis fit to the distal ring to allow for weightbearing

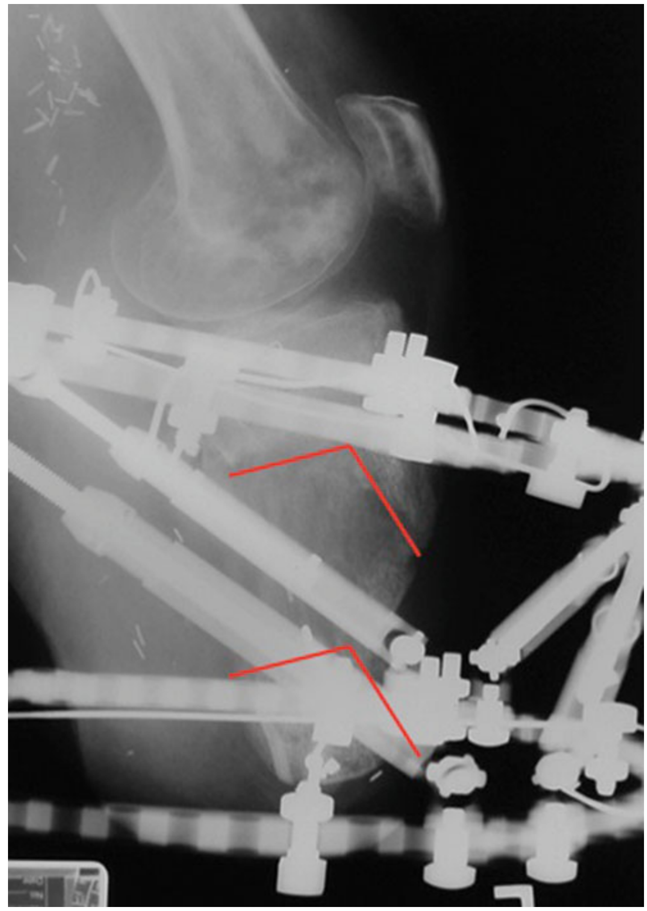

Fig. 5 Final lateral X-ray prior to Ilizarov frame removal. Day 274 in Ilizarov. Note spatial frame struts were substituted for the initial distraction rods in order to assist with residual deformity correction

7 Technical Pearls

A non-conventional corticotomy is often required with short end segments, in this case, an "L-shaped" corticotomy, where the vertical limb was performed with drill holes and an osteotome and the horizontal limb was performed with a Gigli saw, stopping short of the anterior cortex, as viewed with intraoperative fluoroscopy. Gigli saw use for a portion of the corticotomy has the advantage of preserving periosteum more than an open corticotomy with a power saw and osteotome.

8 Outcome Clinical Photos and Radiographs

See Figs. 5, 6, and 7.

9 Avoiding and Managing Problems

Potential skin and soft tissue concerns must be addressed prior to stump lengthening. If skin and soft tissue coverage are a concern, consider contracture releases, soft tissue expanders, and vascularized skin grafts or flaps prior to bony lengthening. Soft tissue contractures during Ilizarov treatment for stump lengthening are common; therefore, focused exercise therapy for the knee joint through the distraction and consolidation phases is very important. Consideration should also be given for joint manipulation or contracture release at the time of frame removal. In this case, two preconstructed frames were made, and the appropriate frame was selected intraoperatively, in order to ensure appropriate frame fit. The patient and his wife

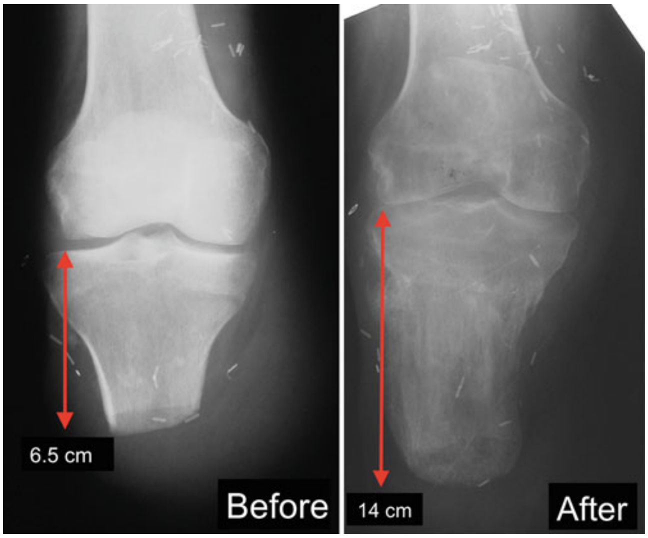

Fig. 6 Comparison of preoperative (*left*) and postoperative (*right*) residual stump lengths, after 284 days in an Ilizarov external fixator

underwent multiple preoperative clinic assessments to discuss the treatment plan, the expected duration of treatment, and the potential complications associated with this uncommon procedure. The patient and his wife were taught how to perform the distraction, three times daily, and time was taken to watch the patient's wife perform the lengthening properly and answer any questions. Patients require close follow-up while undergoing distraction at a corticotomy site in order to monitor soft tissue lengthening, neurovascular status, pin site health, and quality of the regenerate to ensure the lengthening rate appropriately avoids nonunion, or conversely, premature consolidation. This patient was followed every 7–10 days during the distraction phase and monthly during the consolidation phase.

Residual deformity can occur during lengthening. This should be corrected to avoid a lengthening bone with deformity. In this case, spatial frame struts were substituted for the distraction rods, and residual correction of deformity was successfully accomplished.

10 Cross-References

- ▶ Case 56: Lengthening of a Very Short Below Knee Amputation Residual Limb to Enhance Prosthetic Wear

Fig. 7 Final clinical photograph with patient weightbearing as tolerated with a conventional BKA prosthesis

- ▶ Case 57: An Initially Successful Lengthening of a Traumatic Below Knee Amputation Stump by Ilizarov Technique with Subsequent Failure due to Soft Tissue Conditions

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Case 59: Femoral Stump (Residual Limb) Lengthening with a Motorized Intramedullary Lengthening Rod

Søren Kold

Contents

Abstract

This is a case of a 26 year old male with bilateral traumatic femoral amputations. The patient was unable to use a weight-bearing prosthesis on the left side due to a very short stump. The stump was lengthened 50 mm with a motorized intramedullary lengthening rod (Fitbone TAM, WITTENSTEIN Intens GmbH, Igersheim, Germany). Hereafter the patient could use a weight-bearing prosthesis.

1 Brief Clinical History

This is a case of a 26 year old male with traumatic through-the-knee amputation on the right side and a high femoral thigh amputation on the left side. The remaining femur on the left side measured 15 cm from the piriformis fossa to the distal bone tip. Due to the very short weight arm of the remaining femoral residual limb, the patient was not able to properly fit a prosthesis 3 years after the amputation. The patient wanted to wear a prosthesis without restrictions. The patient specifically did not want an osseointegrated femoral implant but desired a conventional suspended transfemoral prosthesis.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

Søren Kold, M.D., Ph.D., and Knud Stenild Christensen, M.D., did the preoperative planning, surgery, and postoperative follow-up of the presented case in collaboration.

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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Fig. 1 (**a**) Preoperative picture of the residual limb. (**b**) Anterolateral preoperative view of the residual limb showing sufficient distal soft tissue coverage to allow bone lengthening

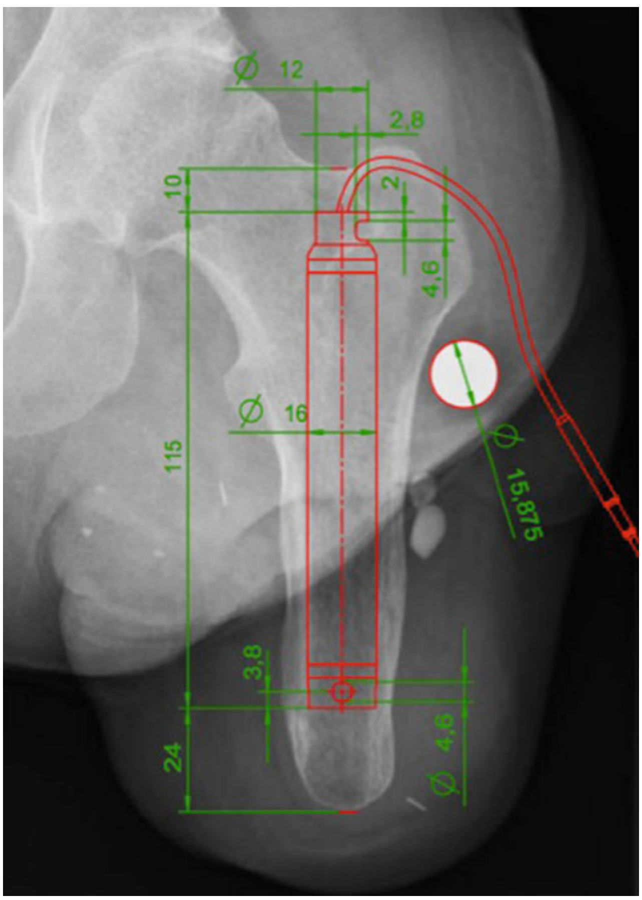

Fig. 2 Preoperative X-ray with the planned femoral lengthening rod superimposed

3 Preoperative Problem List

- Short residual limb making prosthetic wear difficult.
- A sufficient amount of soft tissue, including mobile skin, should be present distally for the bone tip excursion (Fig. 1).
- Femoral bone stump: Length, diameter and anatomy, as well as bone quality should allow for implantation of a femoral rod (Fig. 2).
- The hip joint should be stable with good range of motion.

4 Treatment Strategy

A femoral osteotomy was performed with predrilling and a chisel approximately 25 mm distal for the lesser trochanter (Fig. 4). A custom-made 115 mm long rod (Fitbone TAM, WITTENSTEIN Intens GmbH, Igersheim, Germany) with a motor unit allowing for a maximum of 50 mm of lengthening was inserted after retrograde reaming. The rod was fixed proximally to the bone by an anterior to posterior blocking screw in half of a hole in the proximal part of the rod (Fig. 3). Distally the rod was fixed by an anterior to posterior locking screw passing through a hole in the middle of the rod (Fig. 3). A subcutaneously placed antenna was connected to the motor unit inside the lengthening rod (Fig. 3). The patient held a transducer over the antenna to activate the motor unit of the lengthening rod. Lengthening was started at the 11th postoperative day at a rate of 1/3 mm three times daily.

The patient did not use a prosthesis during the lengthening. After lengthening, a femoral prosthesis, which transferred weight load at the ischial bone of the pelvis, was provided. The prosthesis was hereafter gradually adapted to transfer the weight load through the femur.

Due to the initial short femoral length, it was necessary to insert a short elongation rod with a maximum telescopic lengthening range of 50 mm. The patient is able to fit a weight-bearing prosthesis on the elongated femoral stump. However, the fitting of a prosthesis would benefit from

Fig. 3 Picture of the lengthening rod with fixation screws, receiver, and transducer

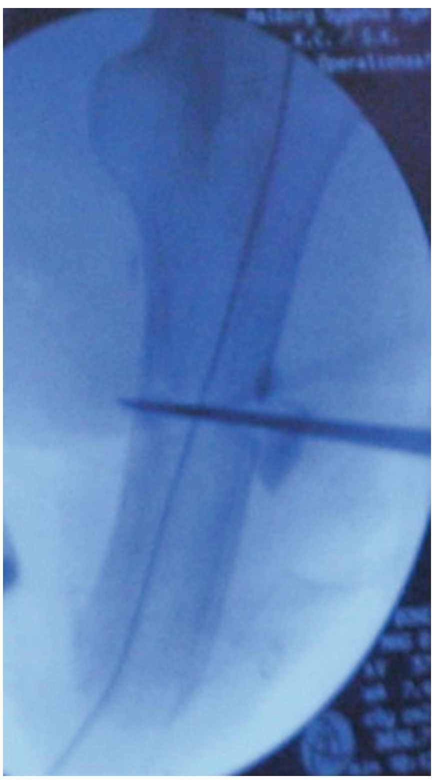

Fig. 4 Intraoperative fluoroscopy showing the level of the osteotomy

Fig. 5 Immediate postoperative X-ray showing the implanted lengthening rod

further elongation of the stump, and the soft tissue conditions of the stump are good. Therefore the patient is scheduled for implantation of a second motorized intramedullary lengthening rod. This second rod will be 165 mm long and will be able to provide up to 10 cm of additional lengthening.

5 Basic Principles

Signs of callus formation in the regenerate were checked radiologically every second week during the lengthening. The lengthening rate was kept at 1 mm per day throughout the entire lengthening period. The soft tissue conditions at

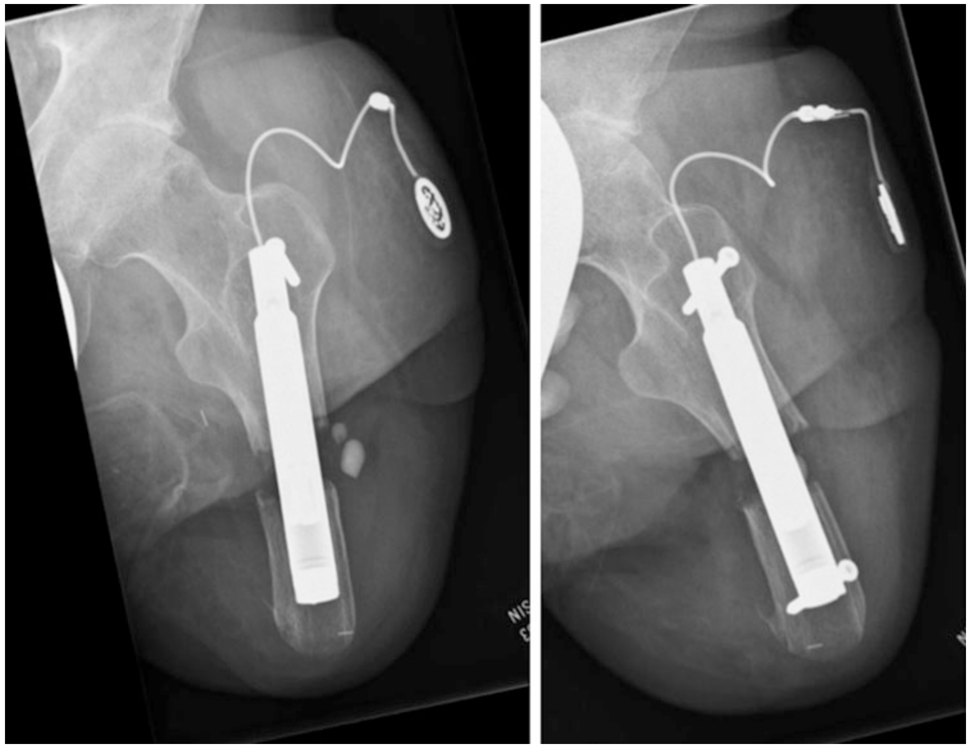

Fig. 6 X-rays taken 14 days after start of lengthening

Fig. 7 Picture of the stump after lengthening has been completed showing sufficient distal soft tissue coverage to allow for further bone lengthening with a longer lengthening rod

the tip of the stump were carefully observed. Physiotherapy ensured that range of motion of the hip joint was kept unchanged.

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

The femoral bone was osteoporotic due to disuse. The femoral canal was reamed from the distal part in a proximal direction prior to retrograde insertion of the lengthening rod. Hereby, a sufficient amount of bone remained proximally to ensure that the rod was kept in place during lengthening even though an antirotation screw only fixed the rod proximally.

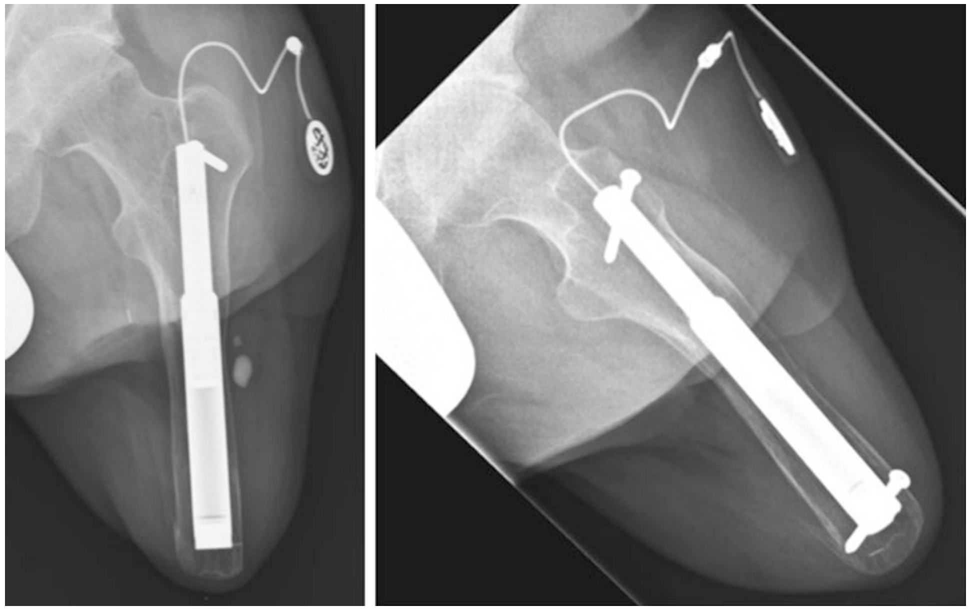

Fig. 8 Latest follow-up frontal and lateral X-rays (16 months postoperative) showing healing of the bone regenerate in three out of four cortices

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

9 Avoiding and Managing Problems

The patient did not use a prosthesis during the lengthening. Hereafter a femoral prosthesis, which transferred weight load to the ischial bone of the pelvis, was provided. This prosthesis was gradually reshaped in order to transfer the weight load through the femur.

10 Cross-References

- ▶ Case 55: Motorized Intramedullary Transport and Lengthening Nail Used to Reconstruct a Nonunion/Bone Defect of the Tibia
- ▶ Case 86: Humeral Lengthening with a Motorized Intramedullary Lengthening Nail

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Case 60: Post-traumatic Short Femoral Stump Lengthened with a Monolateral External Fixator

Pablo Wagner, Renee Hunter, and John E. Herzenberg

Contents

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Abstract

This is a case of post-traumatic femoral amputation that occurred after a high-energy war injury. The resulting femoral stump was too short to be fit with a prosthesis. We describe a stump lengthening of 10 cm using distraction osteogenesis with a monolateral external fixator. A successful lengthening was obtained, and the result was a longer and more functional residual limb that could be fit with a standard prosthesis. This resulted in improved gait, lower energy consumption, and high patient satisfaction.

1 Brief Clinical History

A 40 year old patient had a traumatic amputation of the right femur secondary to a traumatic high-explosive war injury (rocket explosion). Prosthetic fitting and placement was difficult given the short length of the femoral stump and redundant soft tissues. Reconstruction was performed by a femoral osteotomy and application of a monolateral external fixator. Over the course of several months, the femur was lengthened to 10 cm.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Short right femoral stump
2. Excess of soft tissues preventing prosthetic fitting
3. Difficulty with prosthetic wear

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Fig. 1 AP right femur

Fig. 2 Lateral right femur

4 Treatment Strategy

1. Percutaneous femoral osteotomy and application of monolateral external fixator.
2. Lengthen the femur to a total of 4 in. to help fit a prosthetic better in the future.

5 Basic Principles

Distraction osteogenesis used for stump lengthening helps with prosthetic fitting. There is a longer stump and less redundant soft tissues. Both factors help for a better prosthetic fitting, giving a better grip and a more stable stump/prosthesis interface that allows better functionality, less energy consumption, and a decreased risk of infection.

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

7 Technical Pearls

1. Make sure to place at least two pins distal to the osteotomy site and three pins proximal to the osteotomy site. A more stable construct is necessary proximally given the deforming force from the psoas tendon.
2. If there is a preexisting hip flexion contracture, consider iliopsoas intramuscular lengthening.
3. Perform a percutaneous osteotomy using a Gigli saw protecting the soft tissues.
4. The osteotomy should be performed distal to the lesser trochanter to have less deforming forces (psoas tendon) through the osteotomy site.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

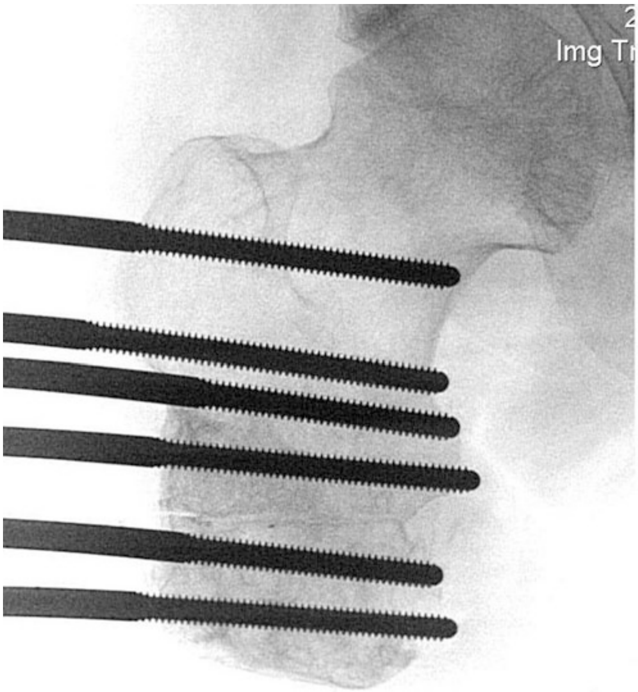

Fig. 3 Intraoperative fluoroscopy view after pin placement in the femur

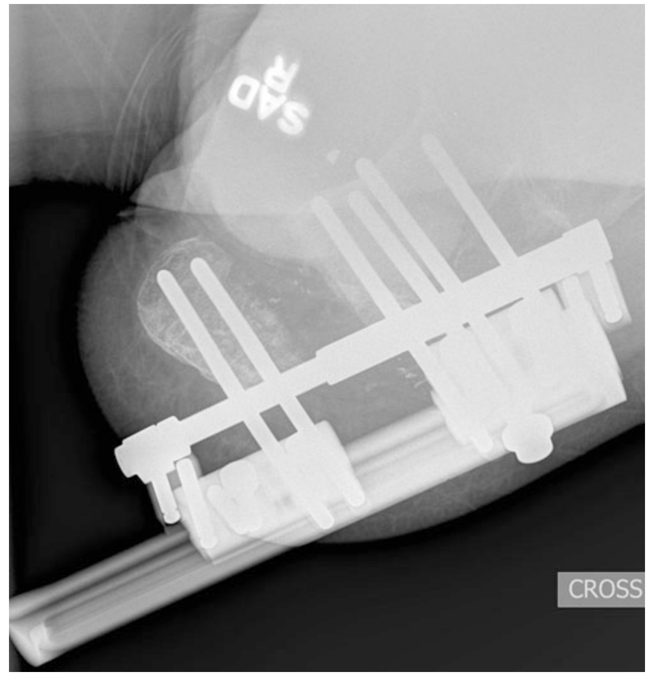

Fig. 5 Lateral X-ray of the right femur during lengthening phase

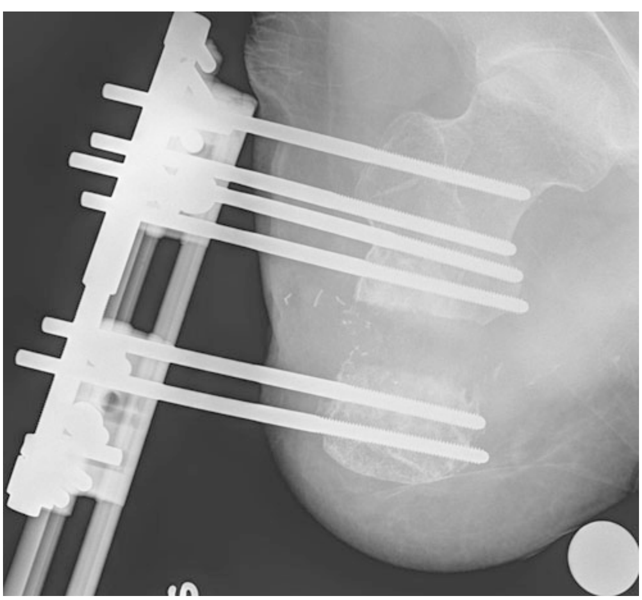

Fig. 4 AP X-ray of the right femur during lengthening phase

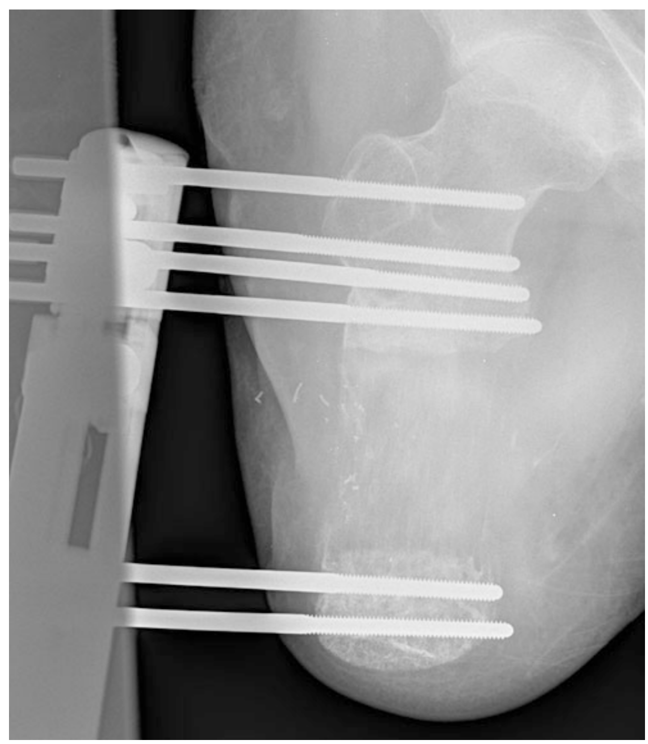

Fig. 6 AP X-ray at the end of lengthening phase

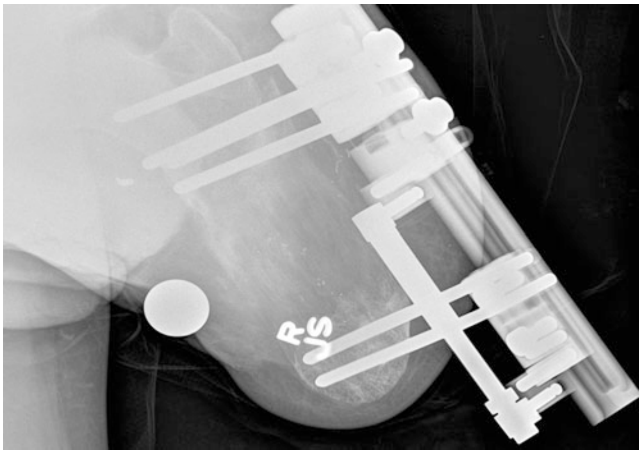

Fig. 7 Lateral X-ray at the end of lengthening phase

Fig. 8 AP X-ray after complete consolidation

9 Avoiding and Managing Problems

1. Do not remove the frame until three of four cortices are healed.
2. Always place at least three pins in the proximal segment (four in this case) to achieve a stable construct.

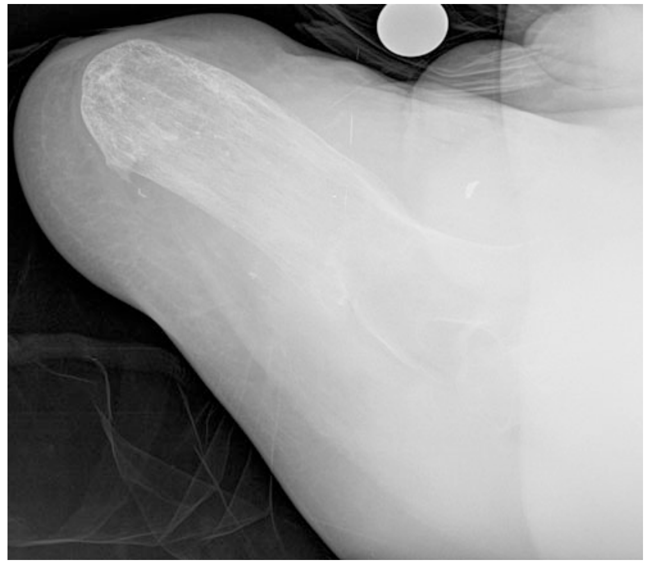

Fig. 9 Lateral X-ray after complete consolidation

3. Await prosthetic fitting until the bone and skin are completely healed and swelling is down. After bone healing is complete, initiate compression techniques such as stockinette or shrinkers to allow a better prosthetic fitting.

10 Cross-References

▶ Case 56: Lengthening of a Very Short Below Knee Amputation Residual Limb to Enhance Prosthetic Wear
▶ Case 58: Below Knee Amputation Stump Lengthening
▶ Case 59: Femoral Stump (Residual Limb) Lengthening with a Motorized Intramedullary Lengthening Rod

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Tumor: An Introduction

Levent Eralp

Bone and soft tissue malignancies are associated with serious diagnostic and therapeutic challenges. Approximately, 10 % of newly diagnosed malignant tumors in children, adolescents, and adults are comprised of bone and soft tissue malignancies (Arndt and Crist 1999). The contemporary treatment approach for malignant bone and soft tissue tumors is wide resection of the tumor followed by the reconstruction of resultant defect with a variety of methods (Eralp et al. 2009). Chemotherapy and radiotherapy are used as adjuvants to surgery for both systemic and local effects, and these are used before and after surgery. The success rates achieved in each step of treatment improve the patient survival. In last three decades, 5-year disease-free survival has increased to 60–70 % (Sweetnam 1989). However, this has been accompanied by both acute and late complications.

The complications which originate from the resection can be divided into two main groups: age independent and age dependent. Age-independent complications can further be subgrouped as having a biological or endoprosthetic etiology – the former including infection and nonunion and the latter including instability, infection, limb shortening, and restricted range of motion. Age-dependent complications can be subcategorized into three subgroups: physeal loss, definite physeal injury, and radiotherapy-induced injury. Complete physeal loss presents with leg length discrepancy; partial physeal loss presents with deformity; and sequel of radiotherapy presents with deformity and pelvis asymmetry (Table 1).

The table summarizes our therapeutic algorithm of solutions to address the complications of bone tumor reconstruction.

In conclusion, we consider the ideal solution for tumor reconstruction to be a single implant that will ensure a near-normal range of motion and equalization of leg lengths with long-term success. However, this ideal is hard to achieve.

In this section, a variety of cases are presented illustrating the challenges of bone tumor reconstruction. These include treatments of both benign and malignant bone tumors as well as acute reconstructions after tumor resection and secondary reconstructions after primary failures. The treatment of bone tumors presents the limb deformity surgeon with the challenges of bone defects, compromised soft tissue envelope, growth plate damage, limb deformity, leg length discrepancy, infection, and endoprosthesis loosening.

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Table 1 Recommended solutions to address complications

Age independent							Age dependent			
Problems and consequent solutions of biological reconstruction			Problems and consequent solutions of endoprosthetic reconstruction				Problems related to physeal loss and consequent solutions	Problems related to partial physeal injury and consequent solutions	Problems related to radiotherapy and consequent solutions	
Solutions for deformity/ shortness	Solutions for infection	Solutions for nonunion	Solutions for loosening	Solutions for restricted ROM	Solutions for infection	Solutions for shortness	Solutions for shortness	Solutions for deformity	Solutions for pelvic asymmetry	Solutions for deformity
Close follow-up	Allograft + bone cement with antibiotic	Stable osteosynthesis	Prothesis without cement	Physical therapy + relaxation operations	Allograft + bone cement with antibiotic	Growing endoprosthesis	Growing endoprosthesis	Close follow-up	Compensation for shortness	Close follow-up
Elongation							Vascularized epiphyseal transfer (for proximal humerus)	Elongation		Elongation
Temporary epiphysiodesis of the joint						Prosthesis + growing stem		Temporary epiphysiodesis of the joint		Temporary epiphysiodesis of the joint
Deformity correction							Prosthesis + growing stem	Deformity correction		Deformity correction

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Part XI

Tumor: Reconstruction Following Resection of Benign Bone Tumor

Case 61: Deformity Correction (Benign Bone Tumor) in Lower Limb Using Taylor Spatial Frame

Hiroyuki Tsuchiya

Contents

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Abstract

Here we present a case of a severe left leg deformity and gait disturbance due to Ollier's disease, which was successfully treated using Taylor spatial frame.

1 Brief Clinical History

A 21 year old male complained of a severe left leg deformity and gait disturbance due to Ollier's disease. He incurred an injury that fractured his left femur when

Fig. 1 Preoperative clinical photo

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Fig. 2 Preoperative radiographs

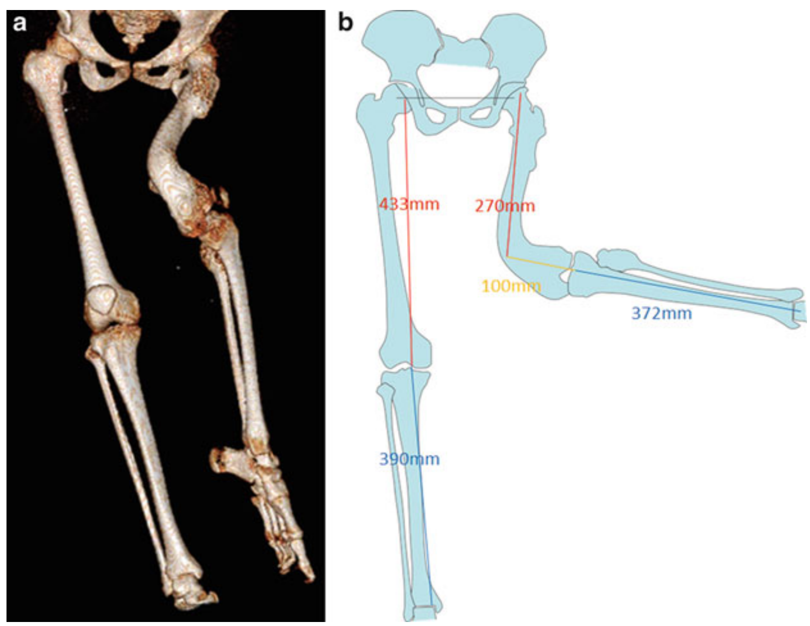

Fig. 3 Preoperative 3D CT (deformity parameters: AP angulation, 83° valgus; AP translation, 0 mm; LAT angulation, 0°; LAT translation, 0 mm anterior; Ax angulation, 0°; Ax translation, 77 mm short)

he was 6 years old; however, noninvasive treatment resulted in a malunion. He was diagnosed with multiple enchondromatoses at 11 years of age. Thereafter, the deformity of his left leg had gradually deteriorated and he also had autism.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

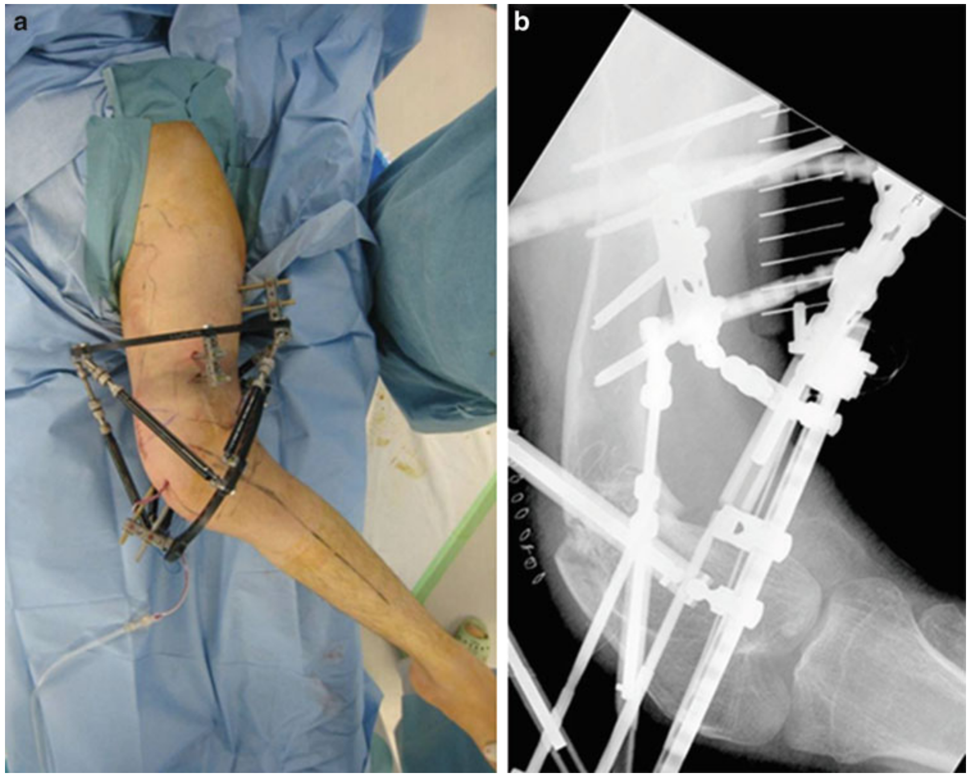

Fig. 4 (**a**, **b**) Placement of Taylor spatial frame, intentional marginal excision. An acute varus correction of 20° was necessary for TSF attachment due to severe valgus deformity

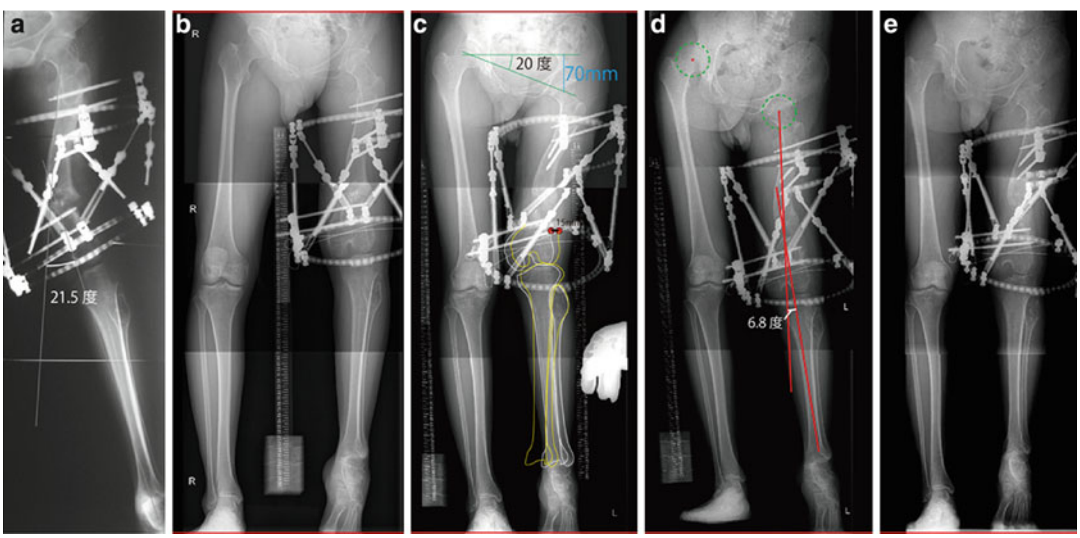

Fig. 5 (**a**–**e**) Deformity correction (5 programs)

3 Preoperative Problem List

(a) Valgus deformity
(b) Limb length discrepancy
(c) Patellar dislocation
(d) Equinus contracture
(e) Rigid scoliosis

4 Treatment Strategy

Multiple steps for deformity correction and limb lengthening using Taylor spatial frame:

Step 1: Correction of femur deformity (TSF)
Step 2: Tibial lengthening (TSF)

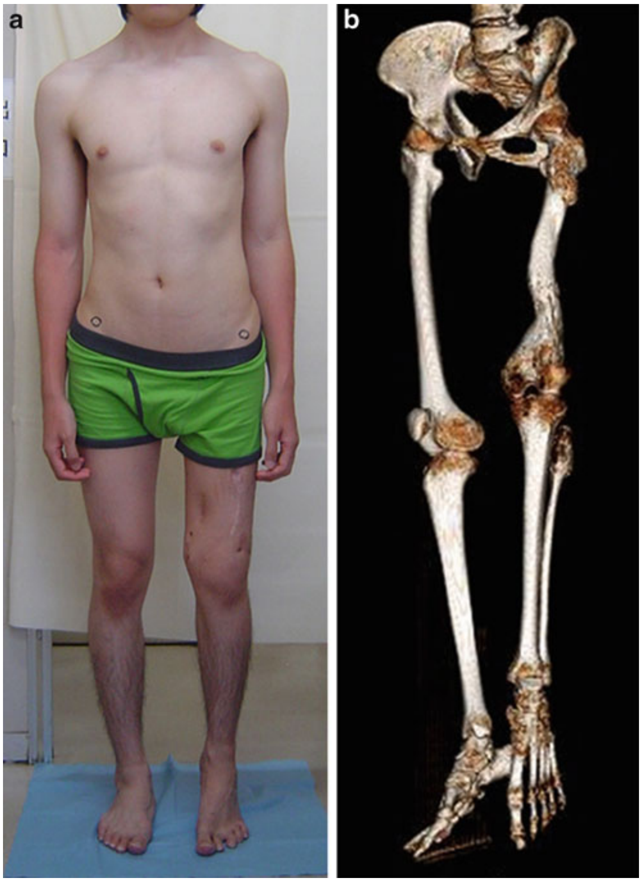

Fig. 6 (**a**, **b**) After TSF removal (lengthening, 6 cm; correction period, 112 days; external fixation period, 382 days; distraction index, 18.7 day/cm; external fixation index, 63.7 day/cm)

Step 3: Correction of ankle deformity and mobilization (TSF)
Step 4: Conversion from TSF to plate fixation

5 Basic Principles

(a) Placement of Taylor spatial frame
(b) Gradual correction and lengthening (reprogramming is necessary for a severe, multi-planar deformity)
(c) TSF removal after maturation of callus formation
(d) Conversion from TSF to plate after correction and lengthening are completed

6 Images During Treatment

See Figs. 4, 5, 6, 7, 8, 9, 10, and 11.

7 Technical Pearls

After surgery, a program of deformity correction is created using a web application. We take a radiograph every 2 weeks until the correction is completed. Additional correction reprogramming is necessary for a severe deformity, as in this case.

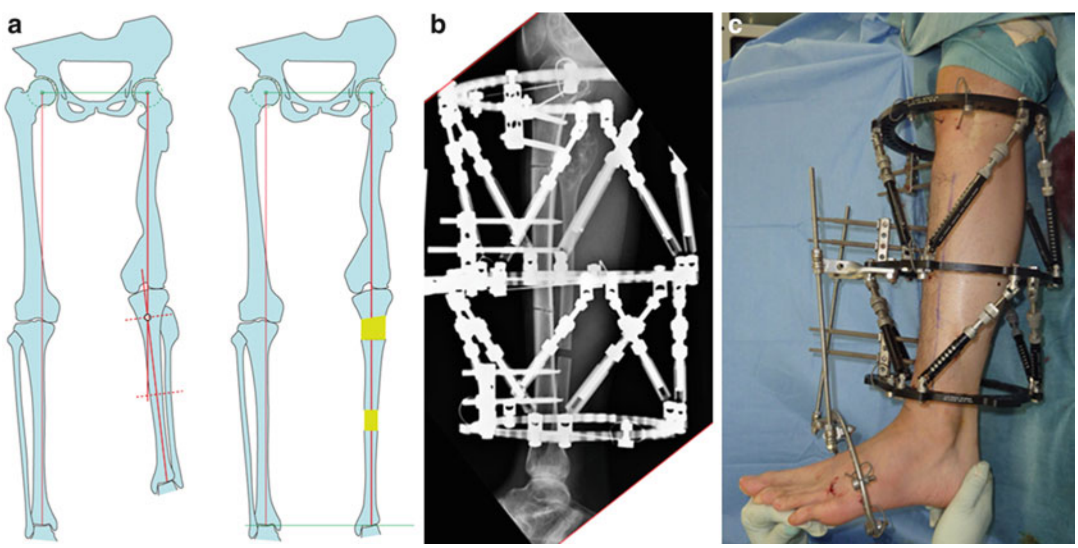

Fig. 7 (**a–c**) Tibial lengthening (50 mm). A natural hinge was added to prevent worsening of equinus contracture

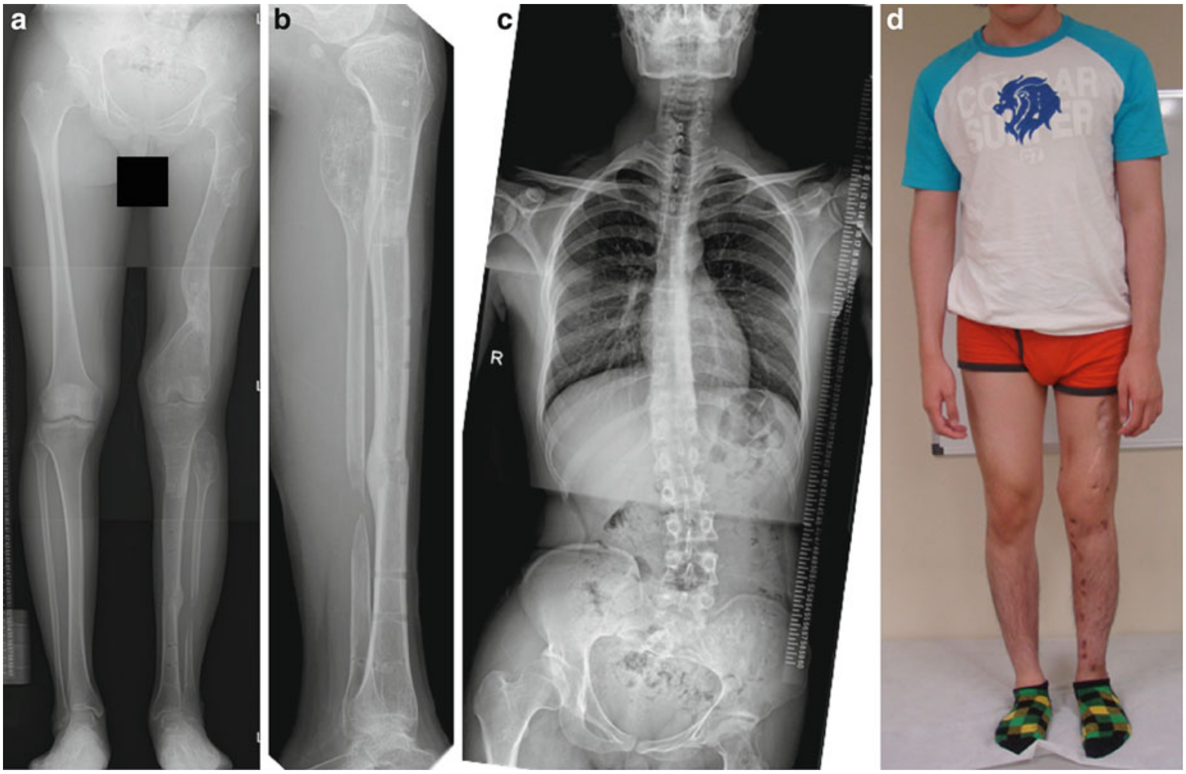

Fig. 8 (**a–d**) Radiographs after tibial lengthening (leg length discrepancy of 30 mm was left to adjust the rigid scoliosis)

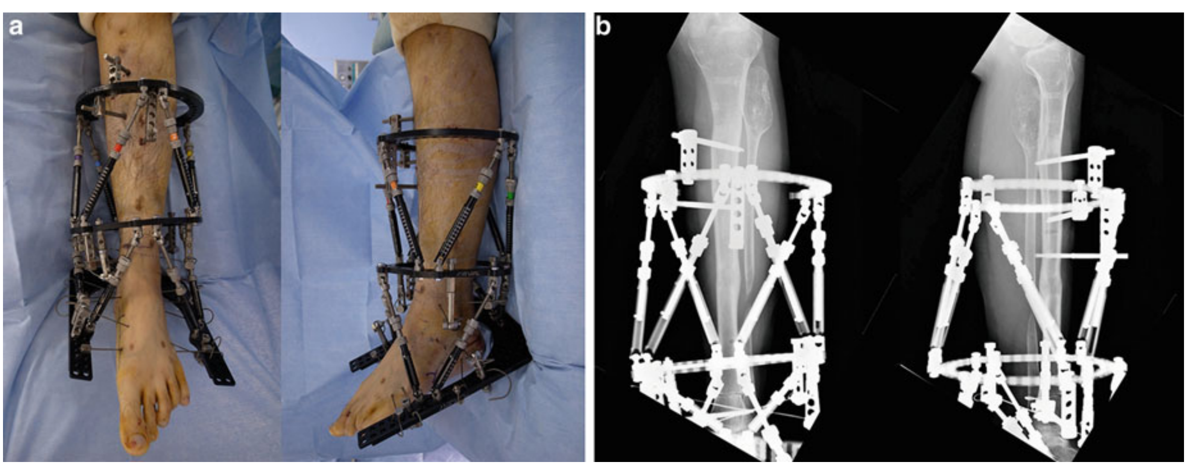

Fig. 9 (**a**, **b**) Correction of ankle deformity and mobilization (TSF)

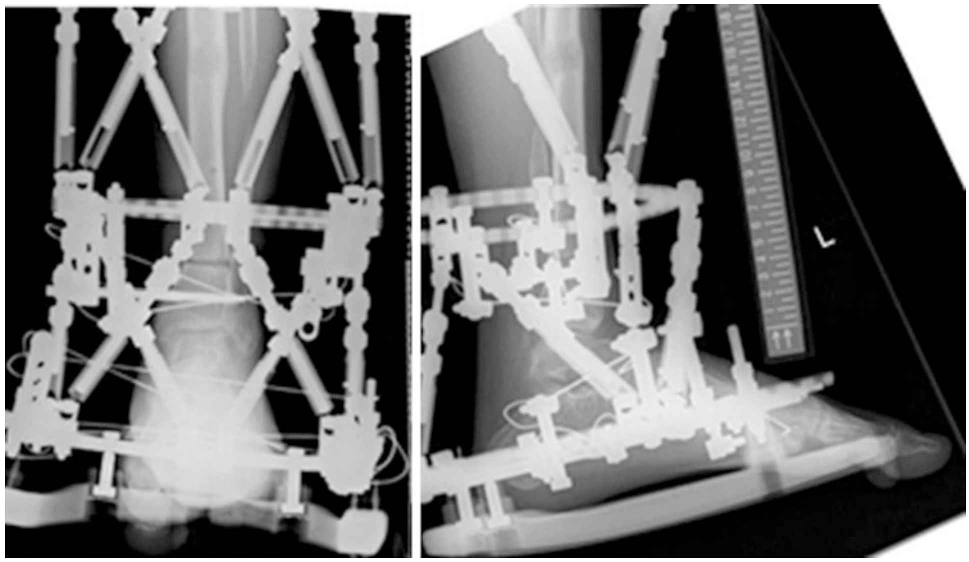

Fig. 10 Radiographs after correction

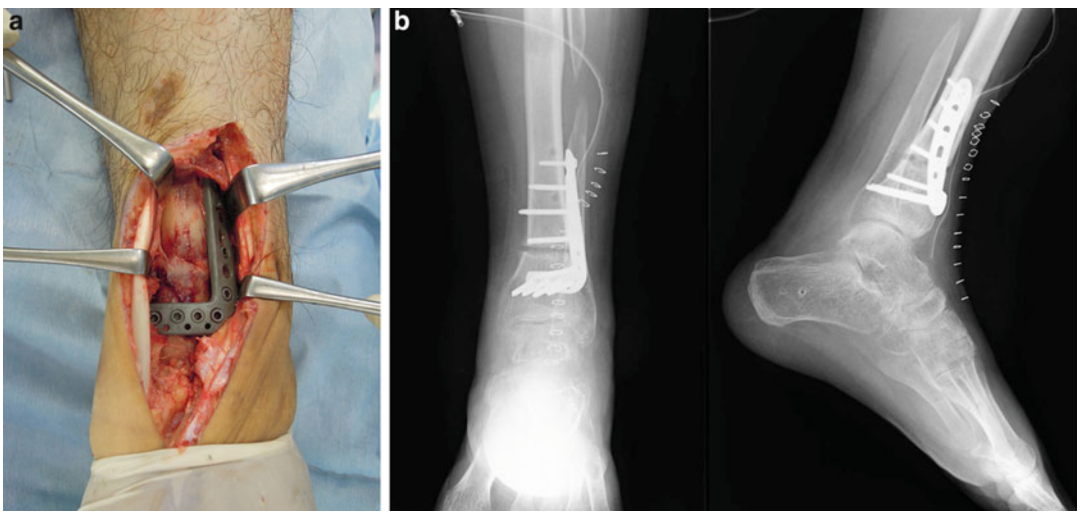

Fig. 11 (**a**, **b**) Conversion from TSF to plate

8 Outcome Clinical Photos and Radiographs

See Fig. 12

9 Avoiding and Managing Problems

Ollier's disease consists of multiple enchondromas that usually develop during childhood. Sometimes, the enchondromas affect an entire long bone. At times, we have to insert wires and pins into the tumor. However, the tumor site is not as strong as an unaffected bone. Therefore, the insertion of wires and pins during surgery must be avoided as much as possible.

10 Cross-References

▶ Tumor: An Introduction

11 See Also in Vol. 1

Case 24: Valgus Deformity of the Distal Femur and LLD Secondary to Posttraumatic Physeal Arrest: Femoral Lengthening with FITBONE Retrograde Intramedullary Nail

Fig. 12 Radiographs 3 months after operation

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Case 62: Correction of Long Bone Deformities due to Ollier's Disease with Ilizarov Method

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Abstract
Ollier's disease is a rare, nonhereditary condition characterized by the presence of multiple enchondromas, especially located at the metaphyseal regions of long bones. It is usually diagnosed by the appearance of multiple metaphyseal deformities and limb length discrepancy (LLD) at mid-childhood. In this case, we present the treatment of an adolescent with valgus deformities of the distal tibia and middle/distal femur, associated with an LLD. Patient was treated with multipl osteotomies, using a monoplanar fixator and a circular external fixator.

1 Brief Clinical History

An 11 year old girl was referred to our clinic with multiple metaphyseal bone lesions, LLD, and angular deformities. Following a percutaneous biopsy of the lesion, a diagnosis of enchondroma was made and radiologically the diagnosis of multiple enchondromatosis (Ollier's disease) was confirmed.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

(a) Valgus deformity of the middle/distal femur
(b) Supramalleolar valgus deformity of the tibia
(c) Short femur and short tibia (6 cm total)

S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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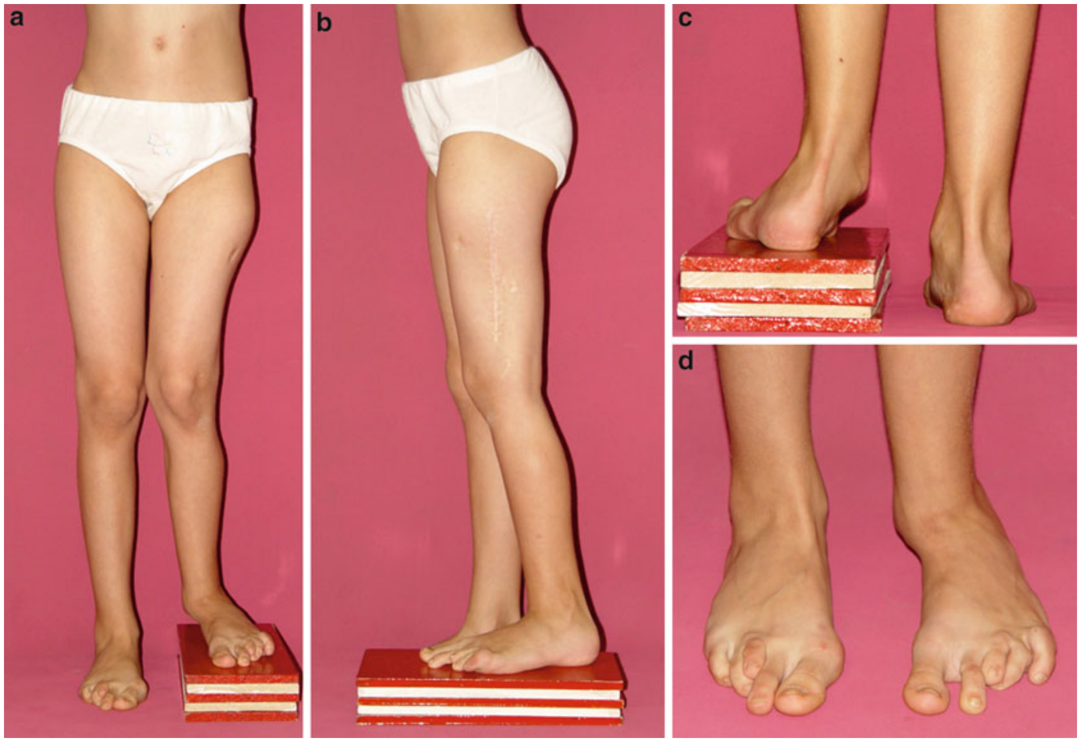

Fig. 1 Preoperative clinical photos of the patient: (**a**, **b**) anteroposterior (AP) and lateral long leg photos, (**c**) severe valgus deformity of the ankle, and (**d**) deformities due to foot involvement

4 Treatment Strategy

(a) Acute correction of the femoral deformity with unilateral external fixator
(b) Gradual femoral lengthening using the same osteotomy and fixator
(c) Proximal tibial osteotomy for lengthening
(d) Distal tibia osteotomy for gradual supramalleolar deformity correction

5 Basic Principles

(a) Simultaneous lengthening and deformity correction or simultaneous correction of the ipsilateral tibia and femur requires meticulous preoperative planning.
(b) Acute correction of a femoral deformity with monolateral fixator is tricky, as the direction of the half pins determines the correction and the new alignment of the bone. Great care is necessary while placing the initial half pins. They have to be perpendicular to the diaphyseal axis (anatomical axis) and angulated to the joint line.
(c) Once half pins are placed properly, placing the monolateral fixator corrects the deformity. Fixation has to be secured with additional transosseous elements. Two half pins on each segment were used for the presented case; however, at least three pins are recommended for each segment, for adequate stability.
(d) Circular external fixators have many advantages over monolateral fixators for tibial deformities and lengthening. But it is necessary to prepare the fixator prior to surgery to save valuable time. The external fixator is prepared so that it is capable of lengthening proximally, while correcting deformity with hinges distally.
(e) Proper preoperative planning, preparation of the fixator, and placing it properly are completely different steps. Errors in any of them will lead to residual deformities at the end.

Fig. 2 (**a**) AP orthoroentgenogram of the lower limbs. (**b**, **c**) Note the valgus deformity of both the femur and supramalleolar region of the tibia

(f) A latent period for lengthening is necessary, while it is possible to start gradual correction of the supramalleolar deformity as soon as possible.

6 Images During Treatment

See Figs. 3, 4, and 5.

7 Technical Pearls

For preoperative planning, it is suggested to take the contralateral limb as a reference for the operated side. However, systemic, congenital, and some developmental diseases affect both limbs and therefore render this technique unreliable. In this case, although contralateral proximal femur is also affected, it is possible to take it as reference.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

(a) Ipsilateral tibial, and femoral lengthening commonly lead to knee stiffness. Also joint stiffness is encountered more often while correcting congenital deformities or lengthening of these patients. Although it is mostly temporary and resolves following fixator removal, physical therapy has to be initiated as soon as possible, and both knee and ankle ranges of motion have to be monitored closely.

(b) Deformity correction during childhood requires long-term follow-up as most of the patients develop

Fig. 3 One week after initiating the femoral lengthening. (**a**) There is a slight translation on the AP view. It was necessary as the osteotomy is just below the CORA, which is preferred to avoid the lesion. (**b**) There is also a minor translation on the lateral view, which is related to improper placement of the half pins

further LLD or deformities which require further lengthening or correction.

(c) Ollier's disease is characterized with malignant transformation of enchondroma lesions to chondrosarcoma, therefore requiring long-term follow-up. Twenty-five percent of the patients develop malignant tumors in a lifetime.

(d) Quality of the newly formed regenerate is controversial, as reported in various studies: "same quality as a healthy bone," "pathologic," and "50–50 % healthy – pathologic." Results of lengthening through the lesion are not clear, regarding the regenerate quality. Therefore, it is wiser to perform the osteotomy below or above the lesion, if possible.

(e) Choice of fixator for femoral lengthening has been discussed in various studies. In our previous published study, unilateral and circular fixators were compared. Unilateral fixators have advantages over circular external fixators with less pin tract problems, joint stiffness, and patient discomfort. The main concerns with unilateral fixator are less control on bone segments and ability to perform only one plane motion. Direction of Schanz screws is the most important independent factor. Understanding of the normal anatomy and pathoanatomy, preoperative planning, and preoperative care is vital.

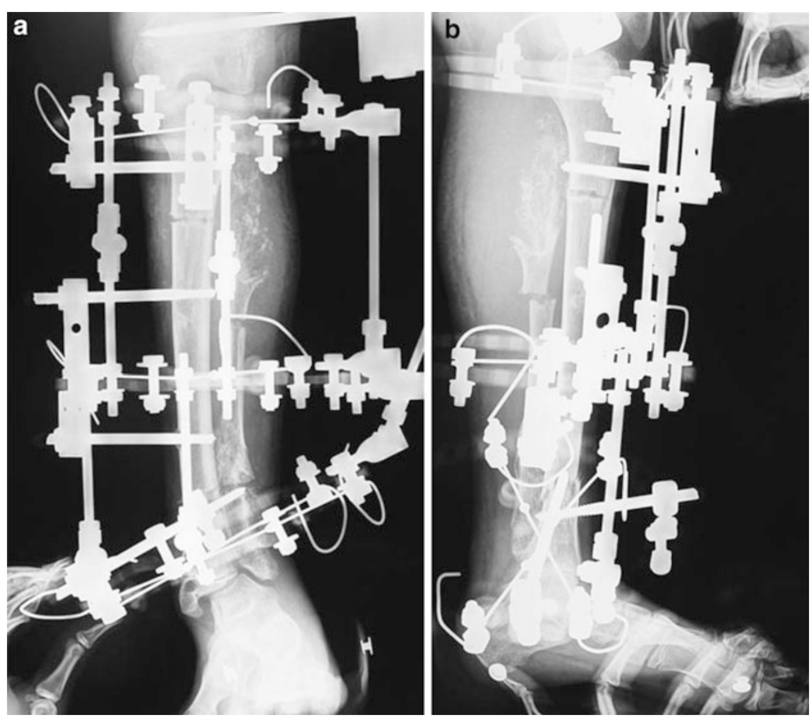

Fig. 4 (**a**) AP and (**b**) lateral views of the tibia. Proximal osteotomy was planned for lengthening, while distal osteotomy for deformity correction. Note that the distal ring is parallel to the ankle joint, and the mid ring is parallel to the proximal one. Once the deformity is corrected, both rings should be parallel

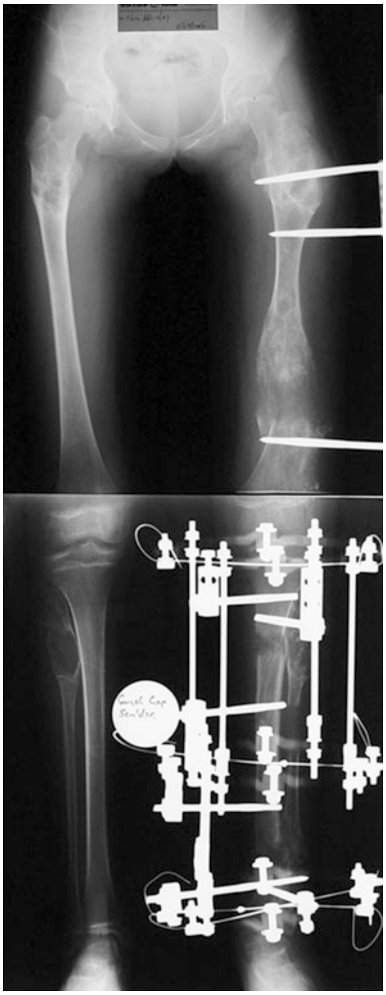

Fig. 5 Orthoroentgenogram at the end of the lengthening, during consolidation. There is no LLD, and mechanical axis of the lower limb is passing through the middle of the knee. Please note that at the distal tibial osteotomy, the hinges were intentionally placed more medially than the bone, in order to allow for some lengthening besides the correction of the deformity

Fig. 6 (**a**) Orthoroentgenogram and (**b**) standing clinical photo of the patient 2 months after fixator removal

10 See Also in Vol. 1

Case 89: Genu valgum and limb length discrepancy in multiple enchondromatosis

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Case 63: Femoral Neck Aneurysmal Bone Cyst Treated with Articulated Distraction and Grafting

Levent Eralp and Ilker Eren

Contents

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Abstract

The proximal femur and acetabulum are frequent sites for benign, active, and aggressive lesions. The risk of pathologic fracture is increased when a bone-destroying pathology involves an anatomic location such as the hip joint that undergoes profound mechanical loading. If the destruction involves a large area around the joint, secure fixation cannot be achieved with internal fixation implants. In this case, a patient with aneurysmal bone cyst in the femoral neck, who was treated with articulated hip distraction, is presented. Curretted area was protected with a external fixator, until the bone union is achieved.

1 Brief Clinical History

A 21 year old male patient with hip and groin pain was referred to our department. It was 6 months since his first complaints started and was recalcitrant to medical consultation. There was no history of trauma. Full range of motion (ROM) with minimal pain was observed. Following the initial clinical evaluation and radiographic examination, the patient was diagnosed of having an aneurysmal bone cyst of the femoral neck.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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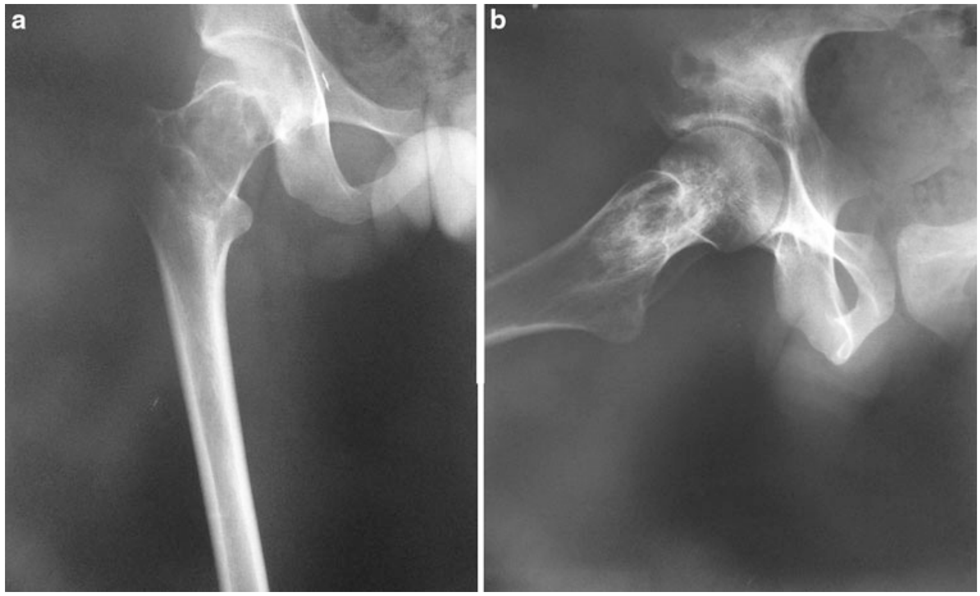

Fig. 1 Preoperative anteroposterior and lateral X-rays of the patient. Lesion extends from the intertrochanteric region to the femoral head. Thin femoral neck cortices and loss of trabecular pattern point toward an impending fracture

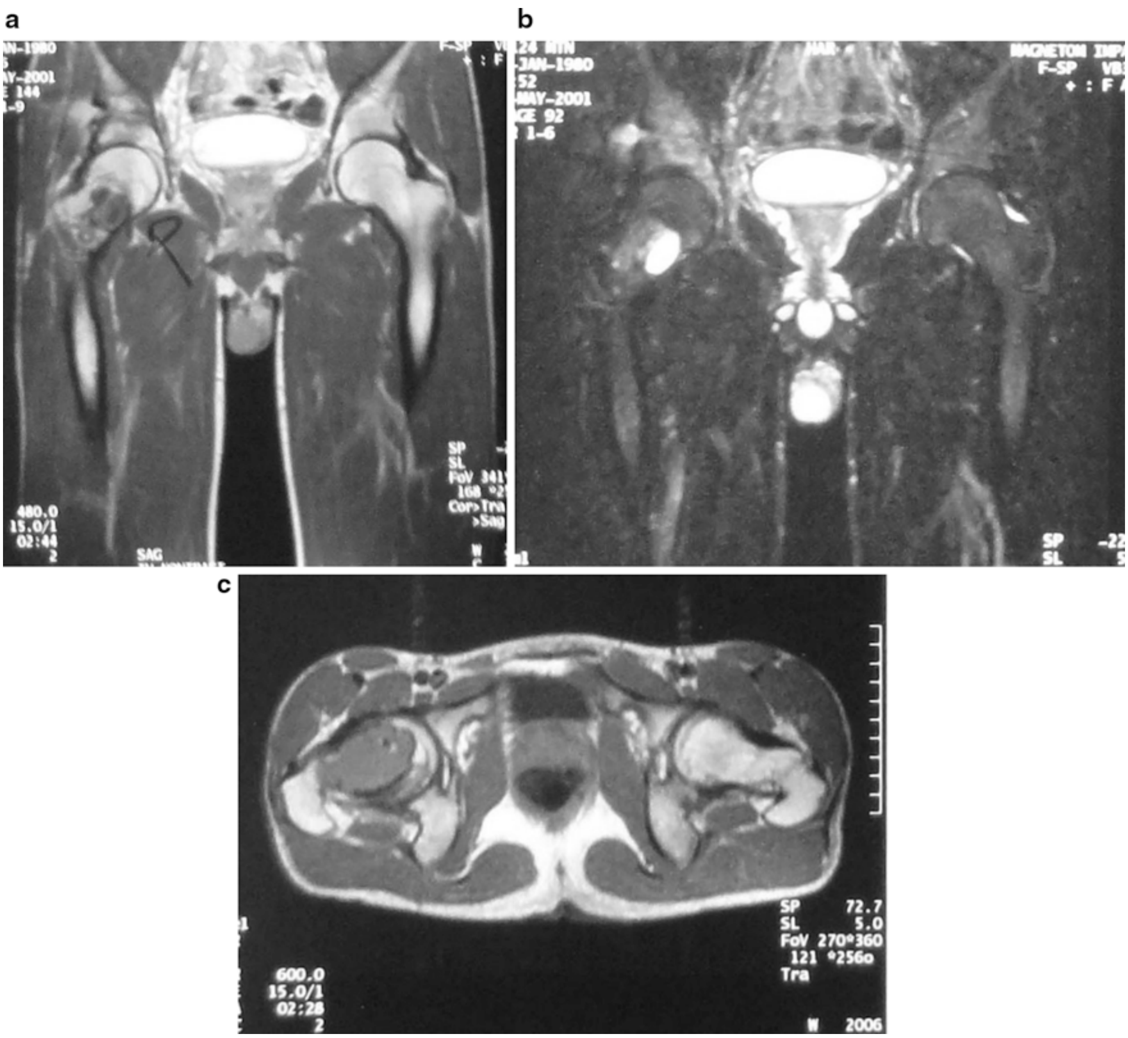

Fig. 2 Magnetic resonance imaging of the femoral neck preoperatively

Fig. 3 Prepared monolateral hinged external fixator. The center of the hinge has to be aligned with the hip center of rotation. Just distally to the hinge, the fixator is able to perform distraction

Fig. 4 Eight weeks postoperatively. There is no major resorption

3 Preoperative Problem List

(a) Aneurysmal bone cyst located at the femoral neck.
(b) Impending fracture, surgery cannot be delayed.
(c) Fewer fixation options due to anatomical location.
(d) Young patient, cannot sacrifice the femoral head.
(e) The solution for a periarticular problem has to be stable enough for early mobilization.

4 Treatment Strategy

(a) Curettage and phenolization of the lesion
(b) Cancellous allografting
(c) Articulated monolateral fixator for fixation

5 Basic Principles

(a) Ask before planning: How to reconstruct a periarticular lesion with inadequate bone stock, so that the joint can be kept mobile postoperatively?
(b) Fixation and curettage of the lesion are two different steps of the procedure, and it is necessary to decide before surgery which should come first. If curettage and fixation are performed from different approaches (like lesion located at the medial femoral condyle with lateral fixation), there's no arguing: fixation first. Based on the location and the extent of the lesion, if we don't expect an intraoperative fracture, curettage can be performed before fixation. However, a surgeon should be able to identify anatomic locations and lesion characteristics which may lead to an intraoperative fracture and apply external fixation firstly.
(c) Curettage of the femoral neck is the preferred treatment method for the lesion. We prefer using high-speed burr and phenolization. For the presented case, cancellous allograft was used to fill the bone defect. Both autogenous grafts and allografts can be used. Autogenous option should always be the first choice; however, it may not be possible for extensive bone defects, or the patient may prefer allografting for donor site morbidity.
(d) Curettage leaves an empty femoral neck without trabecular support and with thin cortices and eventually requires fixation.
(e) Extramedullary internal fixation is not possible for this region. Therefore, intramedullary fixation or external fixation has to be considered. Internal fixation is not viable as there's not enough bone stock in the femoral head.

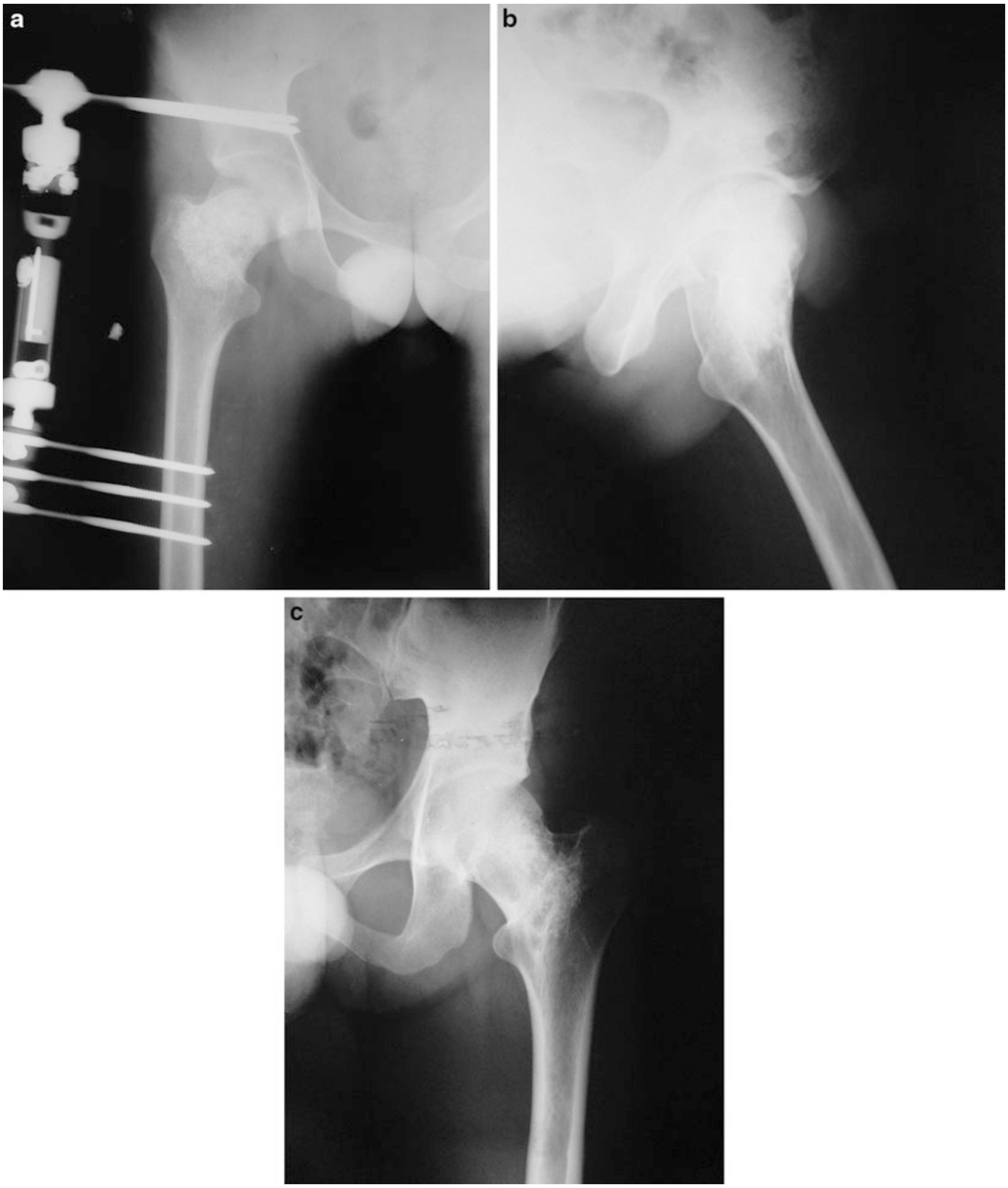

Fig. 5 X-ray of the patient following fixator removal (19 weeks). Although there are minor resorption areas, structural support is established

(f) To achieve early mobilization with secure fixation, articulated monolateral external fixator was preferred. With an articulated fixator, we simulate flexion-extension motion of the hip joint. This is only possible with an accurately placed hinge. To achieve this, a Kirschner wire is inserted under the guidance of an image intensifier. Then, the hinge of the monolateral fixator is aligned with this wire.

(g) Distraction is applied gradually, starting immediately after the surgery, 0.25 mm daily. Once the Shenton's line is broken, we secure the distraction and wait for 3 weeks before flexion-extension is set free.

(h) The external fixator is removed once there's adequate union (19 weeks for this case).

6 Images During Treatment

See Figs. 4 and 5.

7 Technical Pearls

(a) Adequate curettage of the lesion is important; however, extensive curettage may lead to a femoral neck fracture and would render this technique inapplicable.
(b) Even if the articulated fixator preserves major hip ROM, it is not possible to fully mimic hip joint movements. So, it is expected to have a mild ROM loss at the early period. Therefore, physical therapy is required, as soon as possible after fixator removal. Patients usually gain preoperative ROM in 1 month (Fig. 5).
(c) To remove the external fixator safely, remove the fixator, leaving half-pins in place, and let the patient weight-bear. Pain with weight-bearing may point to delayed union.

Fig. 6 First month following fixator removal. The patient gained most of the preoperative ROM

8 Outcome Clinical Photos and Radiographs

See Figs. 6 and 7.

9 Avoiding and Managing Problems

(a) Thin cortices without trabecular support leave the femoral neck extremely fragile. Careful curettage is important. If femoral neck fracture occurs, further fixation will be necessary.
(b) Greatly limited ROM or joint subluxation points to an incorrect hinge placement. Consider reapplication or making the fixator "non-articulated."

10 See Also in Vol. 1

Case 106: Perthes Hip Treated with Articulated Hip Distraction and Small Diameter Core Decompression

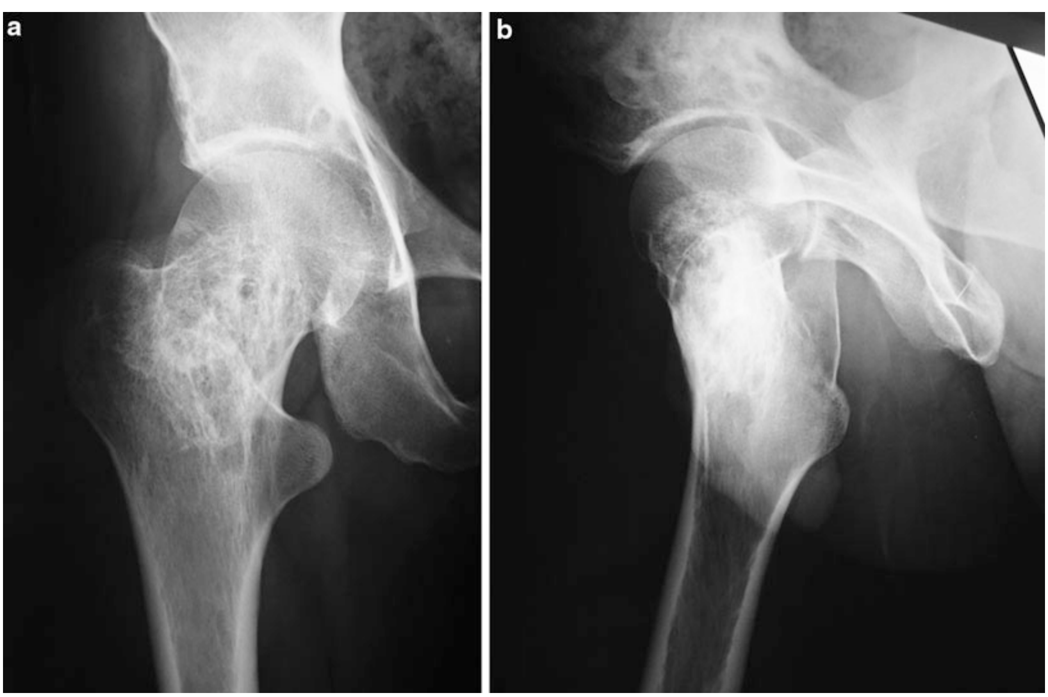

Fig. 7 Ten years postoperatively. Note that grafts incorporated and trabecular pattern formed

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Part XII

Tumor: Reconstruction Following Resection of Malignant Bone Tumor

Case 64: Repair and Lengthening After Nonunion of Free Vascularized Fibula Graft for Reconstruction of Osteosarcoma of the Tibia

S. Robert Rozbruch

Contents

Abstract

A free vascularized fibula reconstruction after resection of osteosarcoma in a child failed with deformity and nonunion. This case illustrates a successful reconstruction of the free vascularized fibula-proximal tibia nonunion. Additional treatment issues included correction of ankle deformity using guided growth and lengthening of the femur with a monolateral frame to correct leg length discrepancy (LLD).

1 Brief Clinical History

At age 10, Adam was diagnosed with osteosarcoma of the right proximal tibia. He underwent resection with knee joint preservation and reconstruction with a contralateral free fibula graft. Connection to the proximal tibia was through a napkin ring allograft. A patella tendon infection developed and further treatment included muscle flap and skin graft coverage. At age 12, he presented to me with nonunion between the free fibula and the proximal tibia, deformity (14° varus, 15° procurvatum), difficulty walking, LLD 1.6 cm (projected additional LLD 3.8 cm from dysfunction of the proximal tibial growth plate), and contralateral ankle valgus (donor site problem from free fibula graft).

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, and 6.

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Fig. 1 *Front view* with brace needed for walking

3 Preoperative Problem List

1. Nonunion at free fibula and proximal tibial junction. There is napkin ring piece of allograft that was placed just below the native proximal tibia, and the free fibula had been inserted into this allograft.
2. Compromised soft tissue envelope (flap and skin graft).
3. Oblique plane deformity (14° varus, 15° procurvatum).
4. LLD 1.6 cm.
5. Projected additional LLD of 3.8 cm (due to proximal tibial growth plate damage).
6. Contralateral tibia valgus deformity related to free fibula donor site.

4 Treatment Strategy

1. Repair of nonunion and correction of deformity with Taylor Spatial Frame (TSF) (Memphis, TN, USA). Minimal incision technique for repair of nonunion, gradual compression, and deformity correction.
2. Right proximal fibula epiphysiodesis to prevent fibula overgrowth.

Fig. 2 (**a**) *Front view* showing varus deformity and flap (**b**). *Side view* showing flexion deformity of knee

Fig. 3 *Back view* with 17 mm lift

Fig. 5 Lateral view of lower extremity. Note flexion deformity (PPTA = 65°)

Fig. 4 Erect leg X-ray showing LLD, nonunion at free fibula and proximal tibial junction, and varus deformity

Fig. 6 AP X-ray of ankle showing valgus deformity (LDTA = 78°)

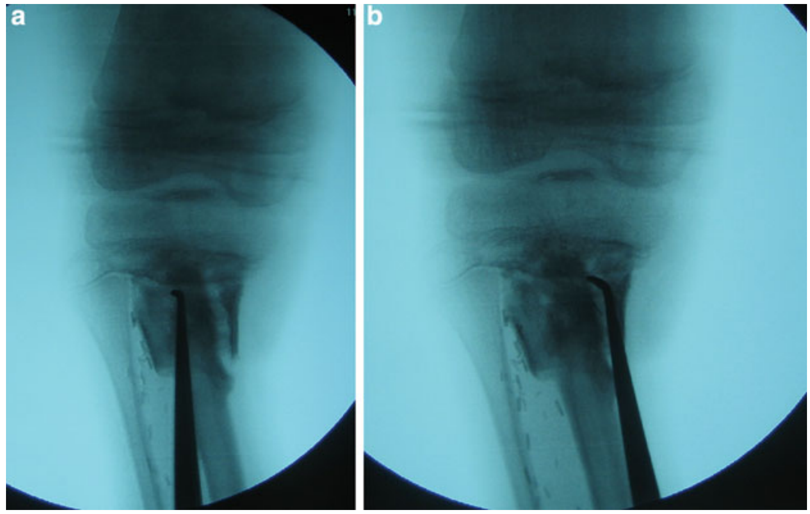

Fig. 7 (**a**, **b**) Intraoperative X-ray images showing minimal incision approach to nonunion

3. Guided growth to correct left tibia and ankle deformity (6 months later).
4. Lengthen right femur to equalize LLD at age 15.

5 Basic Principles

1. Deformity correction needed for nonunion repair.
2. Repair nonunion with minimal incision technique because of compromised soft tissue. Compress nonunion after deformity correction and nonunion repair.
3. Multiple wires in small periarticular fragment needed. Multi-planar with wide crossing angles.
4. Close right proximal fibula growth plate to avoid fibula overgrowth.
5. Guided growth is good strategy for correcting contralateral deformity which occurred as a result of the free fibula harvesting.
6. Correct final LLD with femur lengthening to avoid more surgery on tibia. Accept small knee height difference.

6 Images During Treatment

See Figs. 7, 8, 9, 10, 11, and 12.

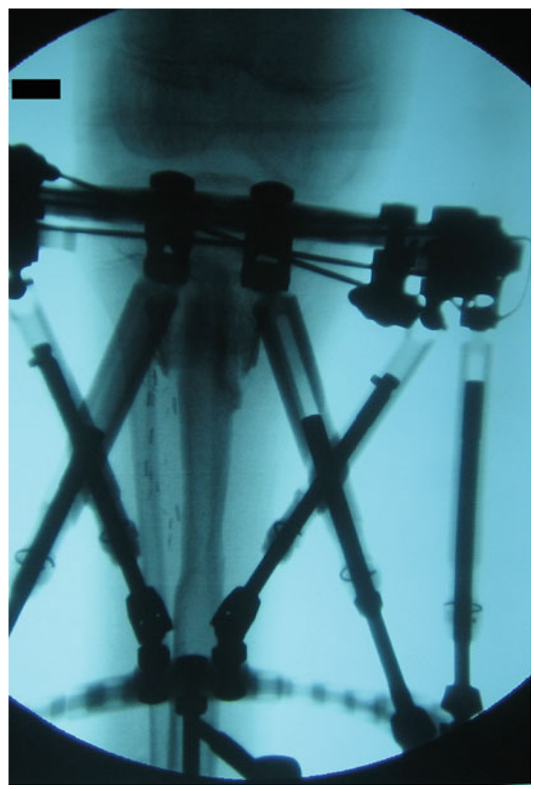

Fig. 8 Intraoperative image after correction of deformity and compression with TSF. Note multiple wires in proximal tibia

7 Technical Pearls

1. Minimal incision approach to nonunion allowed avoidance of flap elevation. With intraoperative X-ray, I stimulated the nonunion with curette (Fig. 7) and then inserted demineralized bone matrix graft via a cannula.
2. The TSF enabled deformity correction acutely with fine tuning and compression gradually. Excellent stability was obtained with the circular frame.

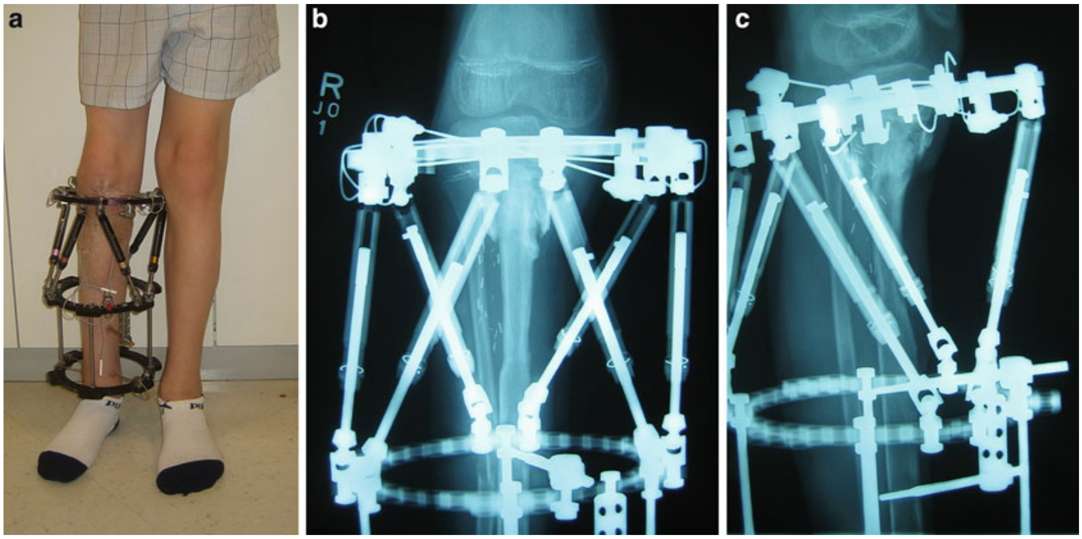

Fig. 9 (**a**) Clinical photo in the TSF 1 month after surgery. (**b**) AP and (**c**) lateral X-ray showing deformity correction in the frame. There are four multi-planar wires in the proximal tibia

Fig. 10 Intraoperative X-ray after insertion of plate across medial distal tibial growth plate using guided growth to correct the valgus deformity

Fig. 11 As predicted he developed 3.5 cm LLD by age 15

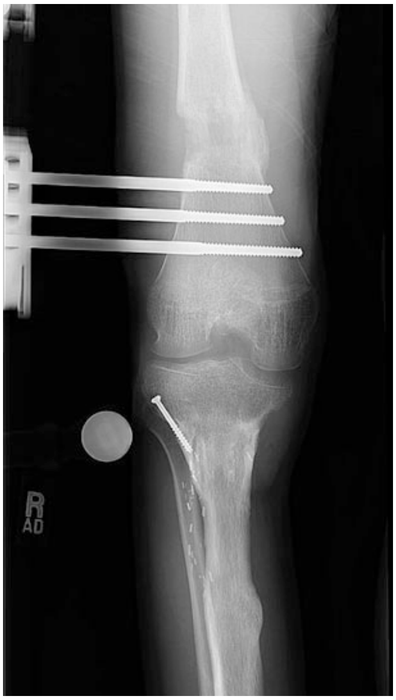

Fig. 12 After 4 cm lengthening of femur at age 16. Monolateral frame was used. (Today I would use an internal lengthening nail but it was not available to us at that time). Note proximal fibula epiphysiodesis and well-healed and remodeled proximal tibia nonunion. Note hypertrophy of free fibula graft

8 Outcome Clinical Photos and Radiographs

See Figs. 13 and 14.

9 Avoiding and Managing Problems

1. The left leg deformity occurred from harvest of the free fibula. Stabilization of the distal tibia to the fibula at the time of harvest may have prevented this.
2. Avoid infection and flap problems by using minimal incision approach without flap elevation to repair nonunion.
3. Avoid additional surgery of complicated right tibia by performing lengthening of the femur. Lengthening could also have been done in the tibia but parents preferred femur.

Fig. 13 (**a**, **b**) Patient at age 17, AP lateral X-rays showing healed, remodeled, and hypertrophied free fibula without deformity

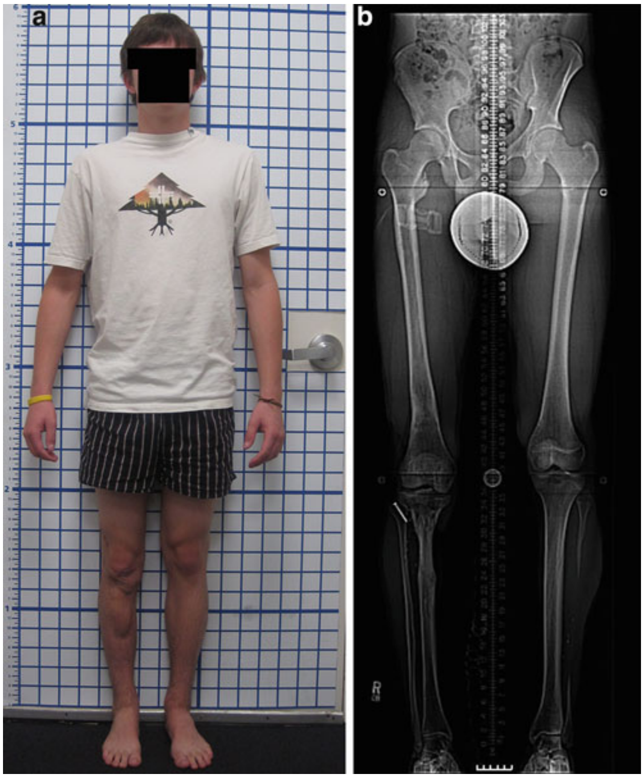

Fig. 14 (**a**, **b**) Patient at age 17, *front view* and erect leg X-ray showing equal leg lengths and corrected deformity of both legs

10 Cross-References

▶ Case 67: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proximal Humerus Using Vascularized Fibular Grafting
▶ Case 77: Reconstruction of Failed Allograft Reconstruction with Combined Technique (Low-Grade Osteosarcoma)

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Case 65: Distraction Epiphysiolysis Prior to Resection of a Malignant Bone Tumor (Osteosarcoma)

Levent Eralp and Ilker Eren

Contents

Abstract

Bone tumors around the knee joint are successfully treated with prosthetic replacement. However, resecting the tumor with the physis leads to limb length discrepancy. Epiphyseal distraction prior to resection creates a safe bone bridge between the physeal area and the tumor, thus rendering intercalary resections possible. We present a case with distal femoral osteosarcoma. Initially, it was not possible to preserve knee joint due to the close proximity of the tumor. Therefore, we performed an epiphyseal distraction to gain a safe bone bridge and performed resection in combination with biologic reconstruction.

1 Brief Clinical History

A 7 year old male complaining of a progressing distal thigh mass who was referred to our clinic. It was 5 months since his family first noticed the mass. Following initial radiological assessment, Tru-Cut biopsy was performed. Osteosarcoma was diagnosed after histopathologic evaluation. Three cycles of preoperative chemotherapy were indicated.

2 Preoperative Clinical Pictures and Radiographs

See Figs. 1, 2, and 3.

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Fig. 1 (**a**, **b**) Post-chemotherapy preoperative radiographs of the patient

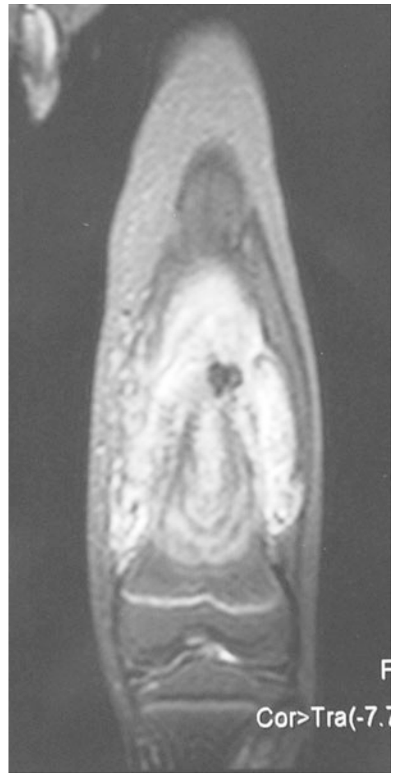

Fig. 2 Preoperative coronal magnetic resonance image of the patient. Note that there is no epiphyseal involvement and there is an intact bone bridge in between

3 Preoperative Problem List

(a) Osteosarcoma of the distal femur.
(b) No involvement of physeal zone or epiphysis; however, lesion is in close proximity which prevents safe osteotomy above physeal cartilage.
(c) Young patient, high expectation of longitudinal growth. Biologic methods have to be preferred, preserving physeal cartilage (and hyaline cartilage) if possible. Any nonbiologic approach will not be sufficient and will require multiple revisions.
(d) Further lengthening surgeries may be required.

4 Treatment Strategy

(a) Resection of bone tumor with proximal safe zone and from the area of epiphysiolysis distally.
(b) Cryopreservation of the bone and removal of the soft tissues and tumor mass.
(c) Harvesting fibula with its vascular supply.
(d) Fixation of both fibula and autologous bone.
(e) Fixation will be preserved with the external fixator, which was also used for the epiphysiolysis.

5 Basic Principles

(a) Soft tissue dissection and proximal osteotomy will be performed in a standard manner. However, even a low-energy osteotomy with osteotome or drill would damage physeal cartilage. Therefore, distal osteotomy is performed sharply with scalpel at the area of epiphysiolysis to preserve physeal cartilage as much as possible.
(b) At least one fibula has to be suitable to be harvested with vascular supply. A vascular surgeon is necessary to prepare and perform anastomosis.
(c) The fibula will not be sufficient to bridge the bone defect. Therefore, cryopreserved bone has to be used. Consider proper fixation for both fibula and autologous bone. As there is a minimal bone stock distally, an internal fixation method itself will not be enough. Therefore, circular external fixator will be used to support fixation.

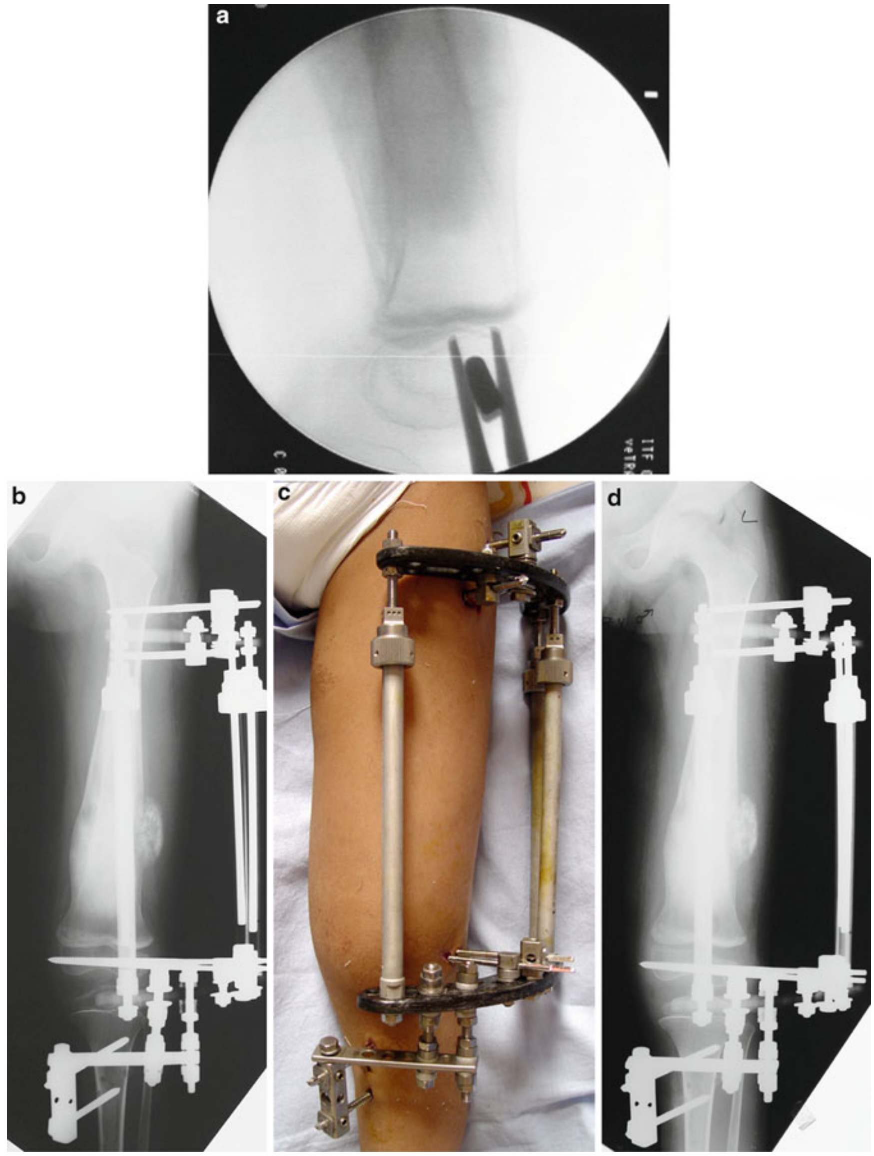

Fig. 3 (**a**–**c**) Application of the frame. Two distal half-pins were utilized in the epiphyseal bone, away from physis. Distraction started immediately after surgery, 1 mm each day (4 × 0.25). Epiphysiolysis was noticed radiographically on the 12th day (**c**)

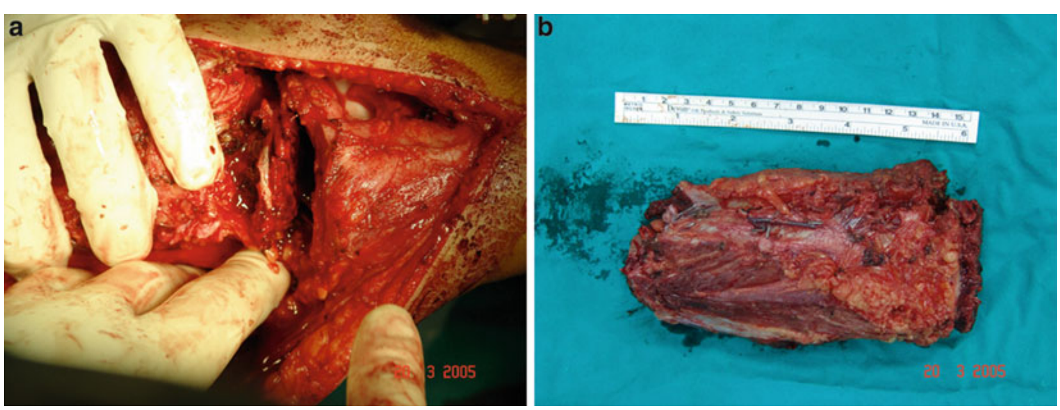

Fig. 4 Tumor was removed sharply from the distal epiphysiolysis area with scalpel (**a**). Soft tissues were removed; remaining bone was cryopreserved before implanting (**b**)

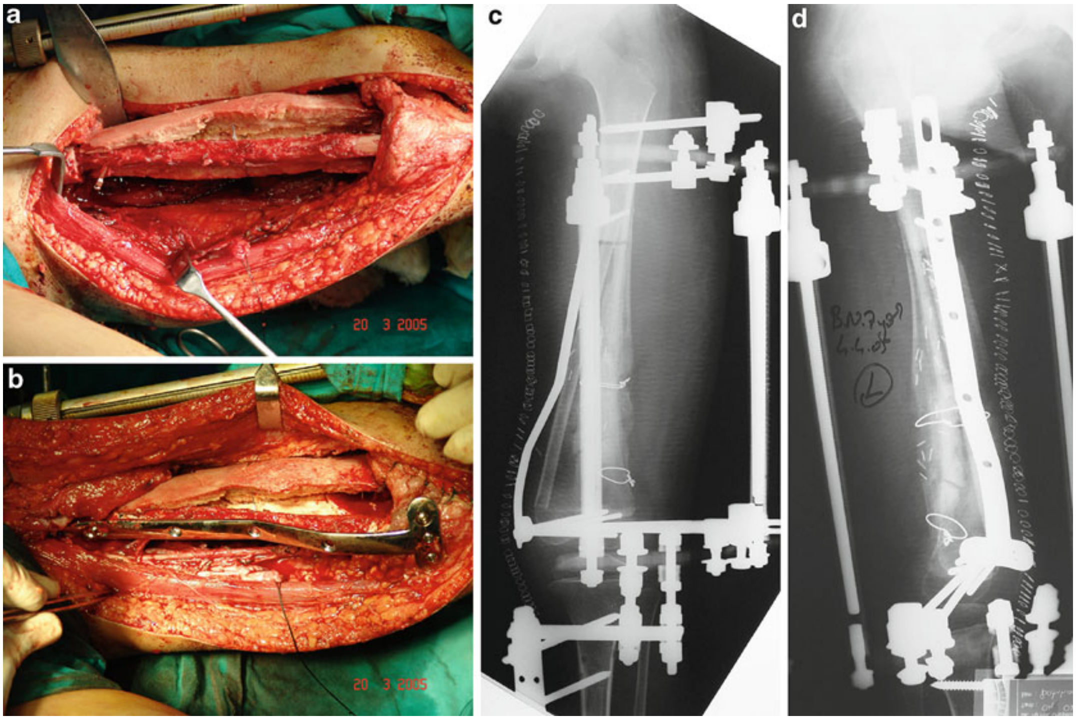

Fig. 5 Medial part of the autologous bone was removed, so that fibula would fit its medullary canal (**a**). Fibula was angled to create a distal medial femoral column (**c**). Proximal part was seated in the medulla. Please also note the distal vascular anastomosis of the fibula. An angled T plate was used as internal fixator (**b**–**d**)

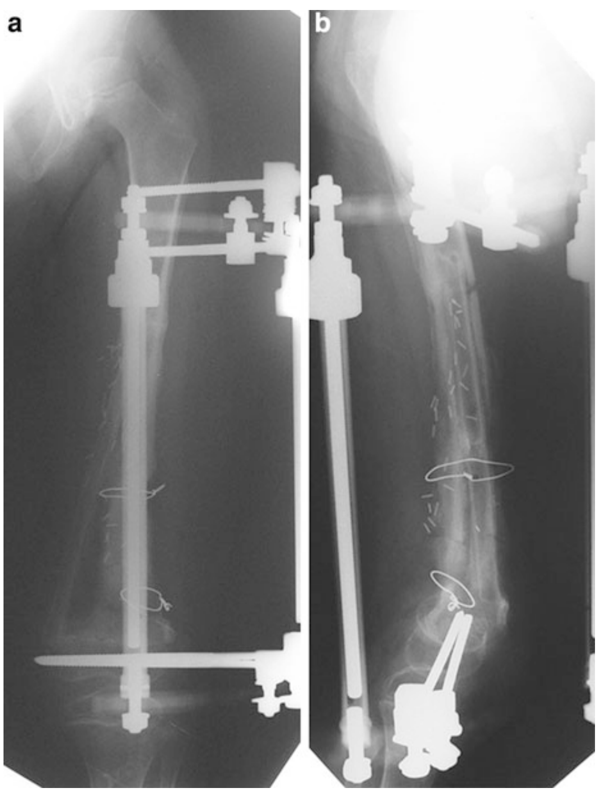

Fig. 6 In the early follow-up, plate was exposed due to soft tissue problems. It was removed on the 3rd month, but circular external fixator was left in place (**a**, **b**)

Fig. 7 External fixator was removed on the 5th month postoperatively. Orthosis was used to preserve union. However, following weight bearing, fracture occurred proximally (**a**, **b**)

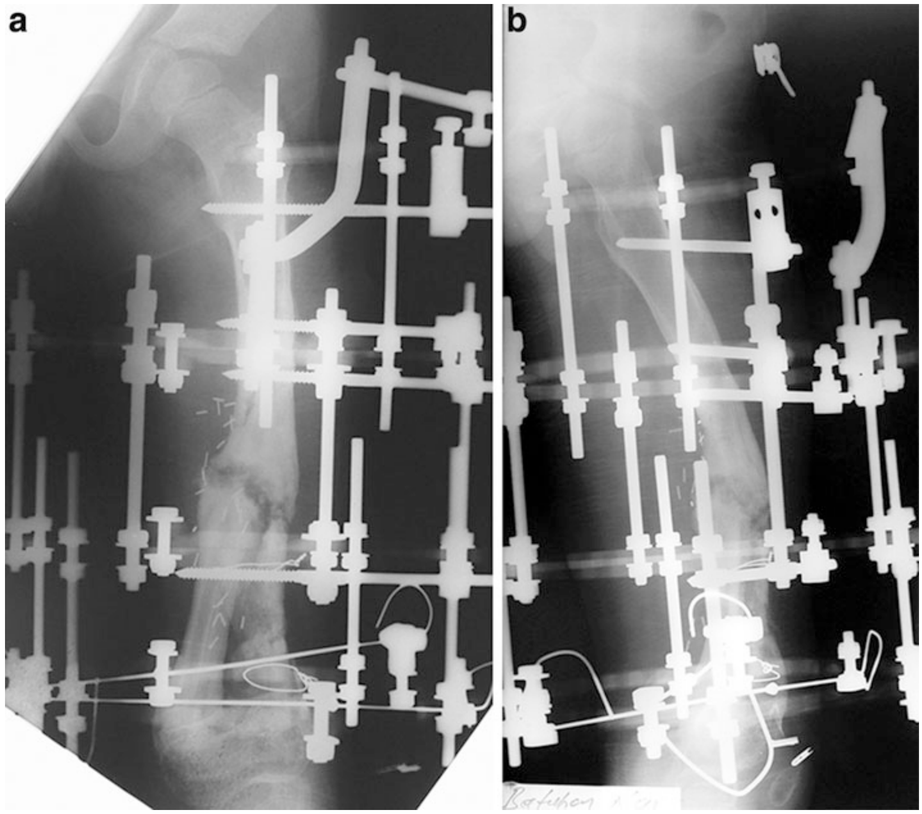

Fig. 8 A circular external fixator was used to achieve union (**a**, **b**)

Fig. 9 Solid union achieved and fixator was removed on the 5th month. Please note the expansion of the fibula. Lateral autologous cryopreserved bone was mostly removed with creeping substitution

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

(a) This technique is only applicable for patients with metaphyseal involvement and open physis. Radiological methods (MRI, CT, etc.) have to be used to demonstrate that the physeal cartilage is not penetrated.
(b) Distraction is initiated immediately after the first stage, 1–2 mm daily. At least 2 cm of lengthening is suggested.
(c) It is possible to carry out the first stage during preoperative chemotherapy; however, immunosuppression may lead to devastating complications.
(d) The epiphyseal area usually has not enough bone stock to be used for distal fixation alone. Consider spanning adjacent joint.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, and 9.

9 Avoiding and Managing Problems

(a) Meticulous placement of the half-pins or Kirschner wires is important, to avoid penetrating and damaging physeal cartilage. Also care is needed to avoid the tumor and leave enough bone in between.

(b) Following initiation of distraction, monitor epiphysiolysis carefully to avoid unnecessary distraction.

(c) As it is mentioned in Fig. 7, bone-graft union problems are encountered commonly. We achieved a partial but insufficient union at the proximal bone-graft interface which ended up with a fracture following fixator removal. Therefore, a second circular external fixator was applied to achieve union without deformity.

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Case 66: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Diaphyseal Tibia Using Circular External Fixator with Trifocal Bone Transport (Distraction Osteogenesis)

Levent Eralp and Ilker Eren

Contents

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Abstract

Adamantinomas are rare bone tumors of unknown origin. They have low potential for metastasis and treatment consists of marginal resection. As they are usually located in the diaphyseal region of the tibia, resection leads to a bone defect. In this case we present a patient with adamantinoma located in the mid-diaphyseal region of the tibia. Following resection, the defect was reconstructed with bifocal transport using Ilizarov ring fixator. At the end of the trasportation of the segment, bone grafting and plate osteosynthesis was performed due to non union of the bone ends.

1 Brief Clinical History

A 14 year old male presented to our clinic complaining of lower leg pain following a sports-related trauma. Radiographs revealed an eccentrically located diaphyseal lesion in his left tibia. A needle biopsy was performed which confirmed the diagnosis of adamantinoma.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

a. Adamantinoma of the tibia
b. No distant metastasis
c. Expected bone defect following resection exceeding 15 cm

S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_240

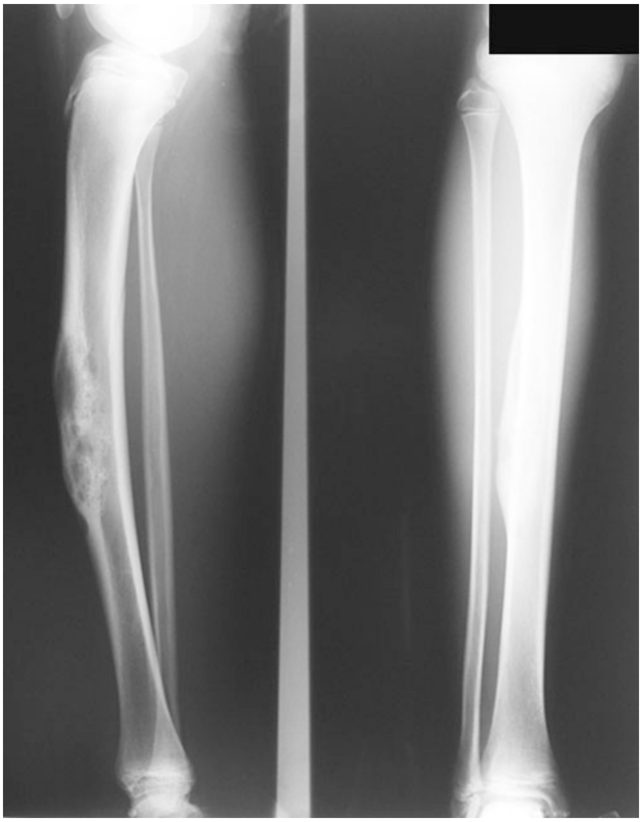

Fig. 1 AP and Lat radiographs of the tibia showing diaphyseal lesion located eccentrically

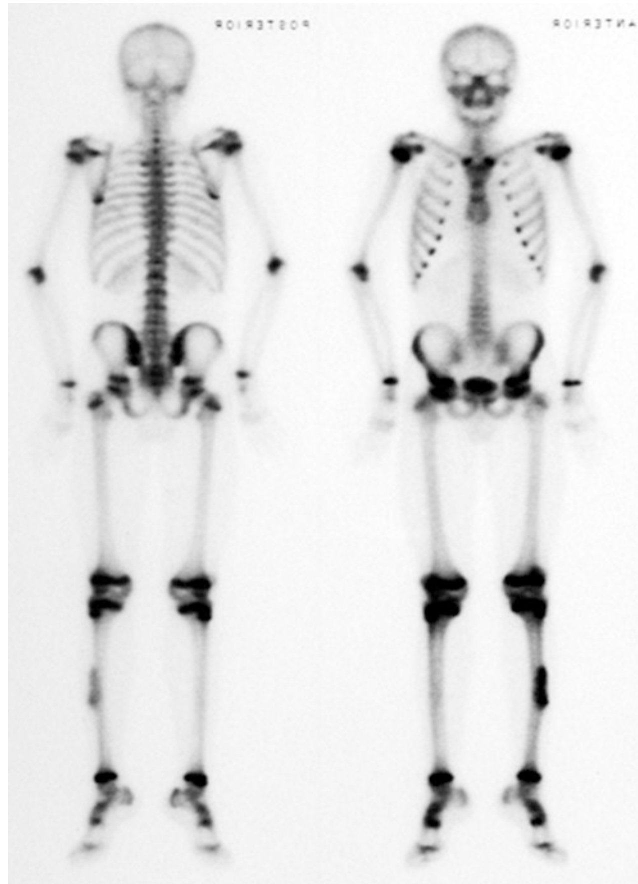

Fig. 2 Tc-99 bone scan demonstrated an isolated diaphyseal lesion

4 Treatment Strategy

a. Resection with at least 1 cm of safe zone, including soft tissues
b. Bifocal bone transport for the defect using traditional Ilizarov circular external fixator (CEF), with proximal and distal metaphyseal osteotomies

5 Basic Principles

a. Adequate tumor excision based on preoperative planning
b. Mounting preoperatively prepared CEF
c. Gradual bone transport (0.5–1.0 mm/day)
d. Removal of CEF after bone union at the docking sites

6 Images During Treatment

See Figs. 4, 5, and 6.

7 Technical Pearls

a. Precise mounting of the frame is necessary to achieve full bone contact at the end of the treatment. Minor deviations from the axis at the beginning of the transport will lead to major problems at the end.
b. As limb lengthening or shortening was not necessary, no fibular osteotomy was performed.
c. Bifocal segment transport requires meticulous neurovascular monitoring to avoid complications.

8 Outcome Clinical Photos and Radiographs

See Figs. 7, 8, 9, and 10.

Fig. 3 Preoperative MRI (**a** and **b**)

Fig. 4 Preoperative planning for the resection. Resection and frame positions are noted. AP (**a**) and Lat (**b**) radiographs

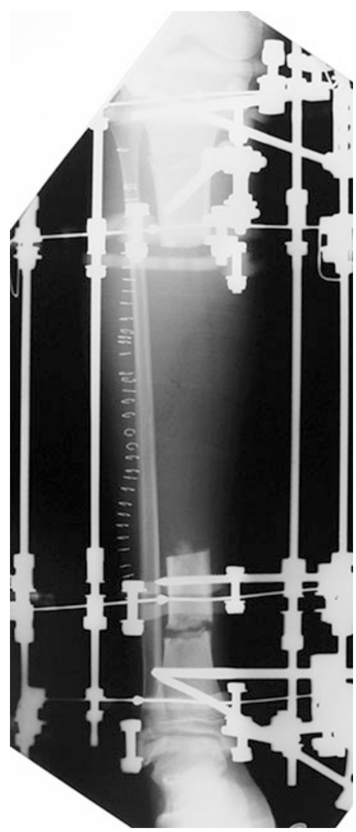

Fig. 5 Early postoperative radiograph. Resection performed, frame mounted. Both osteotomies were created and are waiting for the completion of the latency period before the initiation of the transport

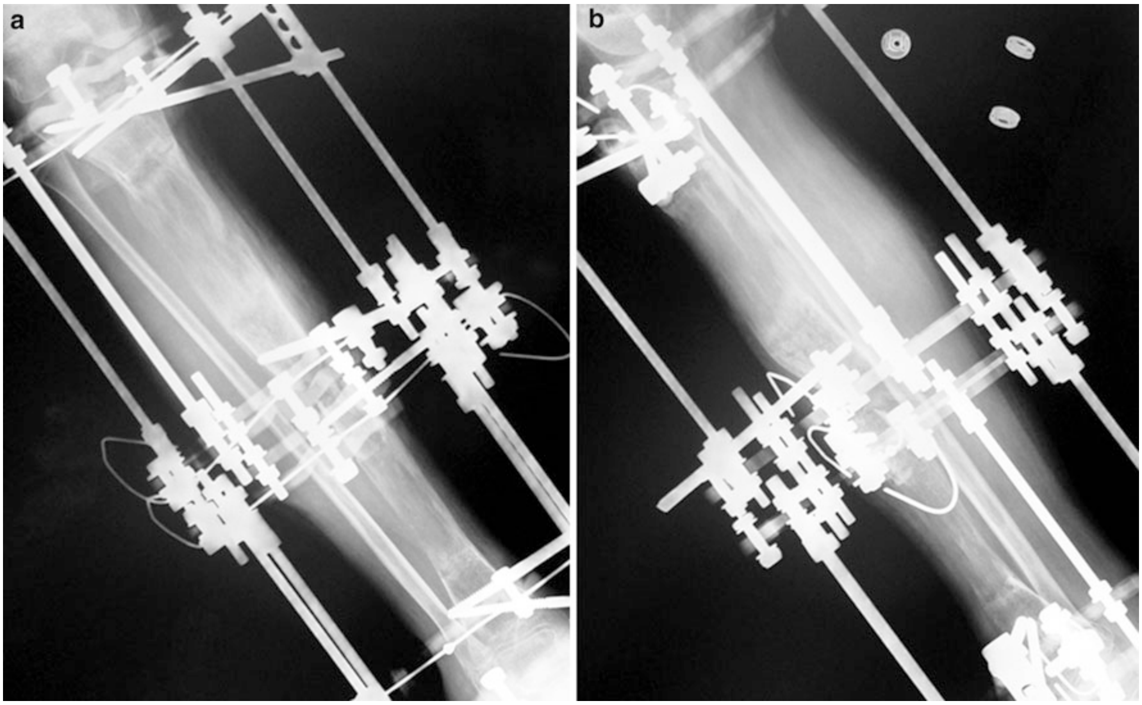

Fig. 6 Two-level osteotomy for transport performed with a high-quality regenerate. Proximal and distal segments are being compressed to achieve union. AP (**a**) and Lat (**b**) radiographs

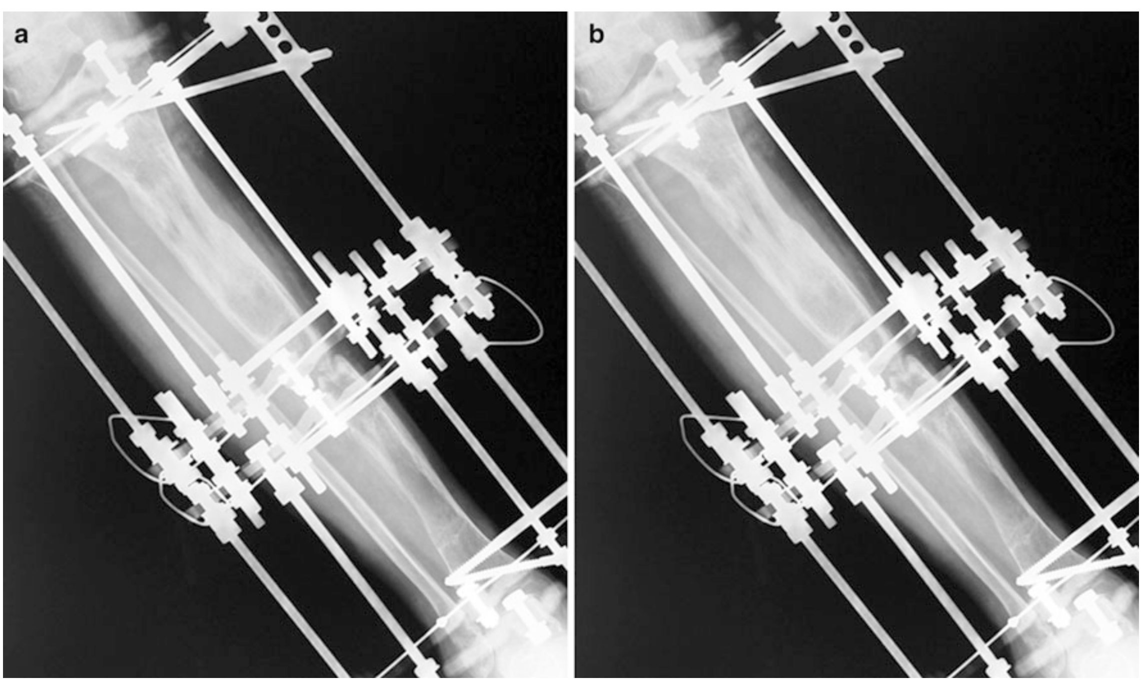

Fig. 7 AP (**a**) and Lat (**b**) radiographs 8 months after operation. Bone grafting performed due to delayed union. Frame is also limiting further compression

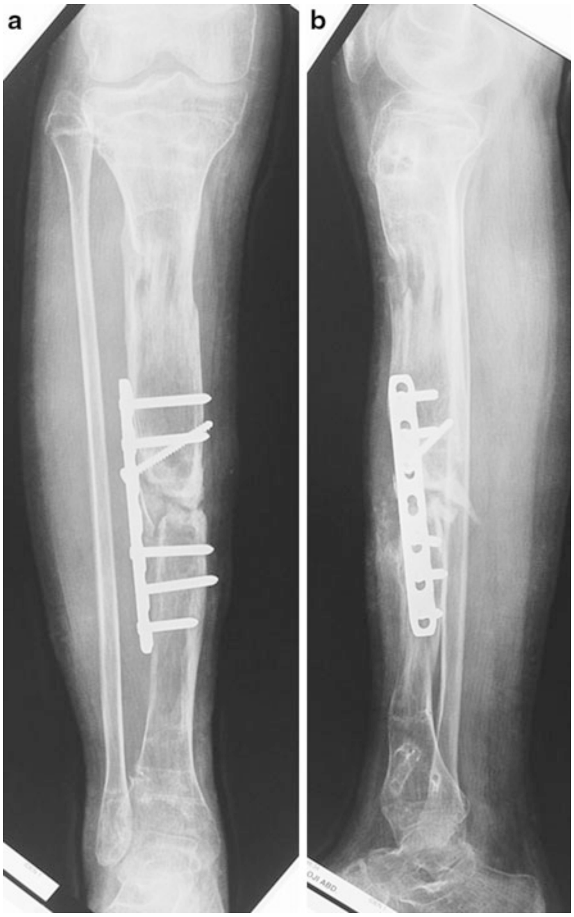

Fig. 8 AP (**a**) and Lat (**b**) radiographs 10 months postoperatively. Due to atrophic nonunion and frame limiting further compression, the fixator device was removed and plate osteosynthesis was performed with additional bone grafting

Fig. 9 Two years after removing device. Successful union achieved with 1 cm of limb length discrepancy. AP (**a**) and Lat (**b**) radiographs

9 Avoiding and Managing Problems

a. Excising the tumor with safe margins is the most important task. Preoperative planning is vital for both successful excision and frame mounting.
b. Wide resection of diaphyseal tumors creates extensive bone defects which are usually too long to transport a single segment. Bifocal segment transport is a good option for such cases. It will decrease the time required for bone transport making fixator time shorter. Also docking site mismatch problems are more frequent with long single-level transports. There is no absolute distance where bifocal transport is indicated, although 8 cm has often been used as a suggested tipping point. The decision between monofocal or bifocal approaches needs to be decided according to patient, bone quality, soft tissue, etc.
c. To avoid pin site infection, keep the area around the pins clean.
d. Docking site problems are commonly encountered with segment transport. Bifocal transport is more prone to such complications. Therefore, transosseous fixation elements have to be carefully chosen and placed so that the fixator itself does imping limiting transport or compression. Bone grafting may be necessary for delayed union with or without internal fixation.

10 Cross-References

▶ Case 78: Tibio-Talar Fusion to Treat Bone Defect and Ankle Arthritis Following Treatment of a Distal Tibial Giant Cell Tumour

Fig. 10 Clinical photos at the end of the treatment. Full range of motion has been achieved (**a**) with negligible limb length discrepancy (**b**)

11 See Also in Vols. 1 and 2

Case 9: Adolescent with Segmental Bone Defect Secondary to Grade IIIB Open Tibial Fracture Treated by Oblique Wire Bone Transport (Vol. 1)
Case 14: Double Level Bone Transport for Severe Bone Loss (Vol. 2)

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Case 67: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proximal Humerus Using Vascularized Fibular Grafting

Hiroyuki Tsuchiya

Contents

Abstract

Here we present a pediatric case of osteosarcoma in the proximal humerus, which was reconstructed using vascularized fibular graft.

1 Brief Clinical History

A 5 year old boy complained of pain and swelling around his right shoulder after it got hit. Radiographs revealed an osteolytic lesion and a pathological fracture in his right proximal humerus. There was no particular event in his past history to account for this. The fracture was displaced just before a biopsy. An incisional biopsy was performed which confirmed the diagnosis of the lesion as osteosarcoma.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.

3 Preoperative Problem List

See Fig. 13.

(a) Osteosarcoma of proximal humerus (epiphysis could be preserved).
(b) Preoperative caffeine-potentiated chemotherapy was very effective.
(c) No distant metastasis (surgical stage IIB: Enneking).

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Fig. 1 Pre-biopsy clinical photo

Fig. 3 Pre-biopsy CT

Fig. 2 Pre-biopsy radiographs

Fig. 4 Just before biopsy radiograph

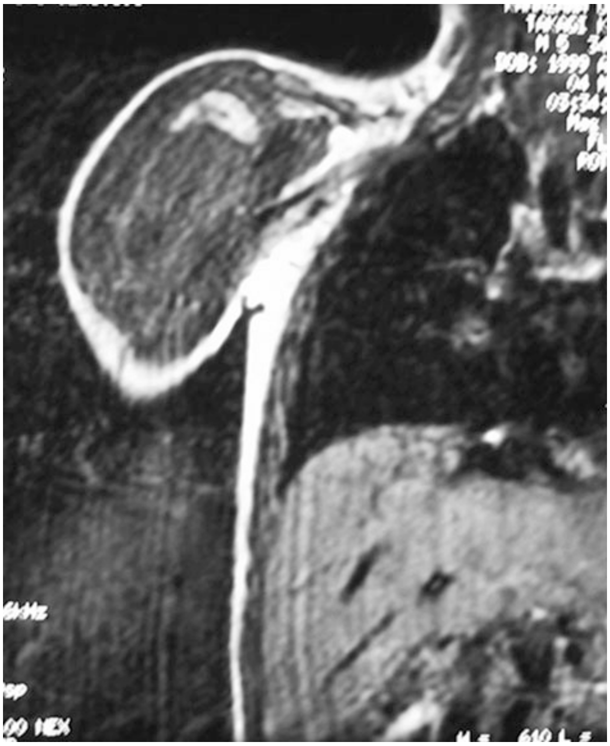

Fig. 5 Pre-chemotherapy MRI

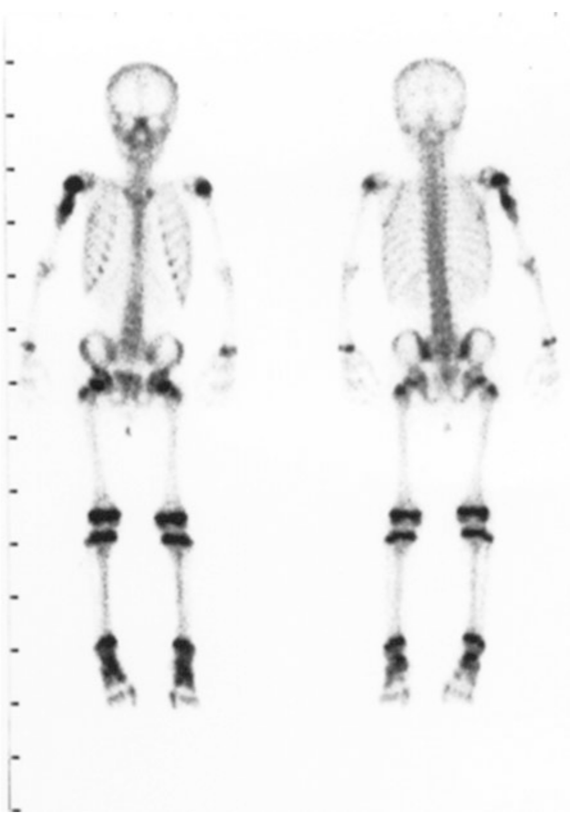

Fig. 6 Pre-chemotherapy bone scan

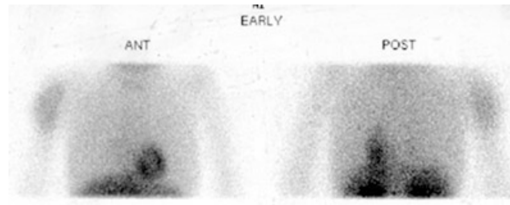

Fig. 7 Pre-chemotherapy thallium scintigram

Fig. 8 Post-chemotherapy radiograph

4 Treatment Strategy

(a) Intentional reduction surgery: marginal, ~1 cm wide excision (Fig. 14)
(b) Placement of external fixator
(c) Harvesting a fibular graft
(d) Fibular graft with microvascular anastomosis

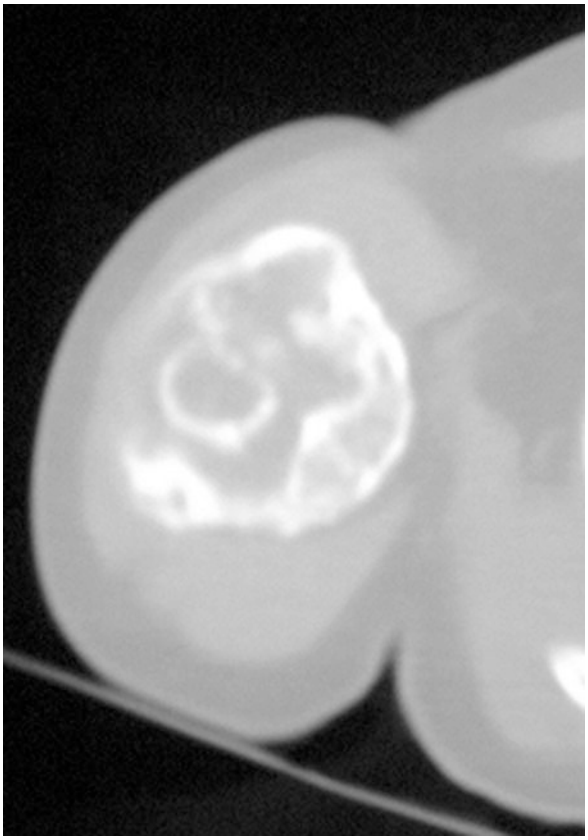

Fig. 9 Post-chemotherapy CT

Fig. 10 Post-chemotherapy MRI

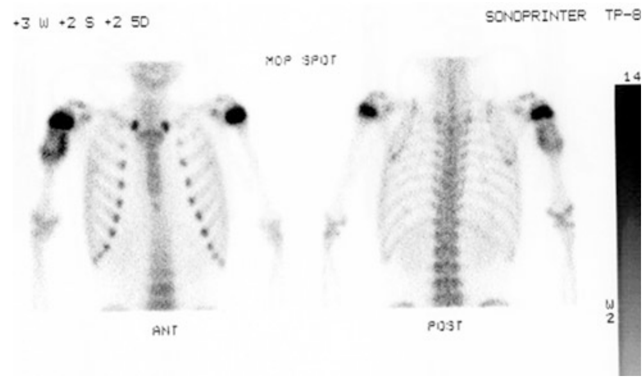

Fig. 11 Post-chemotherapy bone scan

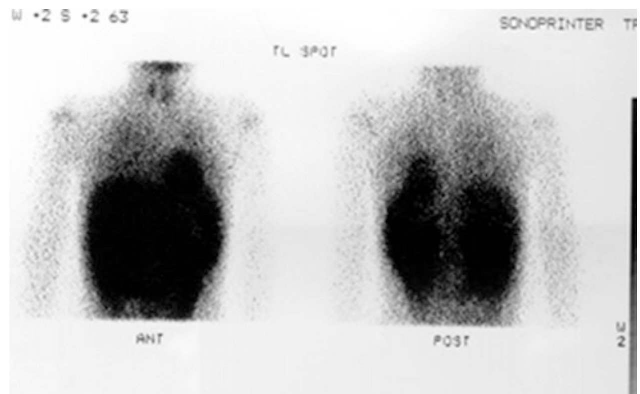

Fig. 12 Post-chemotherapy thallium scintigram

5 Basic Principles

(a) Adequate tumor excision based on CTX response (patellar tendon was removed from the tibial tuberosity).
(b) Placement of external fixator.
(c) Harvesting a fibular graft.
(d) Fibular graft with microvascular anastomosis.

6 Images During Treatment

See Figs. 15, 16, 17, 18, 19, 20, and 21.

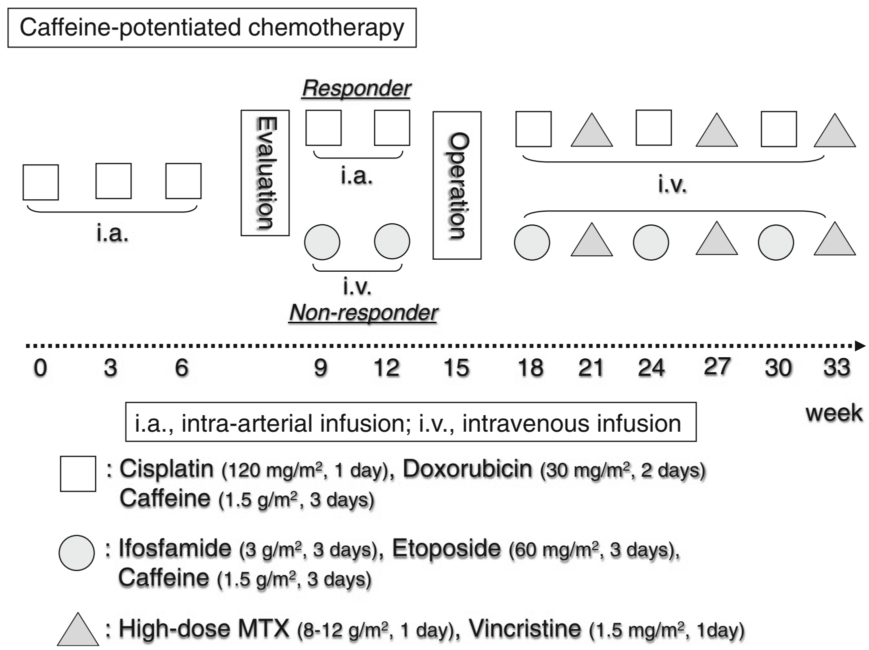

Fig. 13 Caffeine-potentiated chemotherapy

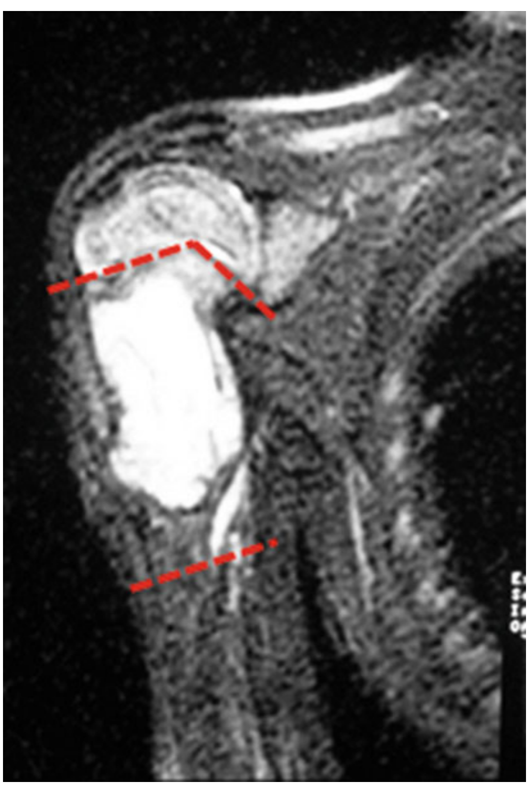

Fig. 14 Plan of tumor excision

7 Technical Pearls

ROM exercises were permitted immediately after the operation. After bone union was achieved, the external fixator was removed (3 months after surgery).

8 Outcome Clinical Photos and Radiographs

See Figs. 22 and 23.

9 Avoiding and Managing Problems

(a) Intentional marginal excision:
Precise evaluation of preoperative chemotherapy and tumor margins using MRI, thallium scintigram, and radiographs. To accurately excise the tumor, it is important to cut precise margins using an X-ray imaging intensifier.

(b) Vascularized fibular graft:
Anastomosis of vessels should be performed by a hand surgeon with training and experience in microsurgery.

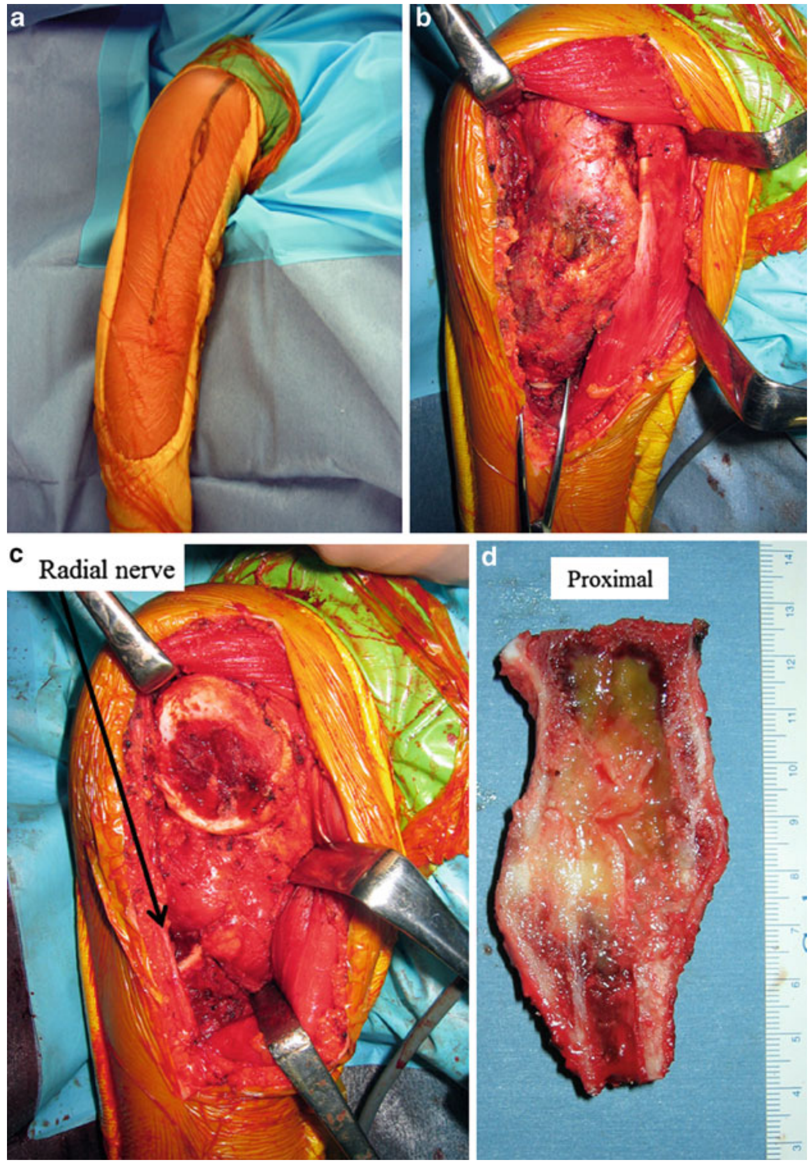

Fig. 15 (**a**) Skin incision, (**b**) exposing the surrounding soft tissues (reactive capsule) of the tumor, (**c**) after tumor excision. Radial nerve was preserved. (**d**) Specimen

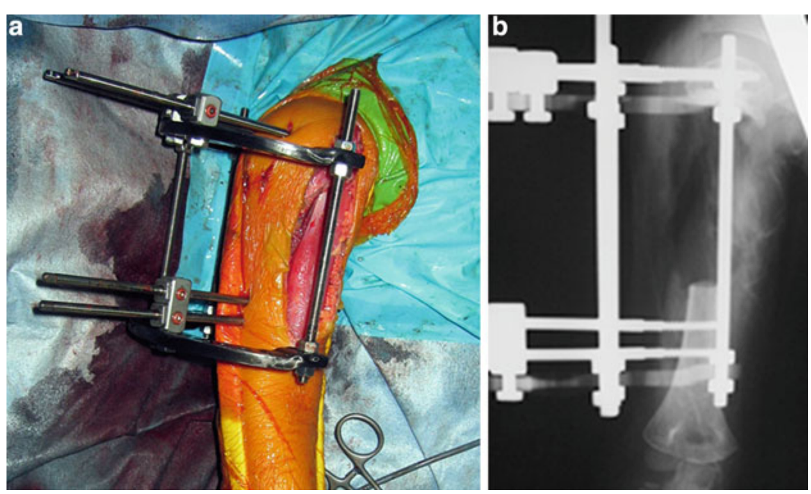

Fig. 16 Placement of external fixation

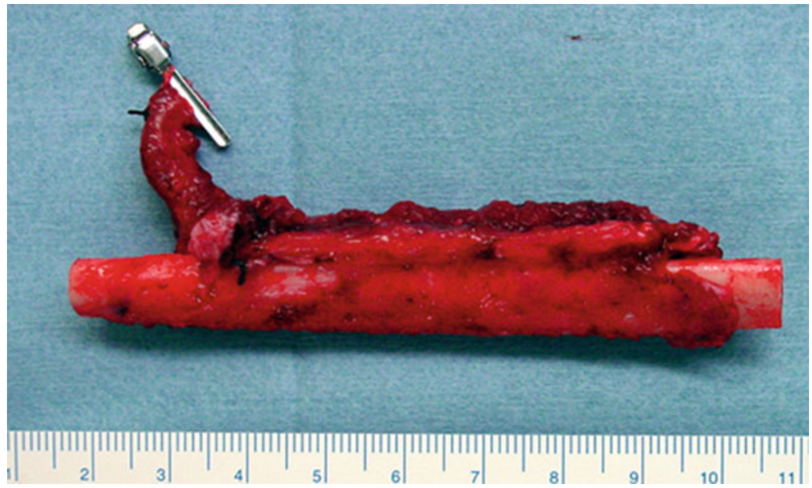

Fig. 17 Harvesting the fibular graft from left fibula

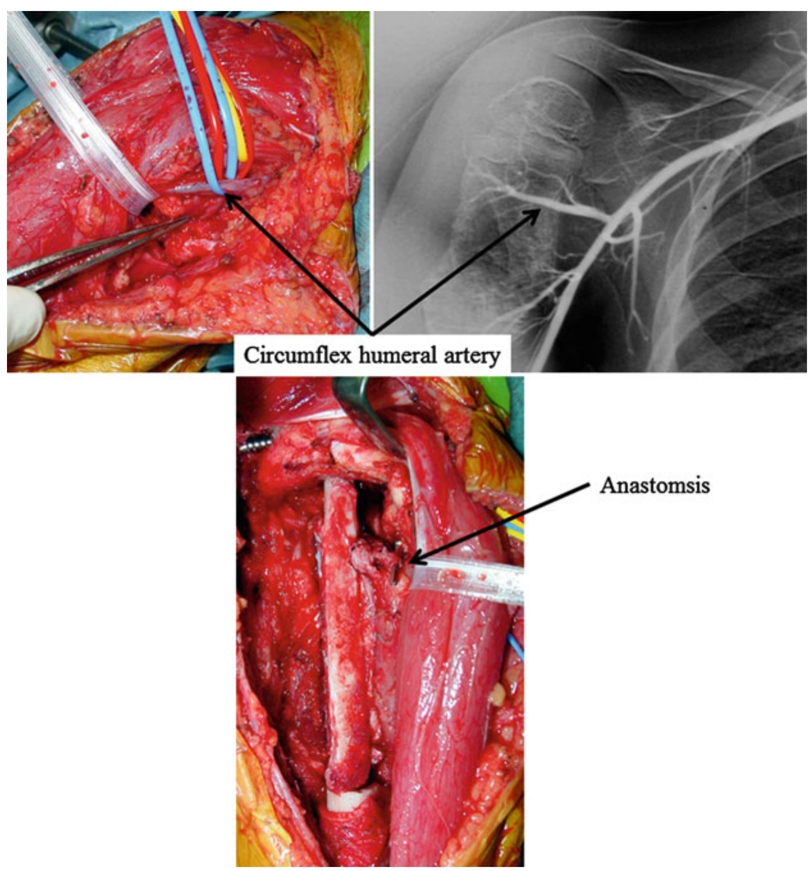

Fig. 18 Fibular graft with microvascular anastomosis

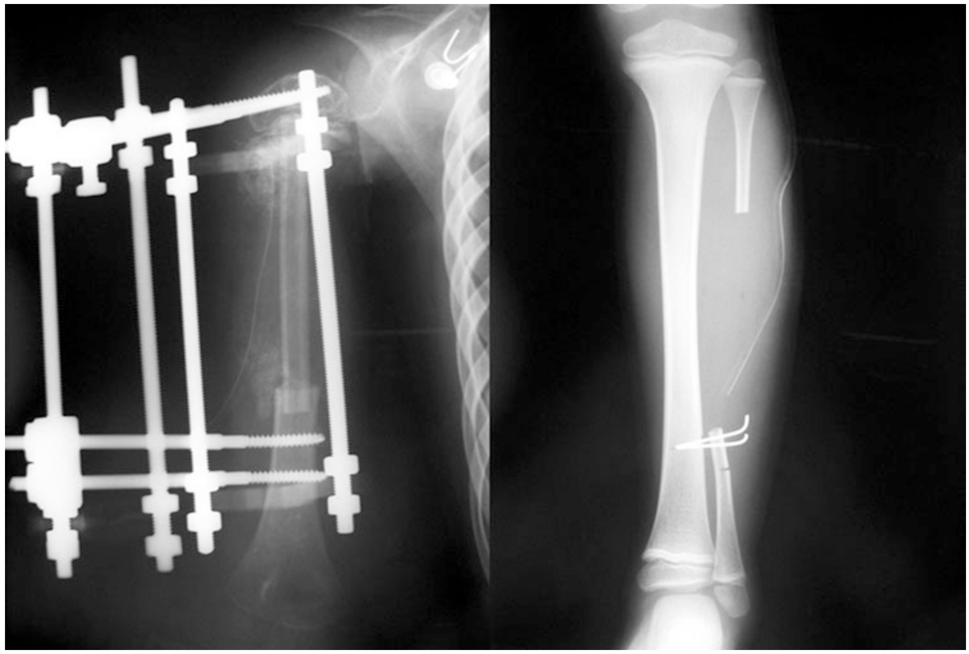

Fig. 19 Radiographs recorded immediately after surgery

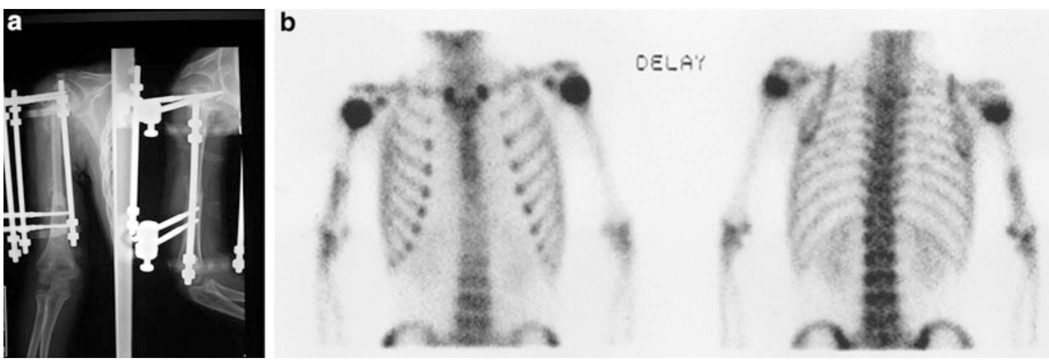

Fig. 20 (**a**, **b**) Radiographs and bone scan 3 months after surgery

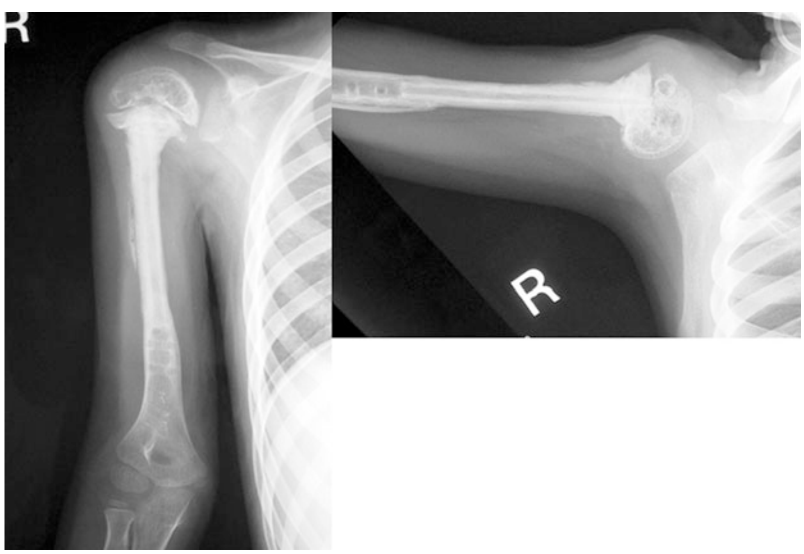

Fig. 21 Radiographs 5 months after surgery

Fig. 22 Radiographs 1.5 years after operation

Fig. 23 Normal limb function was restored

10 Cross-References

▶ Case 64: Repair and Lengthening After Nonunion of Free Vascularized Fibula Graft For Reconstruction of Osteosarcoma of the Tibia
▶ Tumor: An Introduction
▶ Upper Extremity: An Introduction

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Case 68: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proximal Tibia Using a Frozen Autograft

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Contents

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Abstract

Here we present a case of an osteosarcoma in the proximal diaphyseal tibia, which was reconstructed using a frozen autograft.

1 Brief Clinical History

A 12 year old girl complained of pain around her left knee without any known cause. Radiographs revealed an osteoblastic bone lesion in her left proximal tibia. There was no particular event in her past history to account for this. She had an incisional biopsy which confirmed the diagnosis of the lesion as osteosarcoma.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, 7, and 8.

3 Preoperative Problem List

See Fig. 9

(a) Osteosarcoma of the proximal tibia with epiphyseal involvement.
(b) Preoperative caffeine-potentiated chemotherapy was very effective.
(c) No distant metastasis (surgical stage IIB: Enneking).

S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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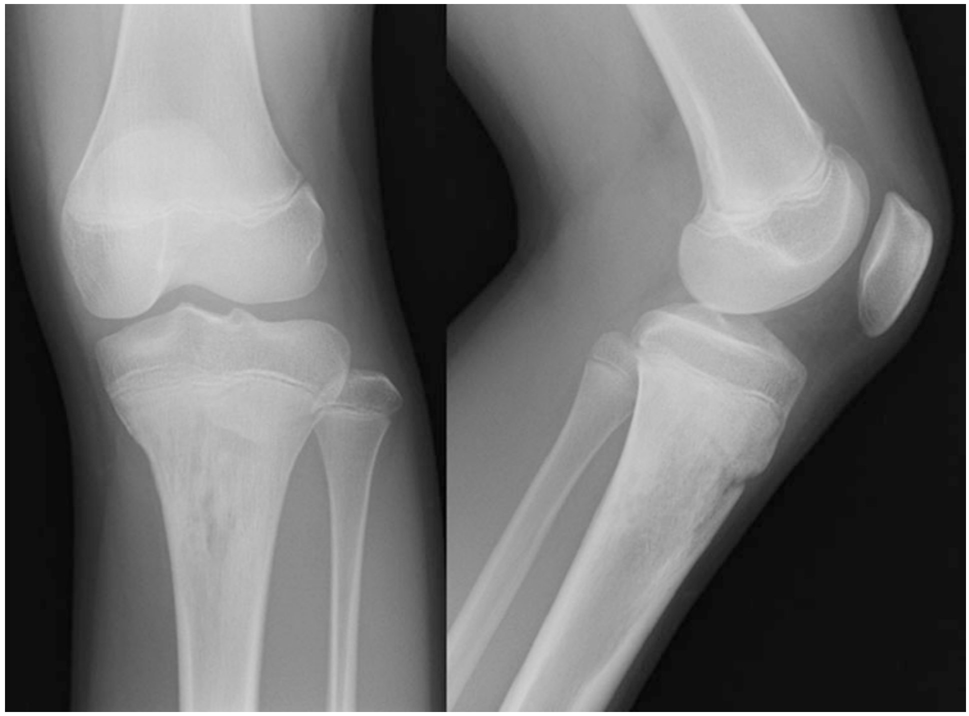

Fig. 1 Pre-chemotherapy radiographs

Fig. 2 Pre-chemotherapy MRI

4 Treatment Strategy

(a) Intentional margin reduction surgery: marginal, ~1 cm wide excision (Fig. 10).
(b) Pedicle freezing (Fig. 11).

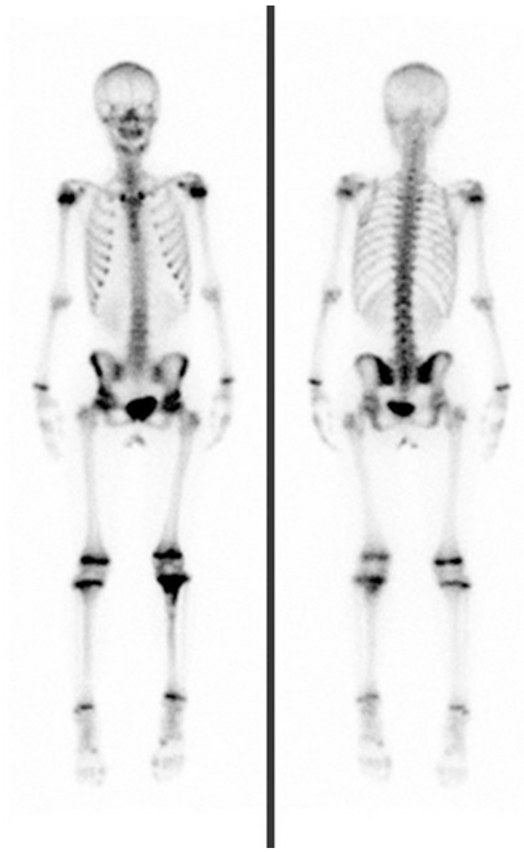

Fig. 3 Pre-chemotherapy bone scan

5 Basic Principles

(a) Adequate tumor excision based on CTX response (the patellar tendon was removed from the tibial tuberosity).
(b) Surrounding soft tissue was protected by surgical sheets. Thereafter, the intramedullary canals were curetted to remove bone marrow and tumor contents in order to prevent graft fracture due to water volume expansion during freezing.
(c) Bony lesions that connected with the limb were carefully rotated and frozen in a container with liquid nitrogen while continuing to protect the surrounding soft tissue with surgical sheets.
(d) All tumors were treated using a one-cycle liquid nitrogen protocol that consisted of freezing in liquid nitrogen for 20 min, thawing at room temperature for 15 min, and continued thawing in distilled water for an additional 10 min. These steps for pedicle freezing were performed while using a tourniquet to prevent tumor dissemination and bleeding.
(e) Reconstructions after freezing were performed using an iodine-supported plate. The patellar tendon was reattached with a spike washer and a screw.

6 Images During Treatment

See Figs. 12, 13, 14, and 15.

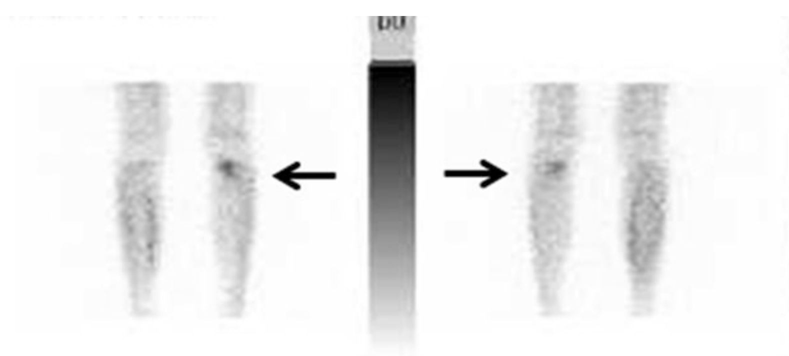

Fig. 4 Pre-chemotherapy thallium scintigram

Fig. 5 Post-chemotherapy radiograph

Fig. 6 Post-chemotherapy MRI

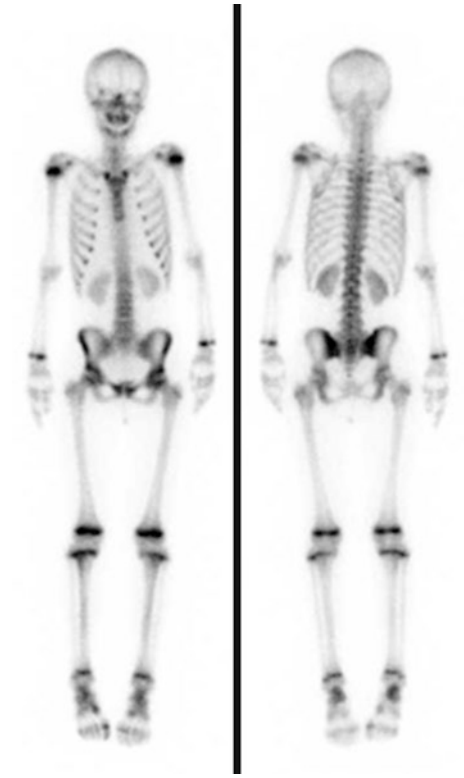

Fig. 7 Post-chemotherapy bone scan

7 Technical Pearls

Knee joint was immobilized by the brace for 6 weeks and ROM exercise was started after that. Partial weight bearing was permitted 3 months after the operation, and full weight bearing was allowed after bone union was achieved (6 months after the operation).

8 Outcome Clinical Photos and Radiographs

See Figs. 16 and 17.

9 Avoiding and Managing Problems

(a) Intentional marginal excision:
Precise evaluation of preoperative chemotherapy and tumor margins using MRI, thallium scintigram, and

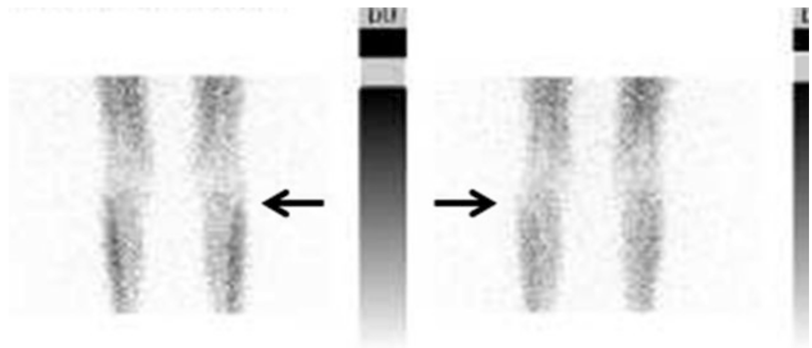

Fig. 8 Post-chemotherapy thallium scintigram

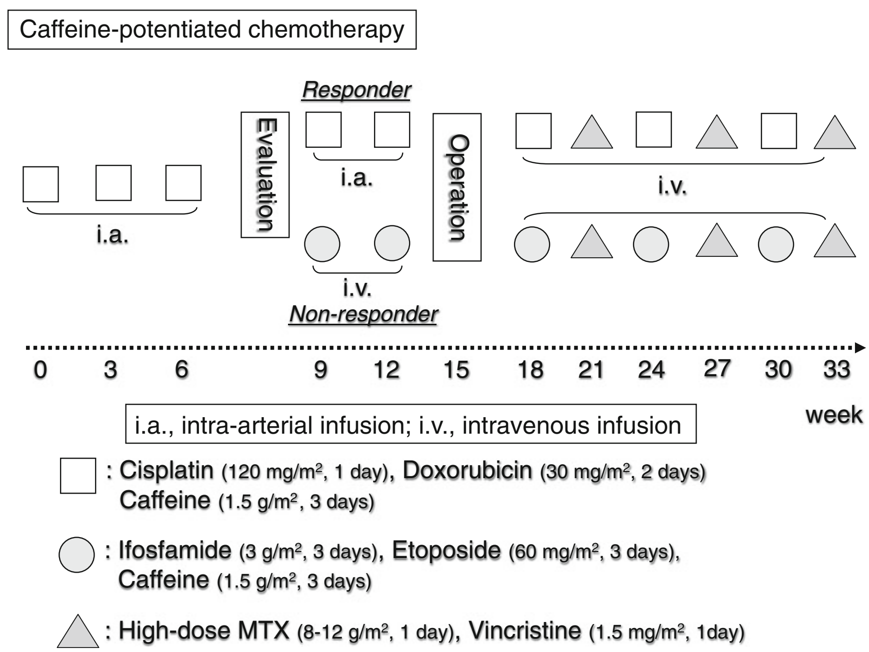

Fig. 9 Caffeine-potentiated chemotherapy

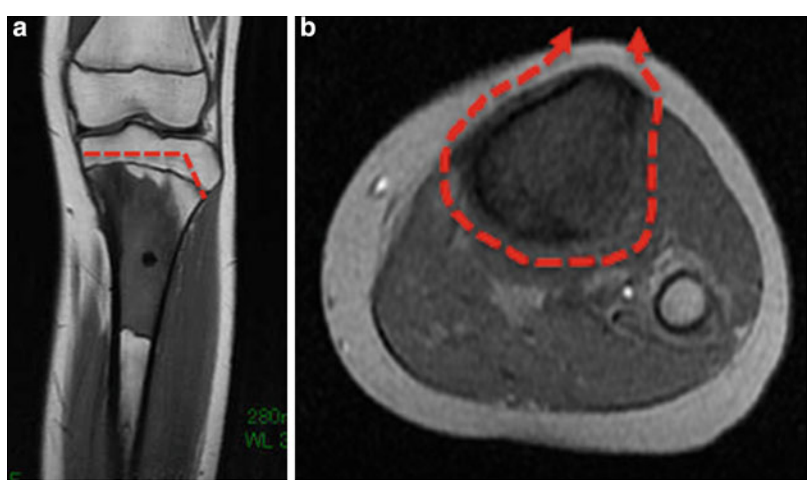

Fig. 10 Plan of tumor excision

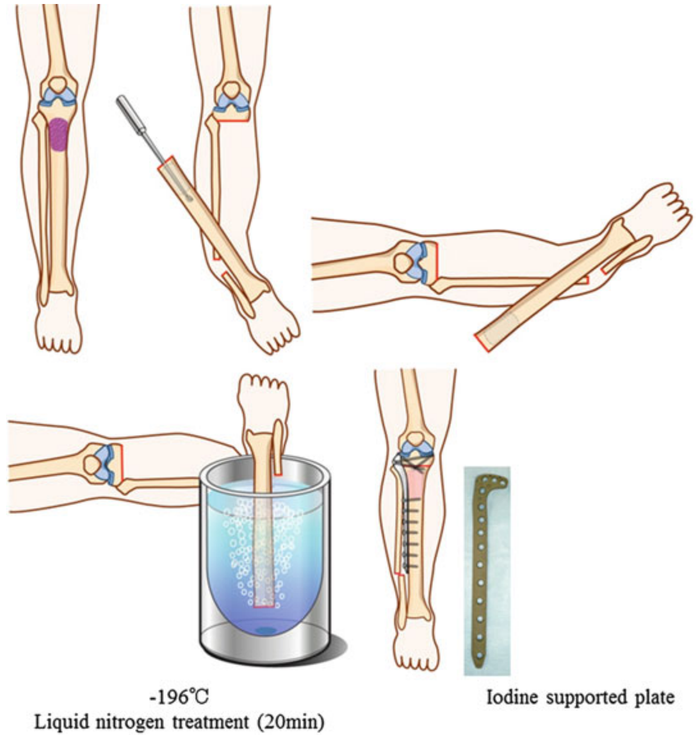

Fig. 11 Images of surgical procedure (pedicle freezing)

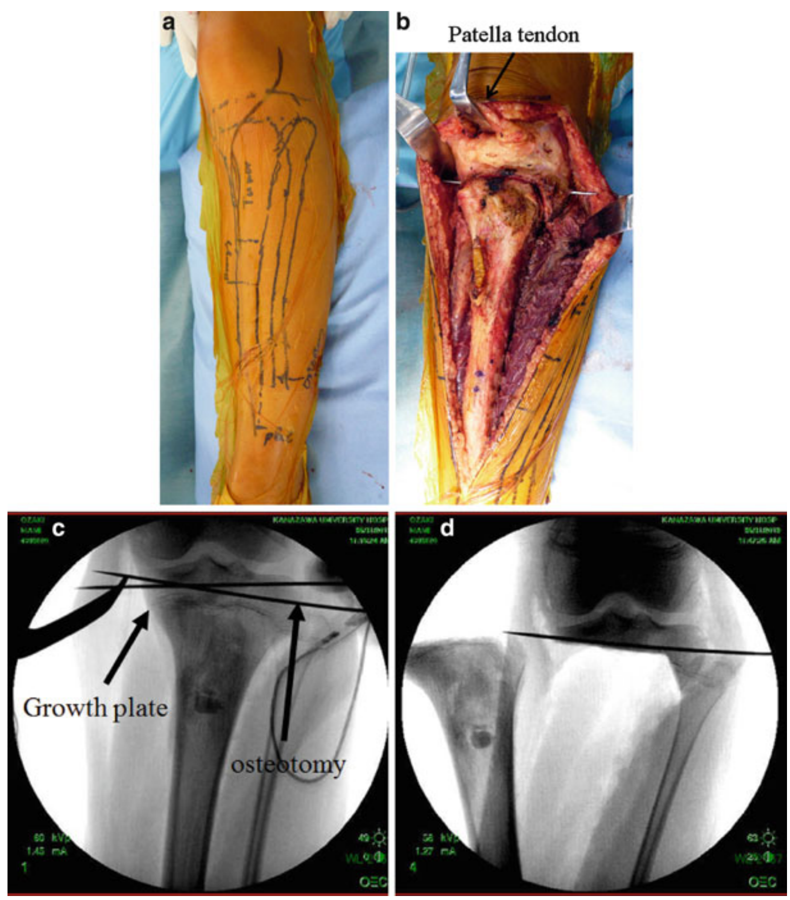

Fig. 12 (**a**) Skin incision, (**b**) cutting tumor's proximal margin (K-wire guided), (**c**) insertion of K-wire just proximal to the portion of the cutting line, (**d**) K-wire-guided cutting

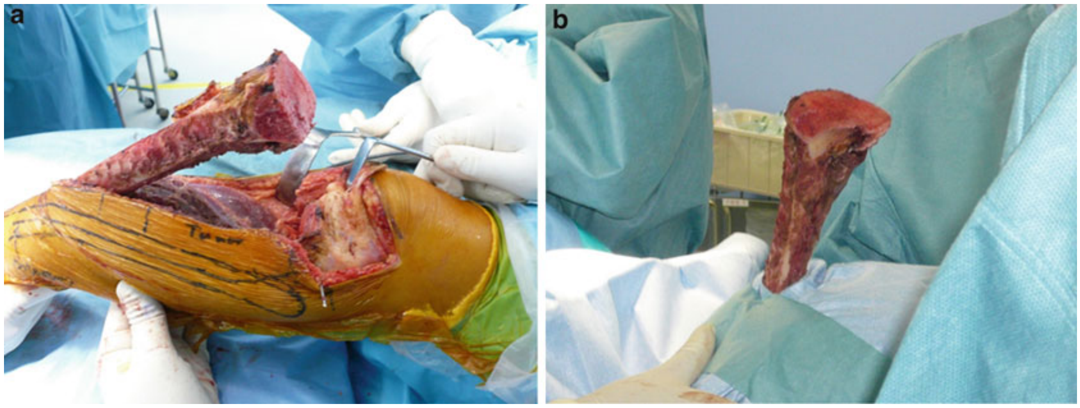

Fig. 13 (**a**, **b**) Preparation for freezing. (**a**) Exposure of freezing site, (**b**) protection of surrounding soft tissue by surgical sheets

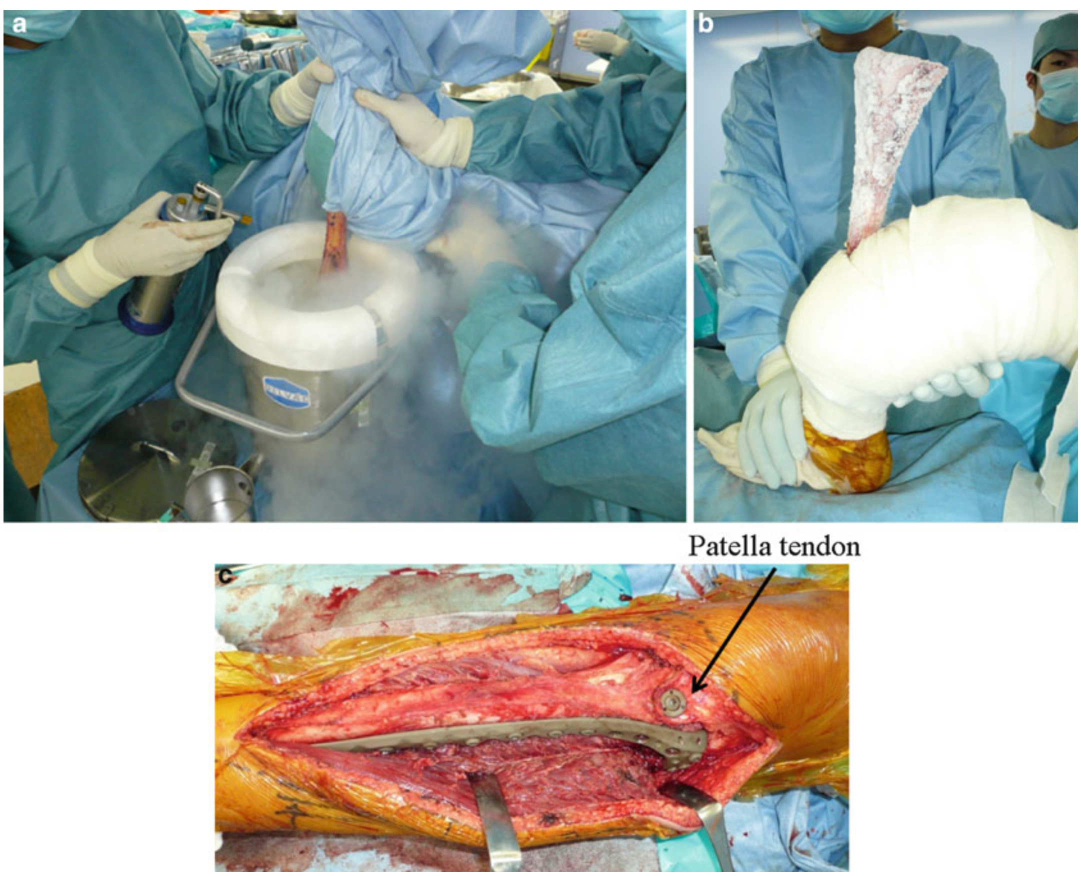

Fig. 14 (**a–c**) Freezing and reconstruction. (**a**) Pedicle freezing, (**b**) Immediately after pedicle freezing, (**c**) reconstruction using iodine-supported plate and screws

Fig. 15 Radiographs recorded immediately after operation

radiographs. To accurately excise the tumor, it is important to cut precise margins using an X-ray imaging intensifier.

(b) Freezing procedure:
To prevent graft fracture during freezing due to water volume expansion, it is important to curette the intramedullary canals and tumor contents.

10 Cross-References

- ▶ Case 75: Failed Allograft Reconstruction (Nonunion) for Malignant Bone
- ▶ Tumor: An Introduction

Fig. 16 Radiographs 30 months after operation

Fig. 17 Normal limb function was restored

References and Suggested Reading

Sakayama K, Kidani T, Sugawara Y, Tauchi H, Fujibuchi T, Tanji N, Yamamoto H, Tsuchiya H (2009) Reconstruction using a frozen bone method for osteosarcoma of the talus. A case report and review of the literature. Anticancer Res 29:4093–4098

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Case 69: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proximal Tibia Using Taylor Spatial Frame (Distraction Osteogenesis)

Hiroyuki Tsuchiya

Contents

Abstract

Here we present a case of osteosarcoma in the proximal diaphyseal tibia, which was reconstructed using Taylor spatial frame.

1 Brief Clinical History

A 17 year old male complained of right lower leg pain, which he had noticed while playing soccer; he was treated with compresses. Four months later, he felt the pain again in the same part of his right leg. Radiographs revealed an osteolytic lesion in his right proximal tibia. There was no particular event in his past history to account for this. An incisional biopsy was performed which confirmed the diagnosis of the lesion as osteosarcoma.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, and 6.

3 Preoperative Problem List

See Fig. 7.

(a) Osteosarcoma of proximal tibia (diaphyseal lesion).
(b) Preoperative caffeine-potentiated chemotherapy was very effective.
(c) No distant metastasis (surgical stage IIB: Enneking).

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_235

Fig. 1 Pre-chemotherapy clinical photo

4 Treatment Strategy

(a) Intentional reduction surgery: marginal, ~1 cm wide excision (Fig. 8).
(b) Bone transport using a Taylor spatial frame (Fig. 9).

5 Basic Principles

(a) Placement of Taylor spatial frame.
(b) Adequate tumor excision based on CTX response.
(c) Gradual bone transport (0.5–1.0 mm/day).
(d) Removal of TSF after bone union at the docking site.

6 Images During Treatment

See Figs. 10, 11, 12, and 13.

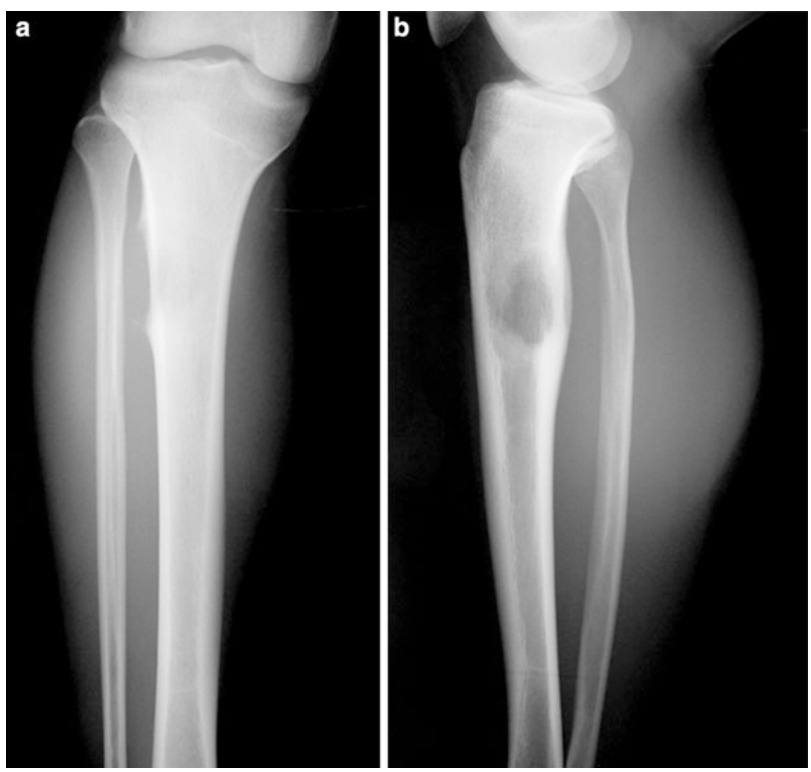


Fig. 2 Pre-chemotherapy radiographs

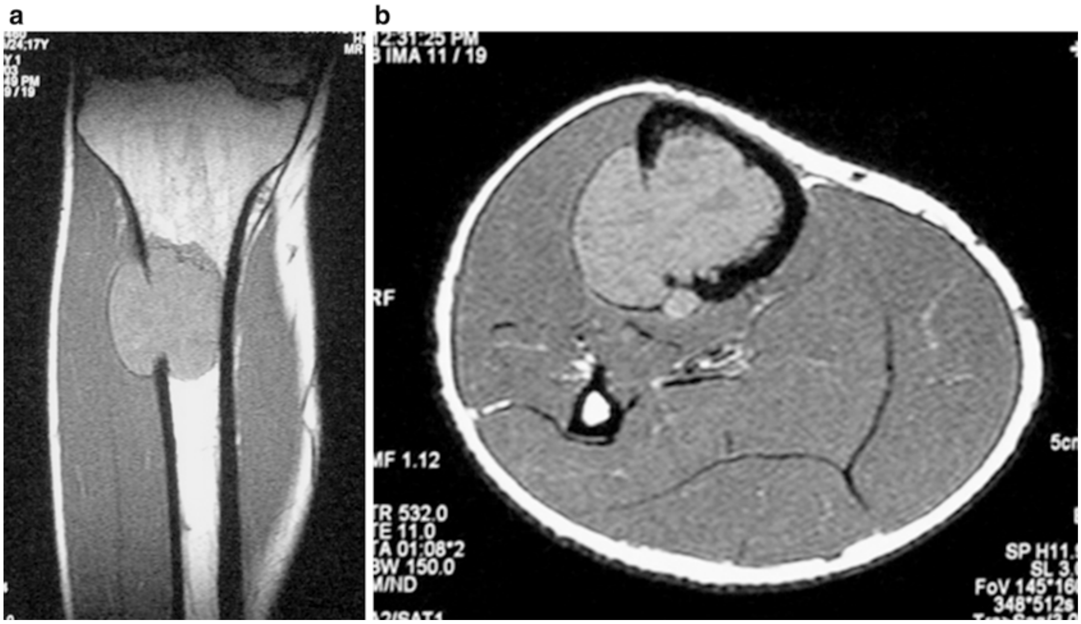


Fig. 3 Pre-chemotherapy MRI

Fig. 4 Pre-chemotherapy thallium scintigram

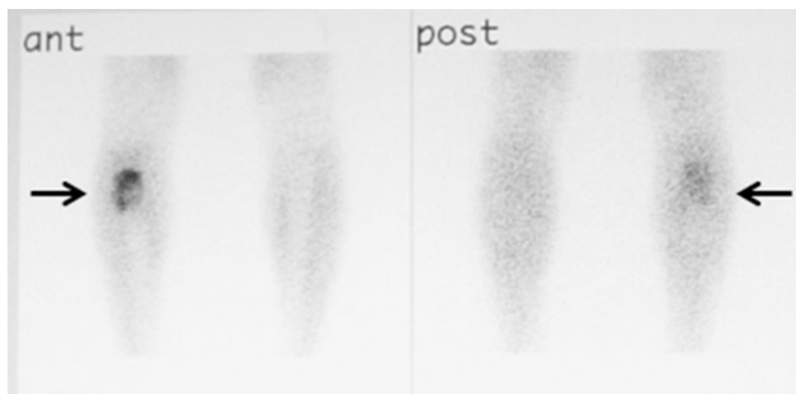
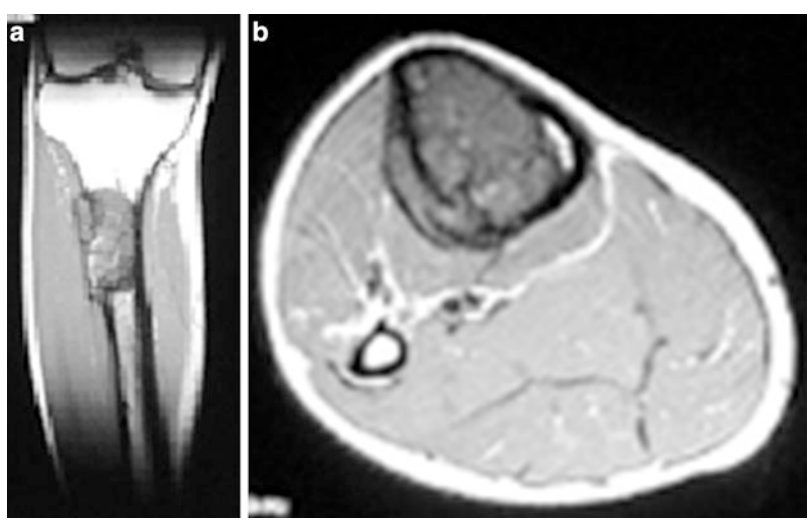


Fig. 5 Post-chemotherapy MRI



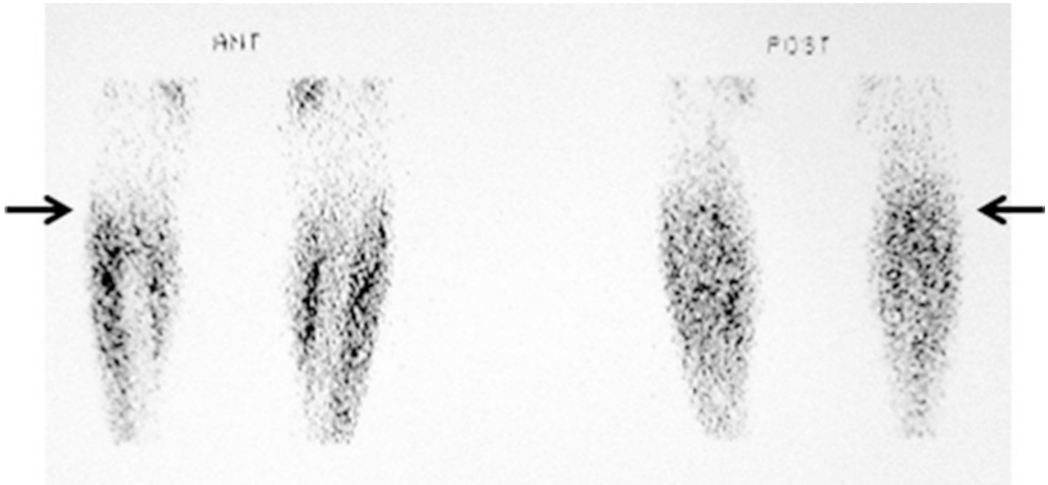
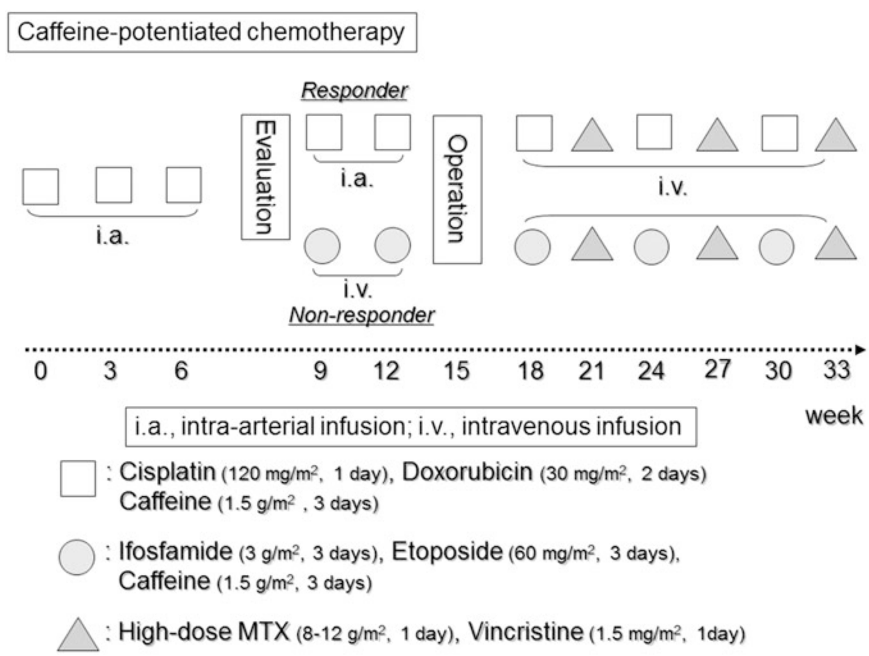


Fig. 6 Post-chemotherapy thallium scintigram (*right*)

Fig. 7 Caffeine-potentiated chemotherapy



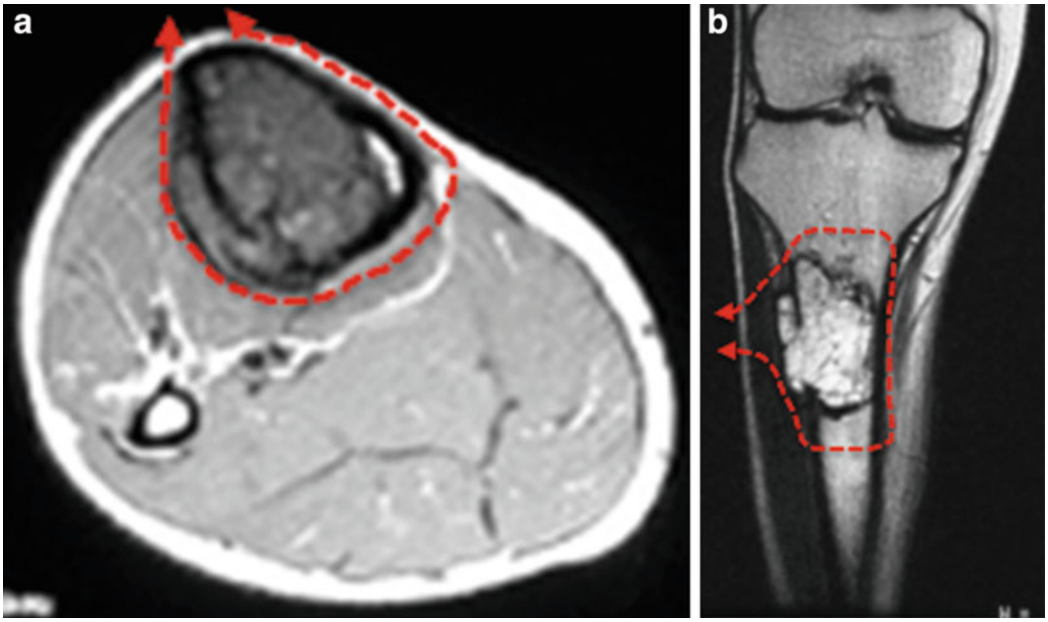
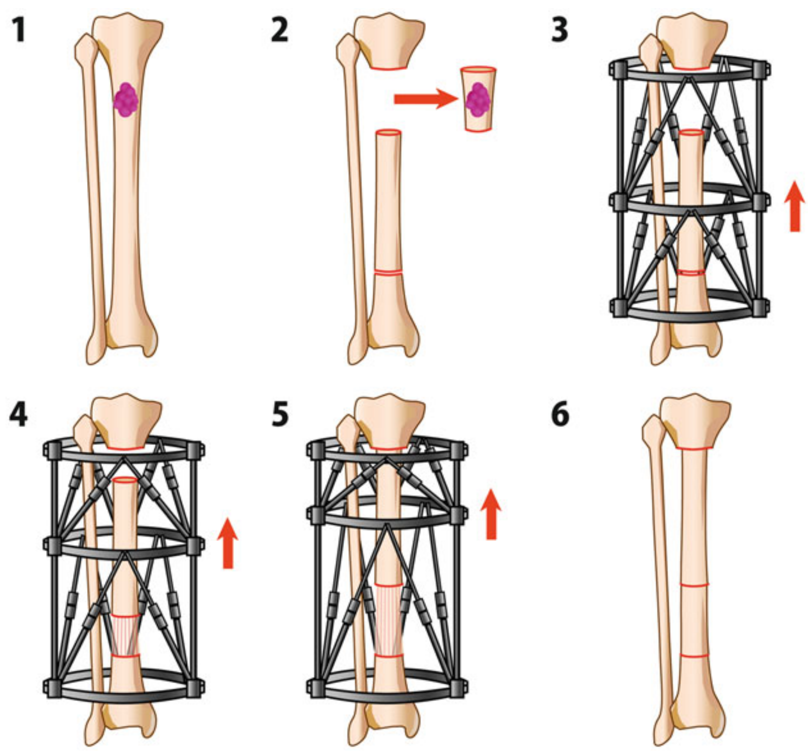


Fig. 8 Plan of tumor excision

Fig. 9 Images during treatment



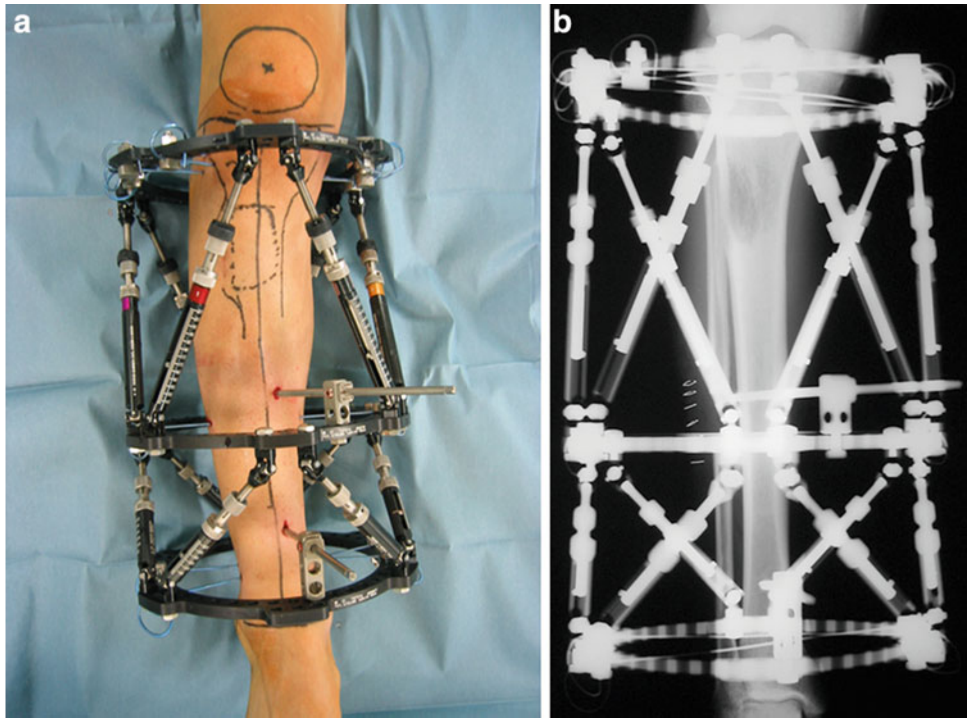


Fig. 10 Placement of a Taylor spatial frame (*left*, clinical photograph; radiograph, *right*)

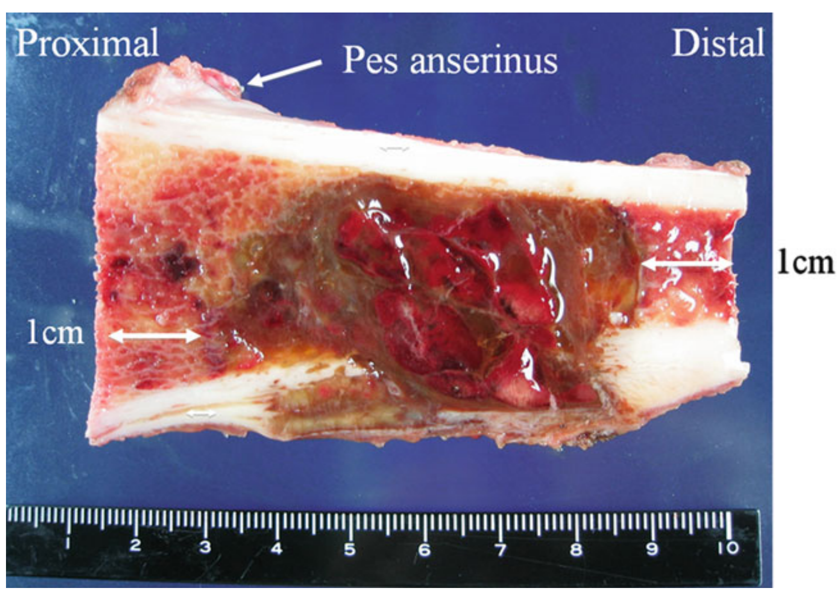


Fig. 11 Specimen of excised tumor

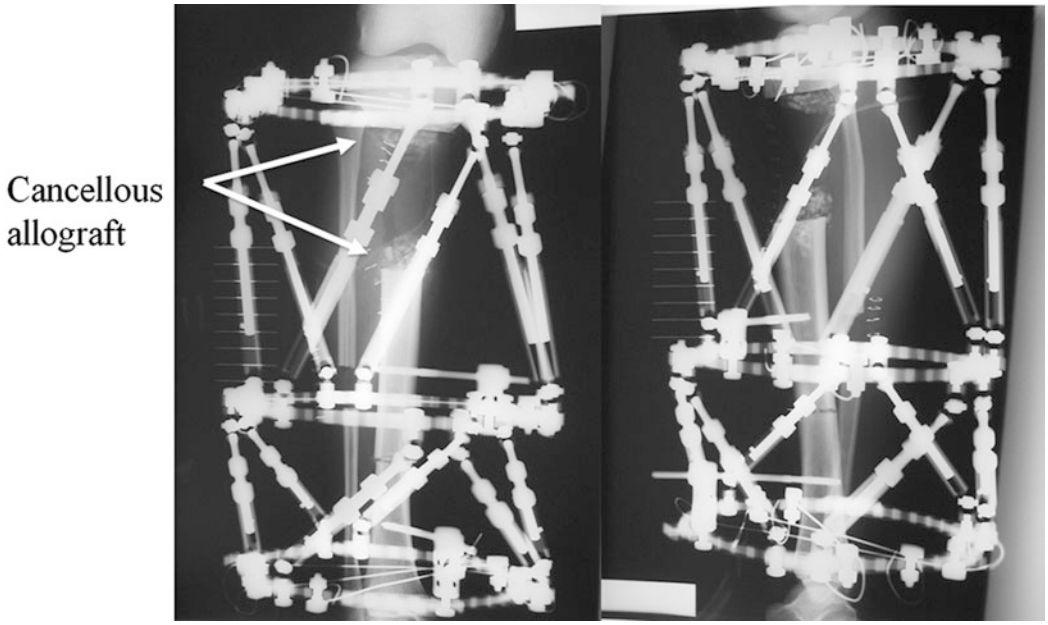


Fig. 12 Radiographs recorded immediately after operation

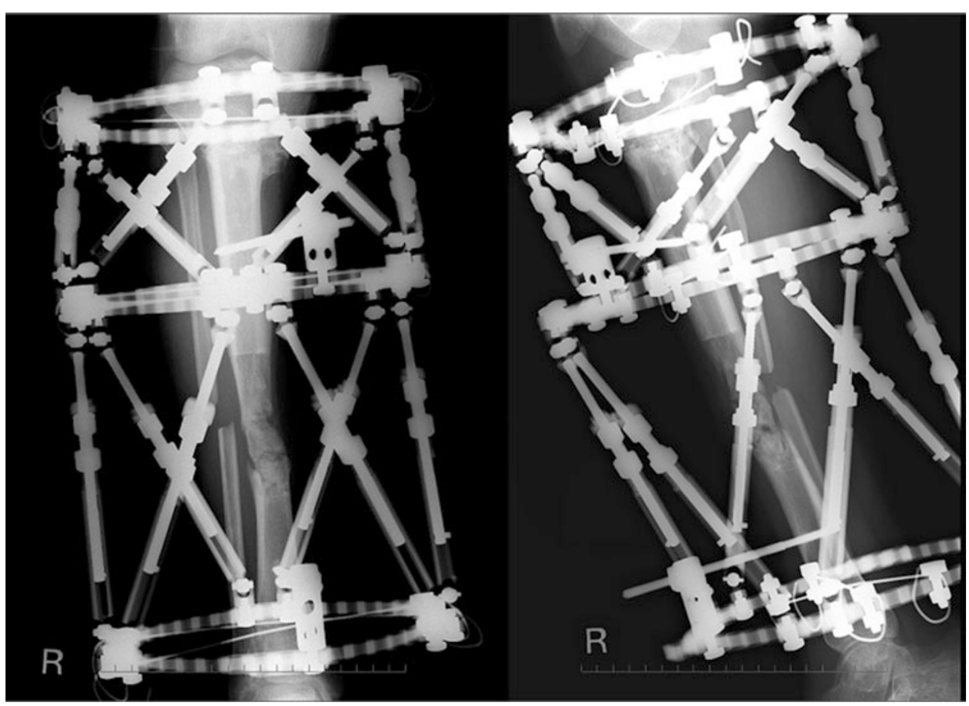


Fig. 13 Radiographs after distraction osteogenesis were completed

Fig. 14 Radiographs 30 months after operation

Fig. 15 Normal limb function was restored

7 Technical Pearls

After surgery, a program for transport is created using web application. We take a radiograph every 2 weeks until transport is completed. Reprogram the transport, if necessary.

8 Outcome Clinical Photos and Radiographs

See Figs. 14 and 15.

9 Avoiding and Managing Problems

(a) Intentional marginal excision:
Precise evaluation of preoperative chemotherapy and tumor margins using MRI, thallium scintigram, and radiographs.
(b) Bone transport using TSF:
To avoid pin site infection, keep the area around the pin clean. Bone graft should be performed at the docking site to facilitate the union.

10 Cross-References

▶ Case 78: Tibio-Talar Fusion to treat bone defect and ankle arthritis following treatment of a distal tibial Giant cell tumour
▶ Tumor: An Introduction

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Case 70: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proxial Tibia Using a Hemicortical Frozen Autograft

Hiroyuki Tsuchiya

Contents

Abstract

Here we present a case of an osteosarcoma in the proximal diaphyseal tibia, which was reconstructed using a hemicortical frozen autograft.

1 Brief Clinical History

An 11 year old girl complained of pain around her left knee without any known cause. Radiographs revealed an osteoblastic bone lesion in her left proximal tibia. There was no particular event in her past history associated with this. An incisional biopsy was performed which confirmed the diagnosis of the lesion as osteosarcoma.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, and 7.

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DOI 10.1007/978-3-319-18020-5_237

Fig. 1 Pre-chemotherapy clinical photo

3 Preoperative Problem List

See Fig. 8.

(a) Osteosarcoma of proximal tibia (hemicortical lesion; epiphysis was partially involved).
(b) Preoperative caffeine-potentiated chemotherapy was very effective.
(c) No distant metastasis (surgical stage IIB: Enneking).

4 Treatment Strategy

(a) Intentional reduction surgery: marginal, ~1 cm wide excision (Fig. 9)
(b) Frozen autograft (Fig. 10)

5 Basic Principles

(a) Adequate tumor excision based on CTX response (patellar tendon was removed from the tibial tuberosity).
(b) All tumors were treated using a one-cycle liquid nitrogen protocol that consisted of freezing in liquid

Fig. 2 Pre-chemotherapy radiographs

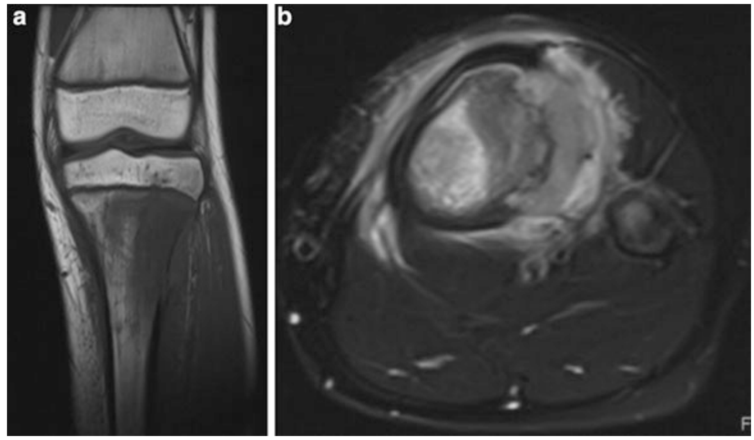

Fig. 3 Pre-chemotherapy MRI

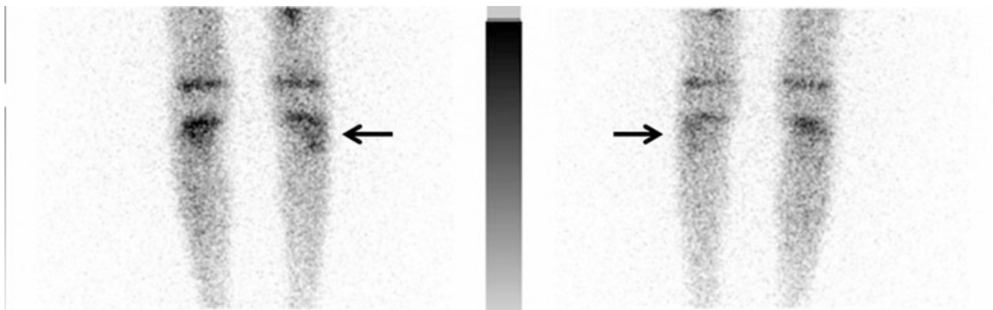

Fig. 4 Pre-chemotherapy thallium scintigram

Fig. 5 Post-chemotherapy radiograph

nitrogen for 20 min, thawing at room temperature for 15 min, and continued thawing in distilled water for an additional 10 min.

(c) Reconstructions after freezing were performed using an iodine-supported plate. The patellar tendon was reattached with a spike washer and a screw.

6 Images During Treatment

See Figs. 11, 12, 13, 14, and 15.

7 Technical Pearls

The knee joint was immobilized with a brace for 6 weeks and ROM exercises were initiated after that. Partial weight bearing was permitted at 3 months after surgery and full weight bearing was allowed after bone union was achieved (6 months after surgery).

8 Outcome Clinical Photos and Radiographs

See Figs. 16 and 17.

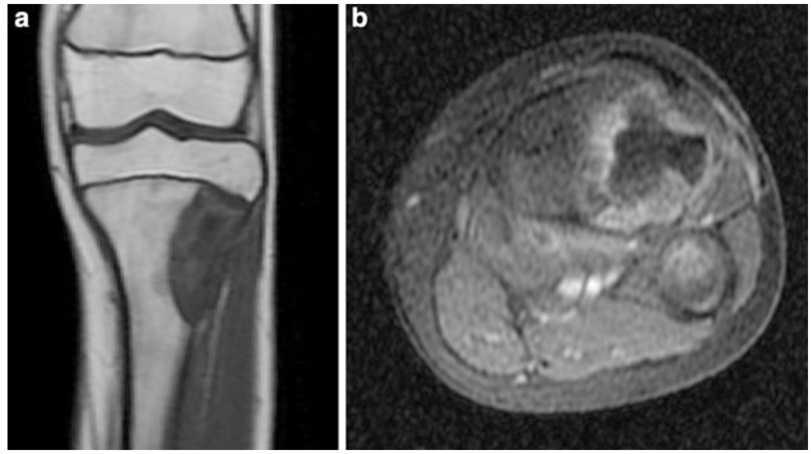

Fig. 6 Post-chemotherapy MRI

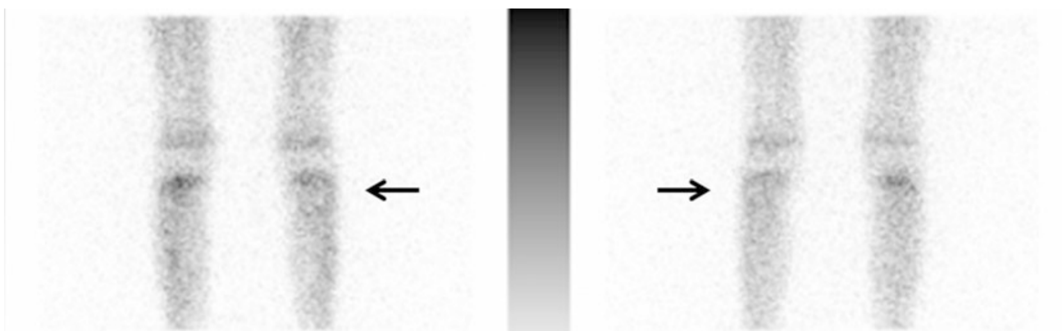

Fig. 7 Post-chemotherapy thallium scintigram

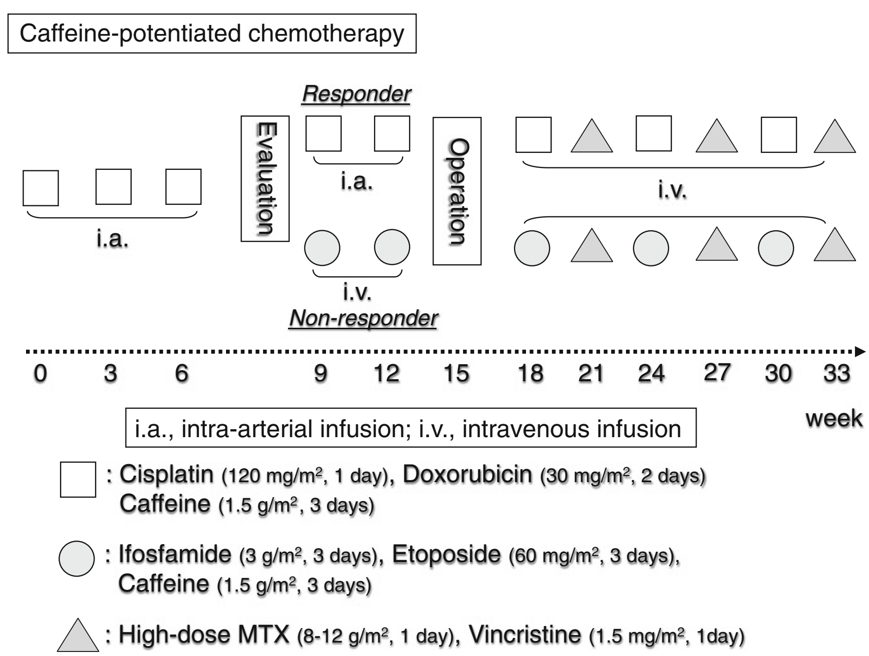

Fig. 8 Caffeine-potentiated chemotherapy

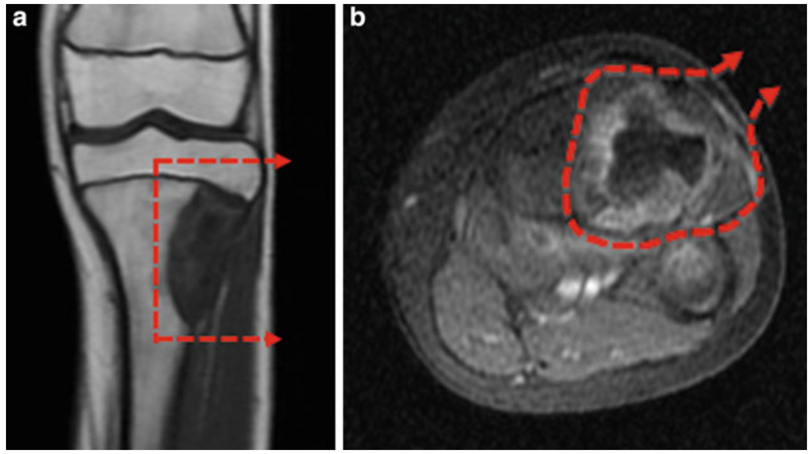

Fig. 9 Plan of tumor excision

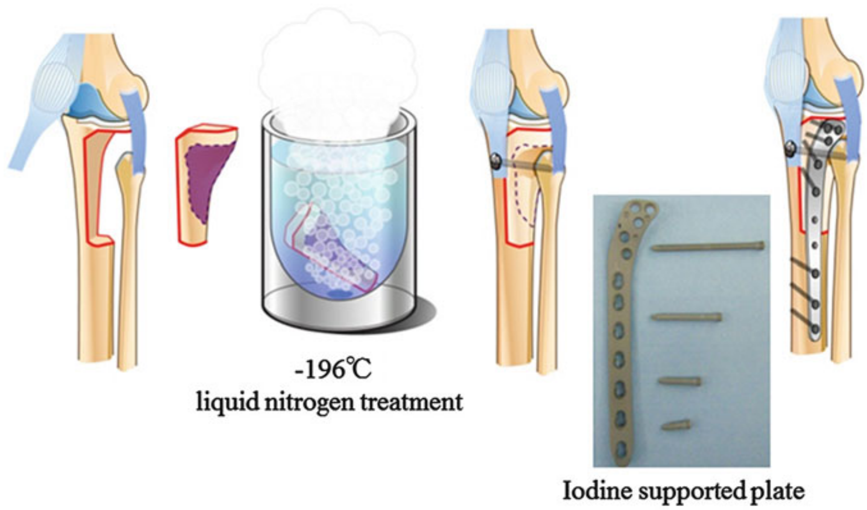

Fig. 10 Images of surgical procedure

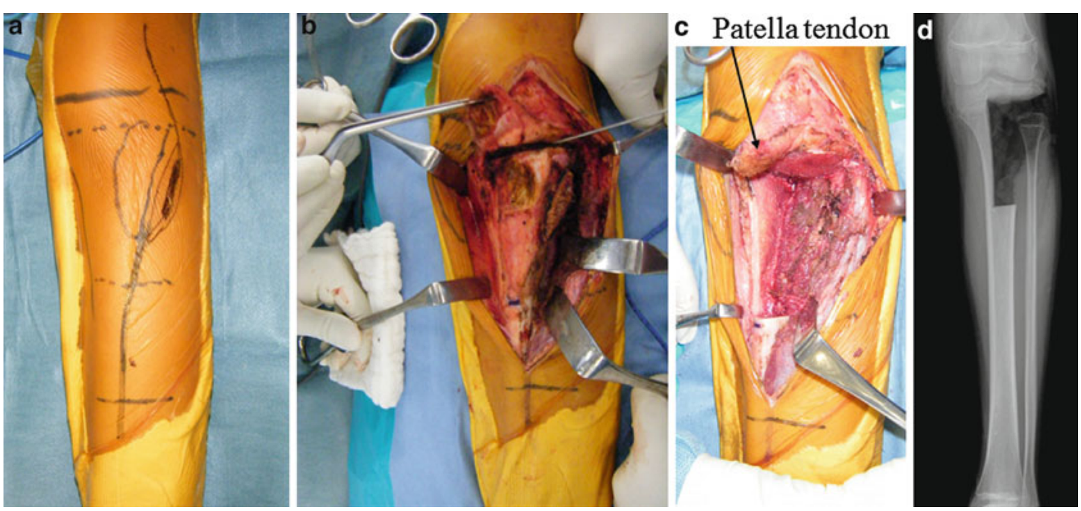

Fig. 11 (**a**–**d**) Intentional marginal excision. (**a**) Skin incision, (**b**) cutting tumor's proximal margin (K-wire guided), (**c**) after tumor excision, (**d**) radiograph after tumor excision

Fig. 12 (**a**–**d**) Preparation for freezing. (**a**, **b**) Tumor specimen (**a** medullary site, **b** bone surface site), (**c**) after curettage of the residual tumor, (**d**) after removing the surrounding soft tissue

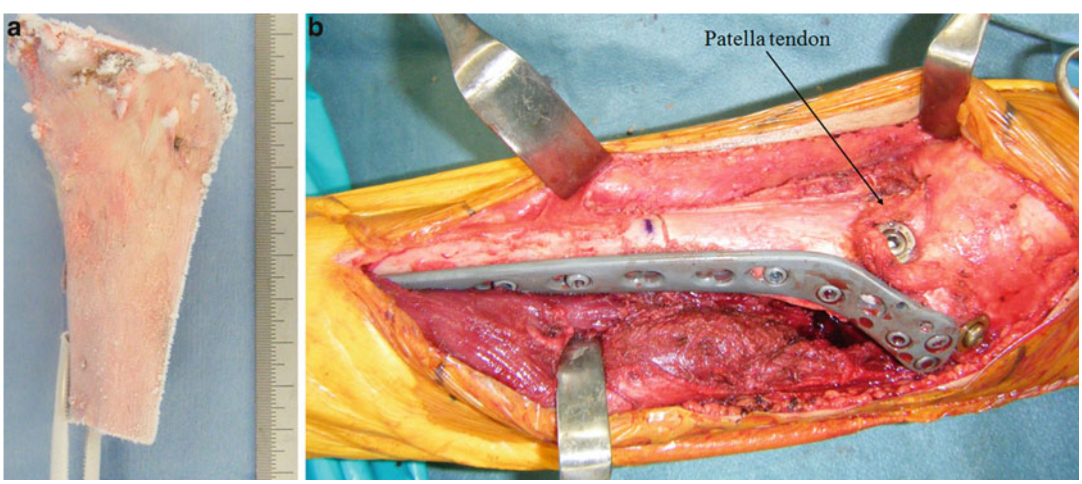

Fig. 13 (**a**, **b**) Freezing and reconstruction. (**a**) Just after freezing, (**b**) reconstruction using an iodine-supported plate and screws

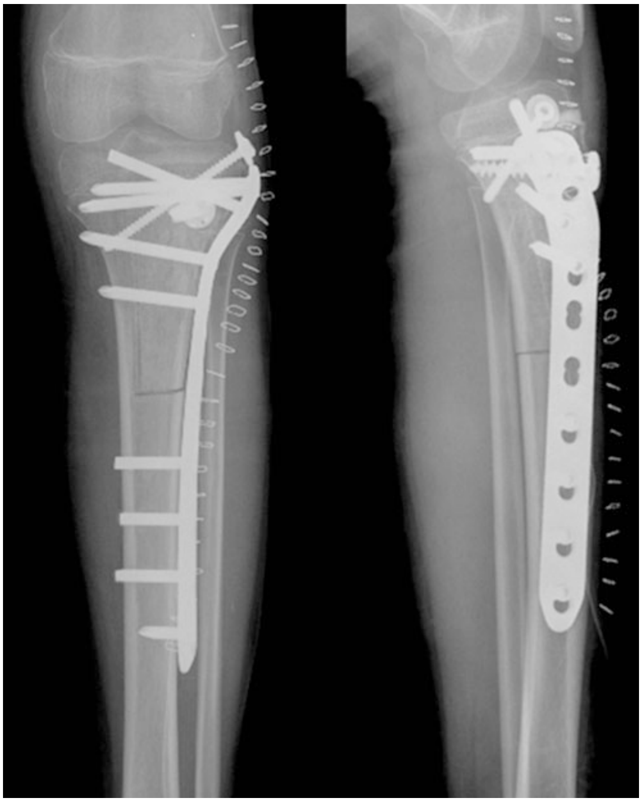

Fig. 14 Radiographs recorded immediately after surgery

9 Avoiding and Managing Problems

(a) Intentional marginal excision:
Precise evaluation of preoperative chemotherapy and tumor margins using MRI, thallium scintigram, and radiographs. To accurately excise the tumor, it is important to cut precise margins using an X-ray imaging intensifier.

(b) Freezing procedure:
To prevent graft fracture during freezing due to water volume expansion, it is important to curette the intramedullary canals and tumor contents.

10 Cross-References

▶ Case 75: Failed Allograft Reconstruction (Nonunion) for Malignant Bone
▶ Tumor: An Introduction

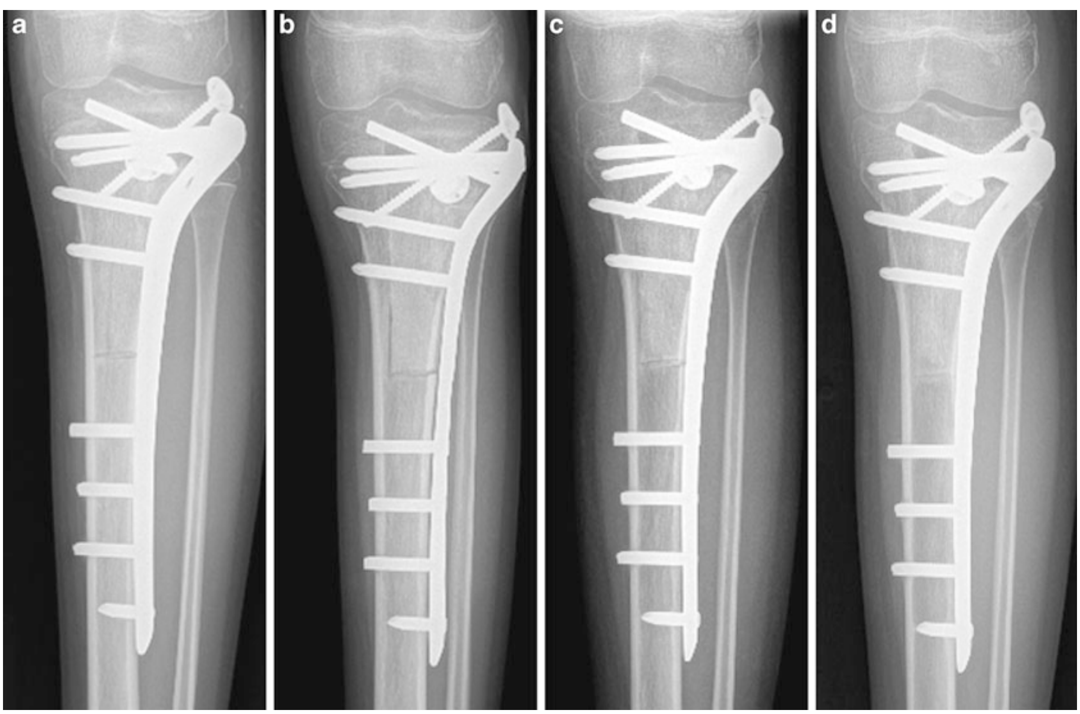

Fig. 15 (**a–d**) Postoperative radiographs. (**a**) 1 month, (**b**) 3 months, (**c**) 6 months, (**d**) 12 months

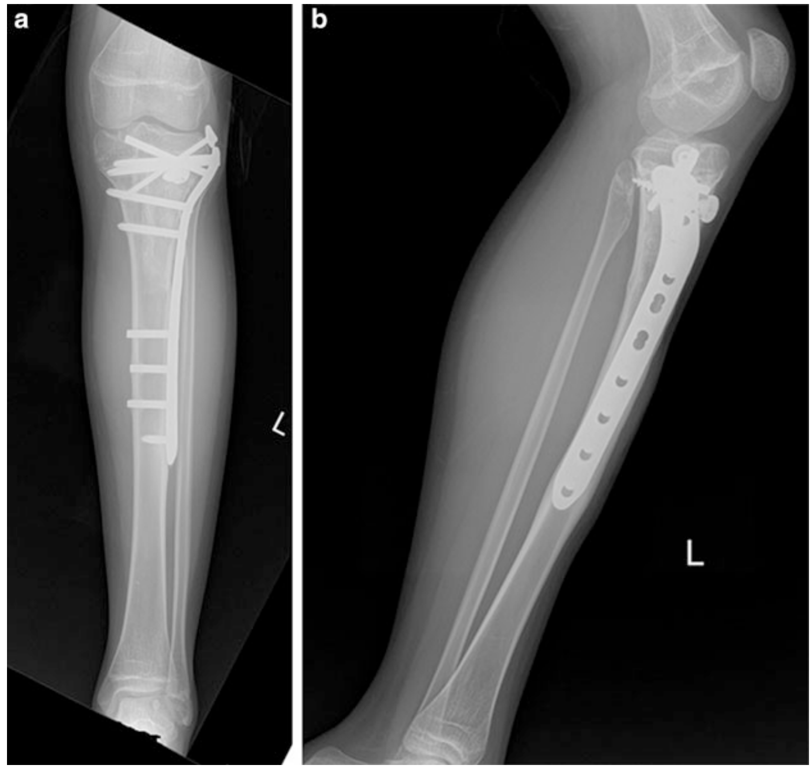

Fig. 16 Radiographs 30 months after operation

Fig. 17 Normal limb function was restored

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Tanzawa Y, Tsuchiya H, Shirai T, Hayashi K, Yo Z, Tomita K (2009) Histological examination of frozen autograft treated by liquid nitrogen removed after implantation. J Orthop Sci 14:761–768

Tsuchiya H, Wan SL, Sakayama K, Yamamoto N, Nishida H, Tomita K (2005) Reconstruction using an autograft containing tumour treated by liquid nitrogen. J Bone Joint Surg Br 87:218–225

Tsuchiya H, Nishida H, Srisawat P, Shirai T, Hayashi K, Takeuchi A, Yamamoto N, Tomita K (2010) Pedicle frozen autograft reconstruction in malignant bone tumors. J Orthop Sci 15:340–349

Tsuchiya H, Shirai T, Nishida H, Murakami H, Kabata T, Yamamoto N, Watanabe K, Nakase J (2012) Innovative antimicrobial coating of titanium implants with iodine. J Orthop Sci 17:595–604

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Case 71: Reconstruction of a 22 cm Femur Bone Defect with Transport Over Nail and Cable Technique

Mitchell Bernstein and S. Robert Rozbruch

Contents

Abstract

This is a case of a 34 year old femoral bone defect from a low-grade osteosarcoma seeking limb salvage. This complex revision was completed in two main stages. The first stage consisted of double-level femur osteotomy and bone transport over an intramedullary nail with a cable system. Stage 2 was accomplished by tibial lengthening with an intramedullary lengthening nail to correct residual limb length discrepancy (LLD).

1 Brief Clinical History

This is a 34 year old male with a history of a low-grade osteosarcoma of the right femoral shaft. He was initially treated with neoadjuvant chemotherapy, wide excision and femoral reconstruction with vascularized free-fibular autograft, and postoperative chemotherapy. The patient required multiple revisions of the free-fibular graft, which eventually failed. The bone defect was subsequently revised at an outside institution with femoral allograft and intramedullary nailing, which developed into an infected nonunion. The allograft and intramedullary nail were removed, the infection was treated, and a new intramedullary nail and allograft were attempted. This failed as well and the patient presented to us with an IM rod and cement in the bone defect. The recommendation for the patient was a hip disarticulation. The patient refused and presented to our clinic for an opinion regarding limb salvage. He presented 5 years after his initial resection, without recurrence of disease or infection.

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DOI 10.1007/978-3-319-18020-5_245

Fig. 1 Standing clinical photograph of the patient demonstrating limb length discrepancy, right short. Patient is standing on 4-cm block

Fig. 2 Clinical photo from side, demonstrating surgical incisions on right thigh and leg for attempted femur reconstruction using ipsilateral free-fibular graft

Fig. 3 Clinical photo of patient from behind

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, and 5.

3 Preoperative Problem List

1. Bone defect right femur 22 cm
2. LLD, right shorter than left, 4 cm
3. Total bone loss right lower extremity, 26 cm
4. Status post ipsilateral failed vascularized free-fibular bone graft
5. History of infected nonunion with multiple procedures to right femur
6. No recurrence of osteosarcoma

4 Treatment Strategy

This complex reconstruction was approached in two stages. The first stage was to remove the IM nail and cement. Then we would regenerate the femoral bone defect with a double-

Fig. 4 (**a**) AP and (**b**) lateral radiographs of the right femur demonstrating an intramedullary nail (*IM*) combined with bone cement spanning the 22-cm bone defect

level bone transport system over a new locked intramedullary nail using a cable-pulley system. This will decrease the time needed in the external fixator. The second stage incorporated tibial bone lengthening with a motorized magnetic intramedullary nail to correct any remaining right lower extremity bone loss.

5 Basic Principles

Large bone defects can be more efficiently managed with double-level osteotomy and bone transport. Bone transport over a nail helps maintain segment alignment and mitigate any sagittal or coronal displacement during transport. The large bone defect was reconstructed with a trifocal technique. With two osteotomies, there are two transport segments moving toward each other. Two regenerate areas of lesser size will unite more quickly than one large area.

Fig. 5 Fifty-one-inch standing erect leg radiograph demonstrating 22-cm bone defect of the right femoral shaft stabilized with an IM rod and bone cement. In addition, the patient had 4 cm of limb length discrepancy

The use of cable and pulleys is an alternative to Ilizarov wires in the transport segment cutting through the skin. Large bone defects are associated with large soft-tissue dead space, which is a risk factor for infection. Antibiotic cement is frequently used to maintain soft-tissue spaces and eradicate infection. Large bone transport segments are associated with resorption and sclerosis at the bone end, so expect the need for debridement to healthy bone and grafting. Nonunion at the docking site is not infrequent.

6 Images During Treatment

See Figs. 6, 7, 8, 9, 10, and 11.

7 Technical Pearls

1. Nonviable bone must be excised to ensure eradication of infection and allow for reliable bony union.
2. Utilization of the femoral arches can help navigate the shape of the femur and allow for anterior constructs.
3. The cable and pulley system is best used with Ilizarov clickers and it is soft tissue friendly. During bone transport, the cable slides under the skin in contrast to

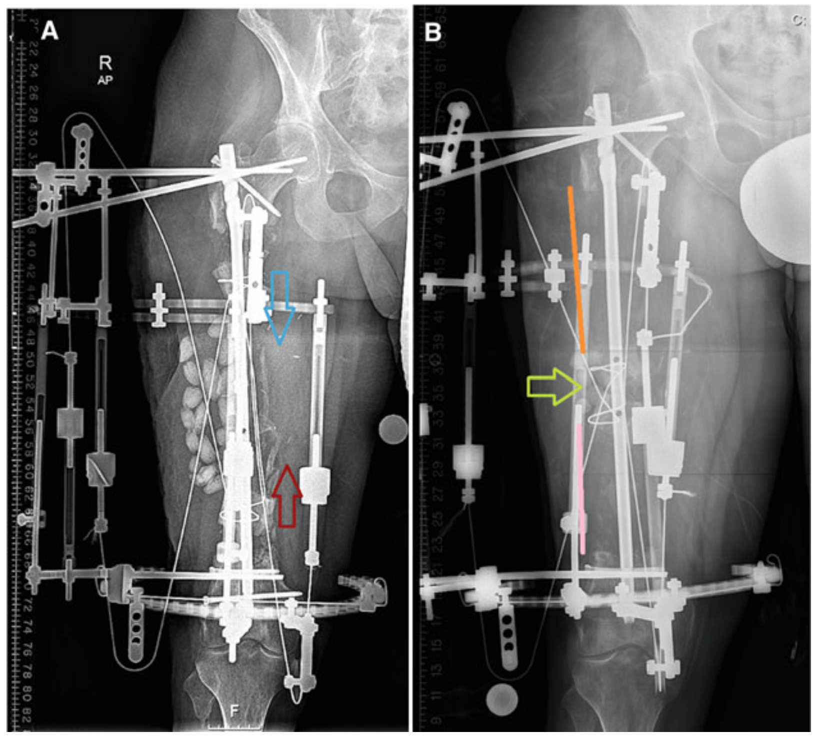

Fig. 6 AP femur X-rays at (**a**) 4 weeks and (**b**) 6 months status post initial double-level femoral osteotomies. Note placement of nonabsorbable antibiotic beads in (**a**) to manage wound infection and dead space during lengthening. The proximal transport segment is being pulled distally (*blue arrow*). The distal transport segment is being pulled proximally (*maroon arrow*) (**b**) at the end of lengthening surgery. Note the immature proximal regenerate (*orange line*), docking site plated (*lime arrow*), and the immature distal regenerate (*pink line*)

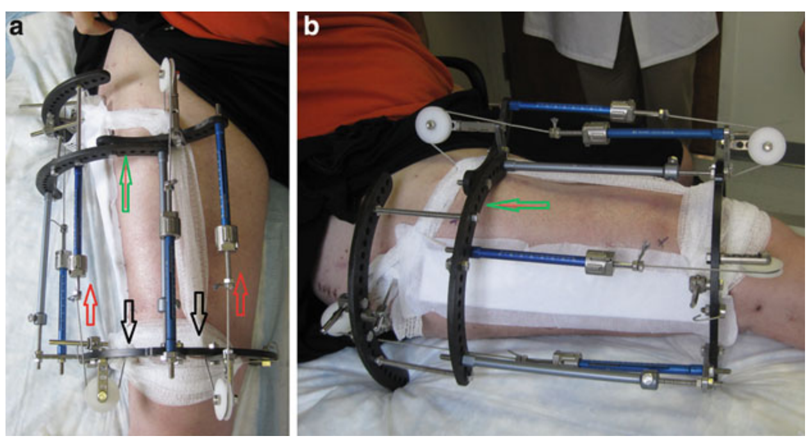

Fig. 7 Clinical photos of the external fixator from the front (**a**) and side (**b**). Femoral arches (*green arrows*) were used to connect anterior Ilizarov clickers off the lateral fixation. Four pulleys are on the frame – two are used to pull the proximal transport fragment in a distal direction and two are used to pull the distal transport fragment in a proximal direction. Note one pair of clickers is pulling the cable around the pulley. The fragment is pulled in a distal direction (*black arrows*) as the clicker pulls the wire in a proximal direction (*red arrows*). Another pair of pulleys is going in the other direction for the other transport fragment

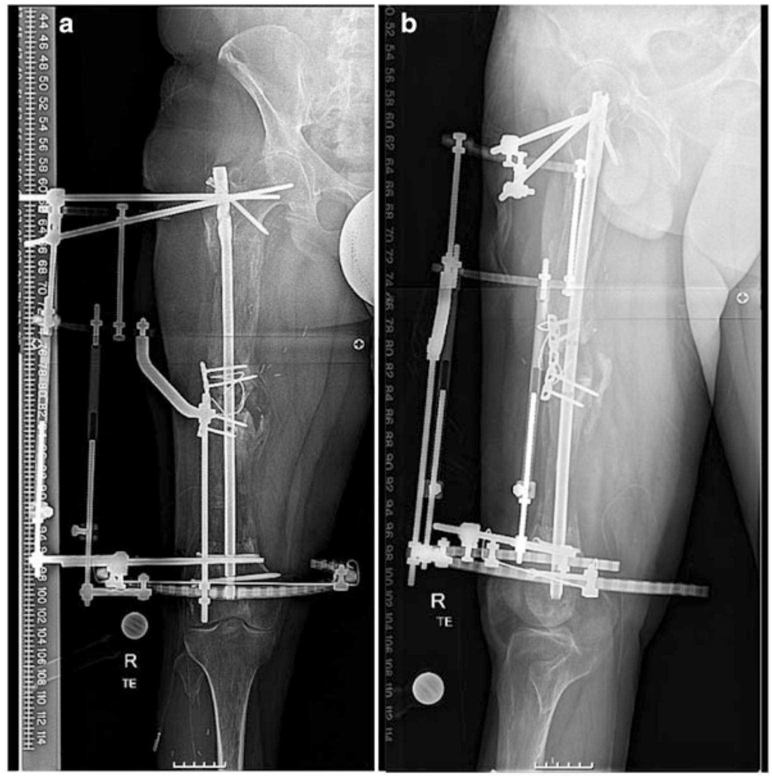

Fig. 8 (**a**) AP and (**b**) lateral radiographs of the right femur after lengthening surgery. Note the additional open reduction and internal fixation of the docking site, which was performed at the end of lengthening surgery. The modified frame (without pulleys) was left in place to add additional stability for a short while

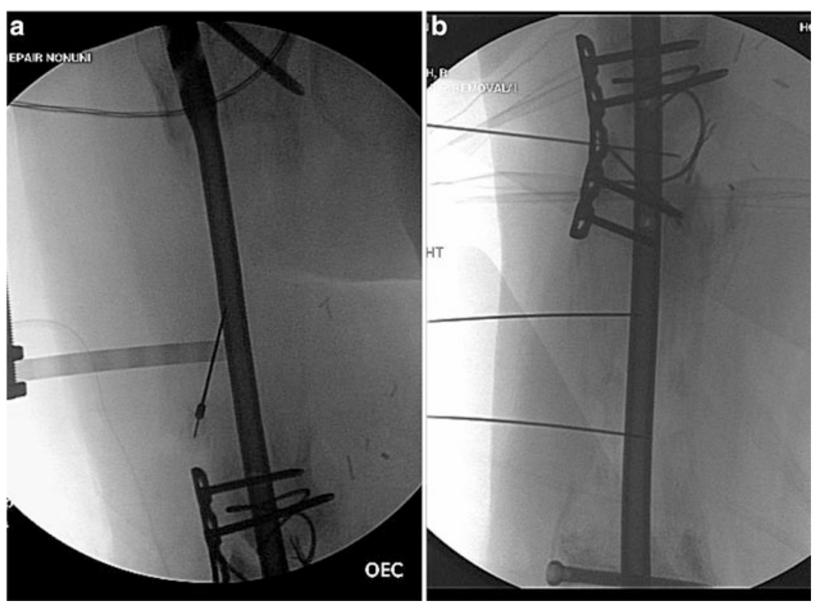

Fig. 9 (**a**) AP proximal and (**b**) AP distal femur demonstrating percutaneous injection of bone marrow aspirate concentrate into regenerate and docking site. Cells were obtained from bilateral iliac crest marrow. Procedure performed at 9 months post initial lengthening surgery to enhance bony healing of the distal femur regenerate

Fig. 10 Standing 51″ erect leg radiograph after removal of right femur external fixator. Bone healing of the proximal and distal regenerate and the docking site (spanned by short plate) is progressing. Note residual LLD, which amounted to 4 cm

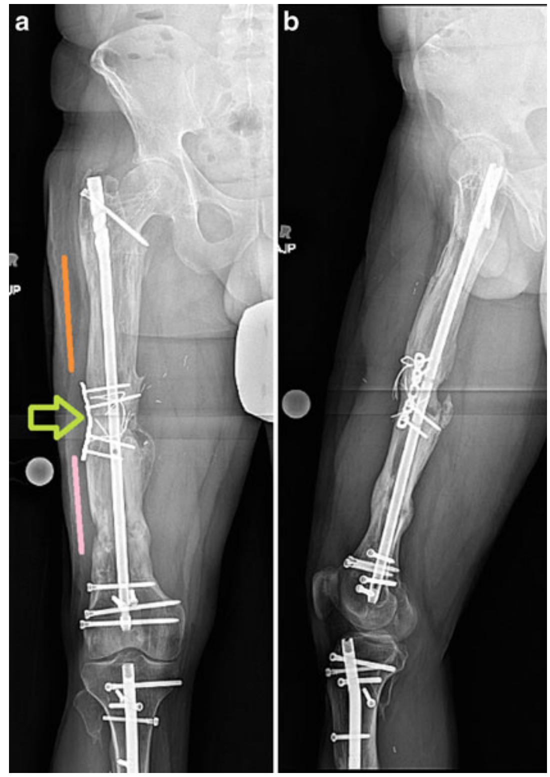

Fig. 12 Final (**a**) AP and (**b**) lateral radiographs of right femur demonstrating 22-cm healed defect. Note the bony union of the proximal regenerate (*orange line*), distal regenerate (*pink line*), and the docking site (*lime arrow*)

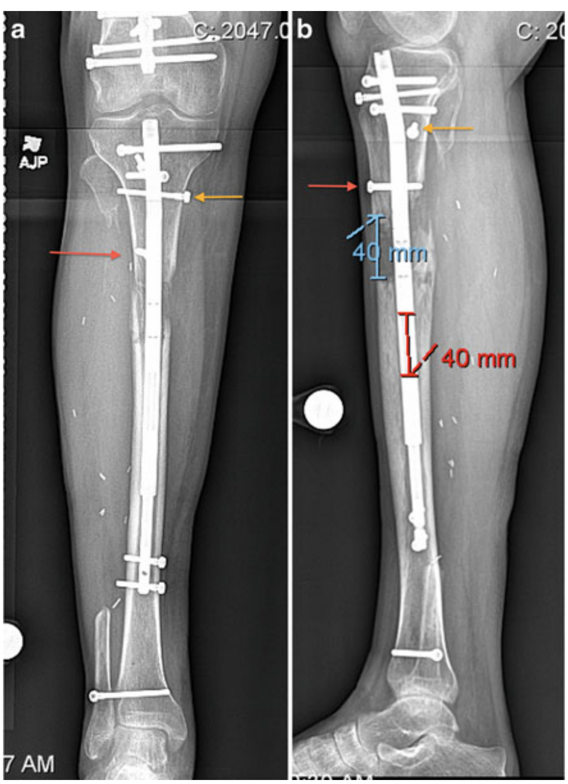

Fig. 11 (**a**) AP and (**b**) lateral of the right tibia after lengthening of 4 cm with intramedullary lengthening nail. Note the addition of anterolateral (*red arrows*) and posterior (*orange arrows*) blocking screws to avoid valgus and procurvatum deformities, respectively, during lengthening

wires that cut through the skin. Ensure proper tensioning during transport. Re-tensioning of cables may need to be done during the lengthening depending on the configuration of the frame. If this occurs, use of a Vise-Grip with smooth duckbills is preferred so that damage to the cable does not occur.

8 Outcome Clinical Photos and Radiographs

See Figs. 12, 13, 14, 15, 16, and 17.

9 Avoiding and Managing Problems

1. Patient selection, education, and frequent follow-up are essential for a successful outcome in complex cases such as those described. Patients should be motivated for limb salvage.
2. Adverse events may be inevitable in such cases. An aggressive surgical approach is best and mitigates decompensation into more severe complications.

Fig. 13 Final (**a**) AP and (**b**) lateral radiographs of right tibia post-internal lengthening nail removal. Note healed regenerate and maintenance of coronal and sagittal alignment. Four-centimeter lengthening was achieved

Fig. 14 Two-year postoperative standing 51-in. erect leg radiograph. Direct limb length measurements indicate residual 10-mm discrepancy, *right* shorter than *left*. Mechanical axis deviation, 6 mm medial

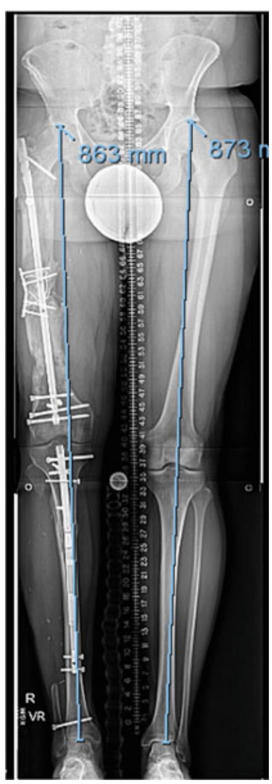

Fig. 15 Final standing clinical photograph

Fig. 16 Final standing clinical photograph demonstrating normal sagittal alignment, no knee flexion contracture, and a plantigrade foot without any perceived limb length inequality

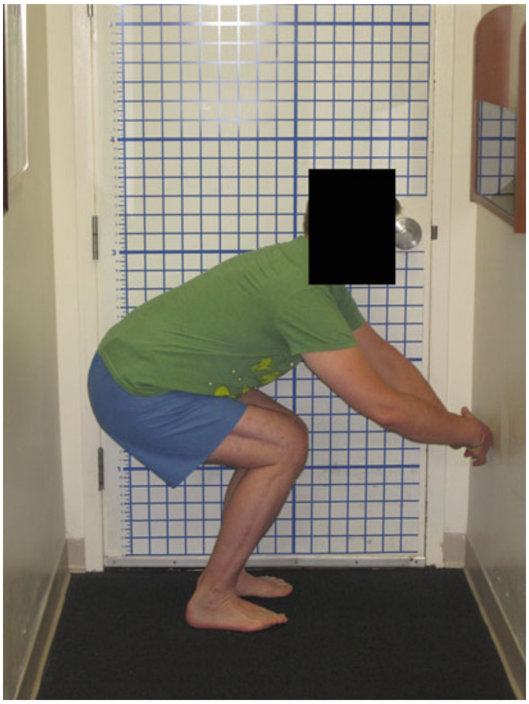

Fig. 17 Final 2-year clinical photograph of patient squatting. Patient has regained quadriceps strength and has knee flexion to 120°. Patient can now squat with 300 lb

3. A staged approach is best. Repeating a new 51-in. hip to ankle X-ray after stage one allows accurate planning of tibial lengthening for the large femoral bone loss.

10 Cross-References

▶ Case 61: Deformity Correction (Benign Bone Tumor) in Lower Limb Using Taylor Spatial Frame

11 See Also in Vol. 2

Case 7: A 12 cm Traumatic Femoral Defect Treated with a Long Oblique Diaphyseal Femoral Osteotomy and Lengthening Over a Nail
Case 9: Limb Salvage After Massive Traumatic Femoral Bone Loss
Case 11: Bone Transport Over a Nail for Infected Tibial Nonunion and Bone Defect

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Case 72: Reconstruction of a Bone Defect, Following Resection of Chondrosarcoma in the Distal Forearm by Segment Transport Over Nail Technique Using Uniplanar Fixator

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Contents

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Abstract

The reconstruction of forearm defects after tumor excision is one of the most challenging cases for orthopedic surgeons. The complex anatomy and high mobility of the region require personalized approaches, and the results usually include serious function loss. We present a patient with a distal radius mass, where the forearm was reconstructed with bone transport and wrist fusion.

1 Brief Clinical History

A 48 year old male presented to our clinic complaining of a progressing forearm mass. He noted that the mass appeared just proximal to the wrist 15 years earlier, but it had converted to rapid growth over the last 9 months. Following this recent rapid progression, an incisional biopsy was performed and grade II chondrosarcoma was diagnosed.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

a. Chondrosarcoma of the distal radius.
b. Possible invasion of neurovascular structures, flexor musculature, and tendons.
c. Radial and ulnar bone defect following resection (radiocarpal and radioulnar joints).

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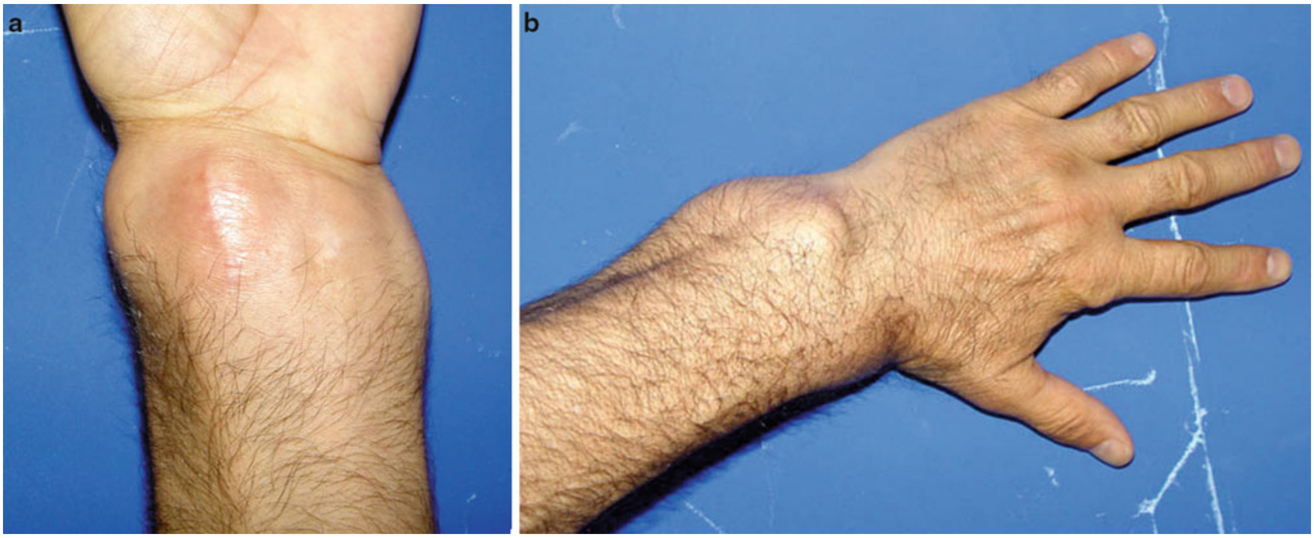

Fig. 1 Clinical pictures of the distal forearm. A biopsy was performed through a small volar incision (**a**). Clinical photo of the dorsal wrist (**b**)

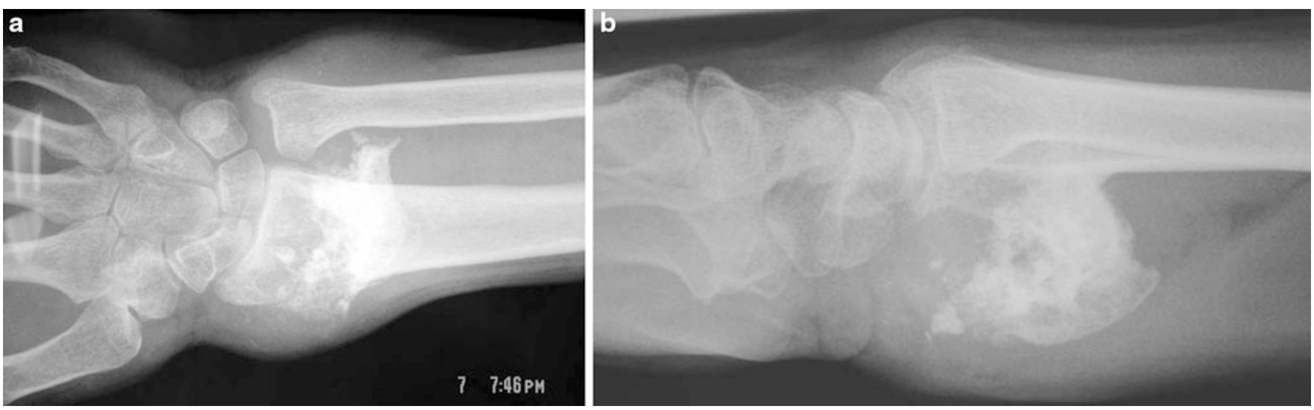

Fig. 2 AP (**a**) and Lat (**b**) radiographs of the mass, originating from the distal radius, invading the distal radioulnar joint and ulna

d. Secondary reconstruction surgery will be necessary for wrist arthrodesis.
e. The patient should be prepared and ready for amputation in any stage of the treatment.

4 Treatment Strategy

a. Resection with at least 1 cm of safe zone of the radius and ulna, also with sufficient soft tissue barrier and safe zone
b. Diaphyseal radial osteotomy and bone transport over nail, with uniplanar fixator
c. Conversion to plate fixation to achieve early fixator removal and regenerate consolidation

5 Basic Principles

a. Adequate tumor excision based on preoperative planning, including distal ulna
b. Preparing and utilizing intramedullary nail through first carpal row
c. Application of uniplanar fixator avoiding contact with the IM nail
d. Gradual bone transport (0.5–1.0 mm/day)
e. Integrated fixation technique with use of internal and external fixation. Early removal of fixator after bone transport to avoid infection. Application of a plate to preserve the regenerate
f. Staged wrist fusion with removal of IM nail and fusion plate insertion

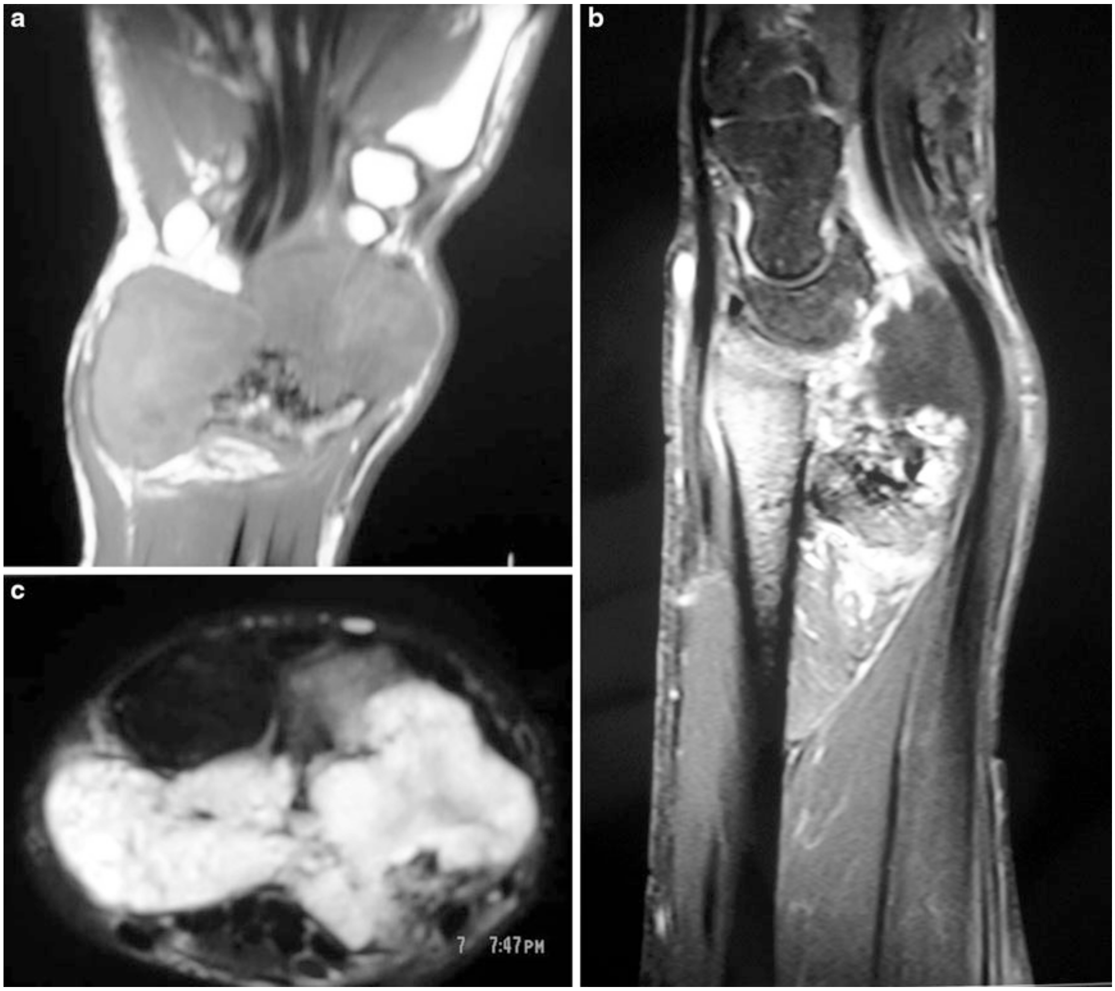

Fig. 3 Magnetic resonance imaging of the mass reveals its expansion toward ulna and volar neurovascular structures (**a**, **b**, **c**)

6 Images During Treatment

See Figs. 4, 5, 6, and 7.

7 Technical Pearls

a. To avoid contamination half pins should not contact the nail. Cannulated half pin insertion technique was used to place half pins strategically missing the nail with bone separating the pins and the nail.
b. It is hard to achieve union at the docking site between the transferred diaphyseal segment and carpal bones (compared to metaphyseal bones). Bone grafting, plating, or any other second surgery is usually necessary to achieve union.
c. Alternatively, it is possible to use vascularized fibula graft to bridge the radial defect and achieve wrist arthrodesis. However, vascularized fibular grafting was contraindicated in this patient due to a previous bilateral tibia–fibula open fracture after a car accident.

8 Outcome Clinical Photos and Radiographs

See Fig. 8.

9 Avoiding and Managing Problems

Excising the tumor with safe margins is the most important management task. For the reconstruction, preoperative planning is vital for both successful excision and frame mounting.

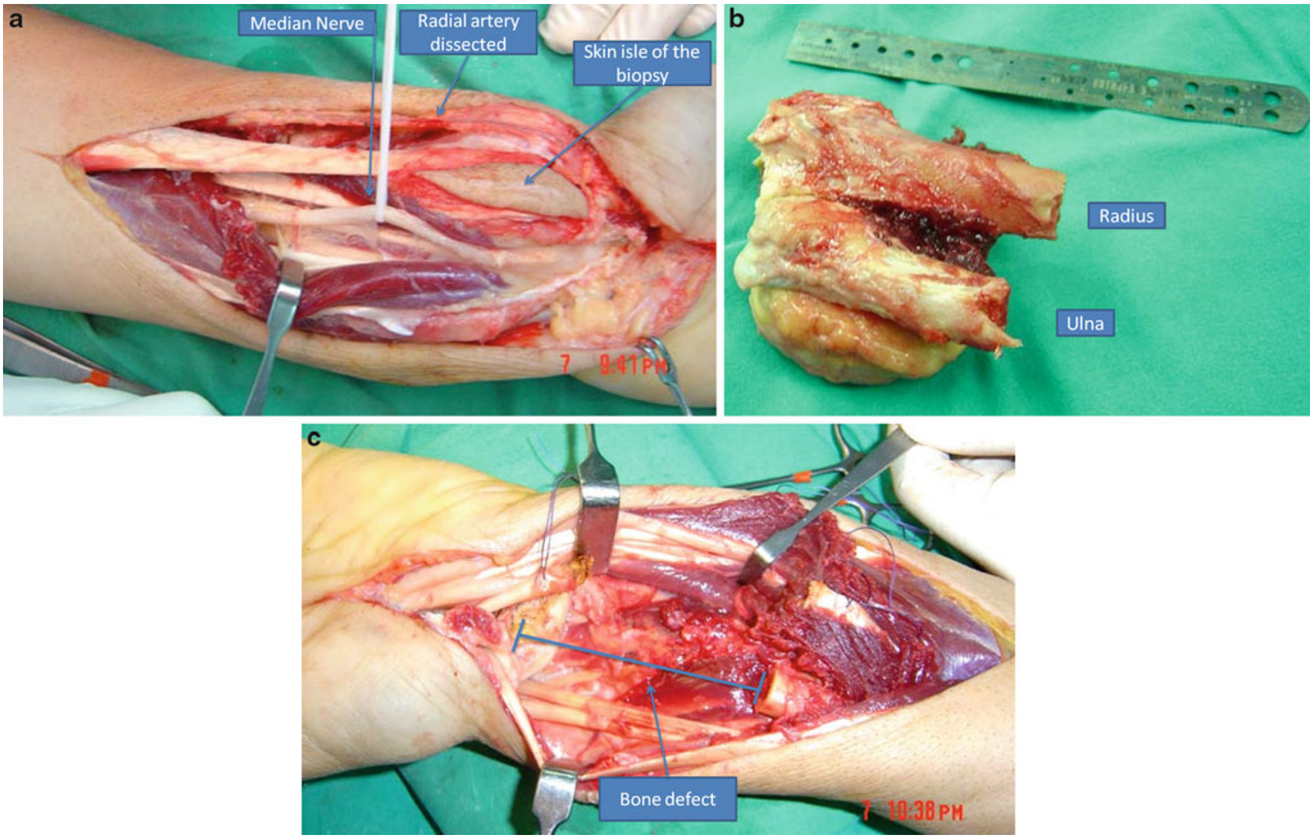

Fig. 4 Intraoperative dissection of the median nerve (**a**). Biopsy incision was left on the mass as a skin island (**b**). Both distal radius and ulna, including expanded tumor and surrounding soft tissues at the volar side, were included. Clinical photo of the bone defect, following resection (**c**)

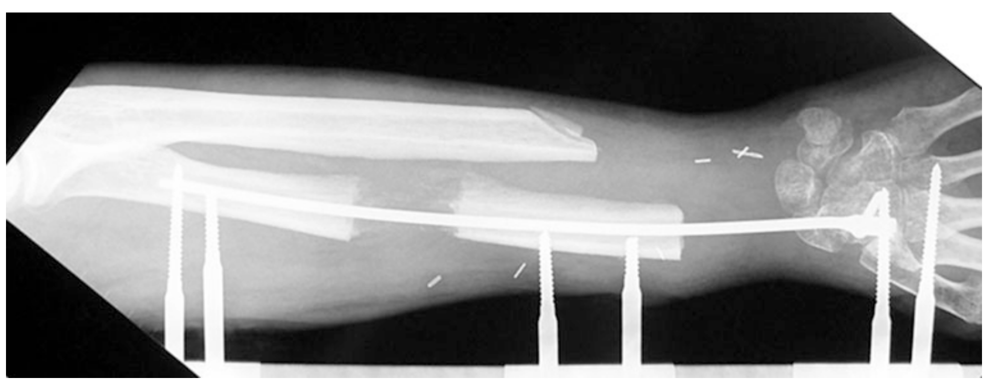

Fig. 5 AP radiograph of the forearm during segment transport. Note the unicortical pin placement and the good quality of the regenerate

Fig. 6 Clinical photo of the forearm at the end of the transport

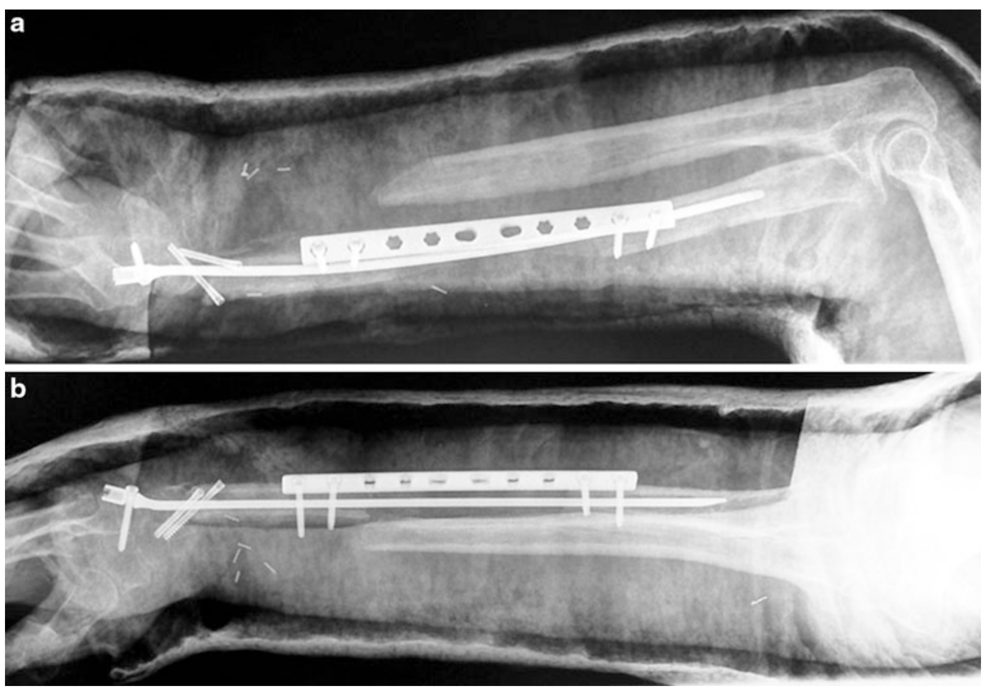

Fig. 7 AP (**a**) and Lat (**b**) radiographs following fixator removal. A broad plate was used to preserve regenerate as the nail is not stable itself

Fig. 8 Following ossification of the regenerate, the nail was removed, and a wrist arthrodesis plate was used to achieve solid union between transported segment and carpal bones. AP (**a**) and Lat (**b**) X-rays

10 Cross-References

- ▶ Case 71: Reconstruction of a 22 cm Femur Bone Defect with Transport Over Nail and Cable Technique
- ▶ Case 93: Correction of Forearm by Corrective Radial Osteotomy and Ulnar Lengthening by Distraction Osteogenesis Deformity in Hereditary Multiple Osteochondromatosis

11 See Also in Vol. 2

Case 11: Bone Transport Over a Nail for Infected Tibial Nonunion and Bone Defect

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Case 73: Pathologic Femur Fracture Close to Distal Femoral Physis

Christopher Iobst

Contents

Abstract

This case highlights the power of external fixation in pediatric trauma. An 8 year old male suffered a pathological fracture of the right distal femur just proximal to the distal femoral physis. The distal fragment was too small for rodding or plating. A circular external fixator was used to successfully reduce and stabilize the fracture. Fixation using wires and pins was achieved in the small distal femoral fragment without disturbing the physis or the knee joint. The more fracture fixaton techniques the surgeon has in his/her armamentarium the better the treatment options for the patient.

1 Brief Clinical History

An 8 year old male presents to the emergency department with pain in his right lower extremity after a fall at school. He is unable to bear weight. This appears to be an isolated injury, and he has an intact neurovascular examination. Radiographs reveal a pathological fracture of the right distal femur. The distal femoral lesion is benign appearing but is large (approximately 5 cm diameter) and located just proximal to the distal femoral physis. He is splinted and admitted to the hospital for definitive treatment of the injury.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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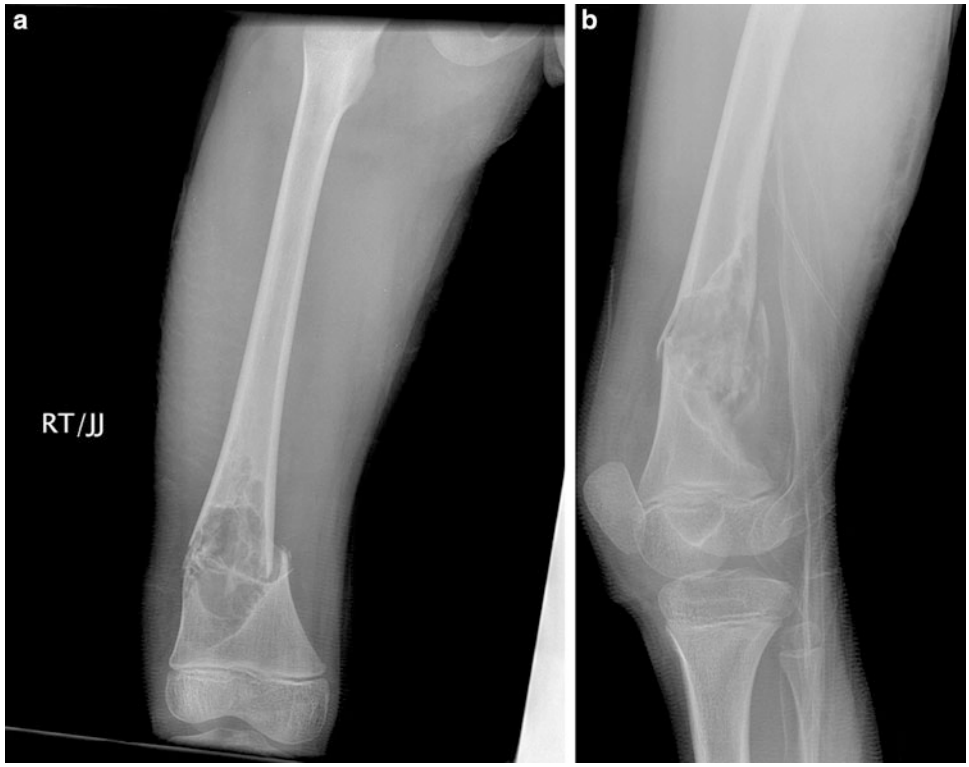

Fig. 1 The antero-posterior (**a**) and lateral (**b**) images demonstrate a minimally displaced pathologic fracture of the right distal femur. The lesion is located just proximal to the distal femoral physis

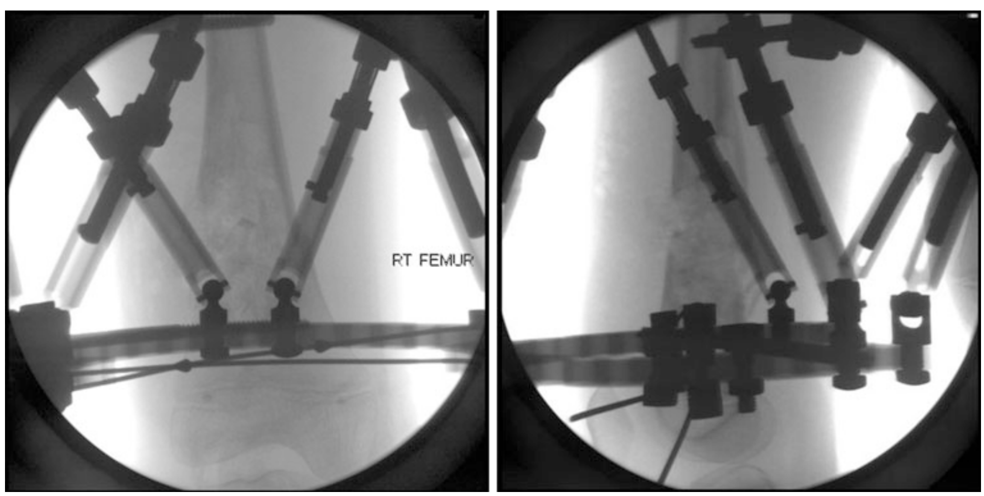

Fig. 2 (**a** and **b**) Intraoperative images demonstrate anatomic reduction of the femur fracture. The distal fragment has been fixed with two opposing olive wires and a single half pin in the metaphyseal bone

3 Preoperative Problem List

1. Pathological fracture of the femur with thinning of the femoral cortex adjacent to the lesion.
2. The small fragment of metaphyseal bone between the cyst/fracture and the distal femoral physis does not leave much space for orthopedic implants (plate/screws, solid intramedullary rod, flexible intramedullary rod).

4 Treatment Strategy

1. Femoral lesion will need intraoperative tissue sample for frozen section.
2. Assuming the lesion is benign, the lesion will require curettage and grafting.
3. The femoral fracture will need stabilization. A long leg cast or a single-leg spica cast could be used but would

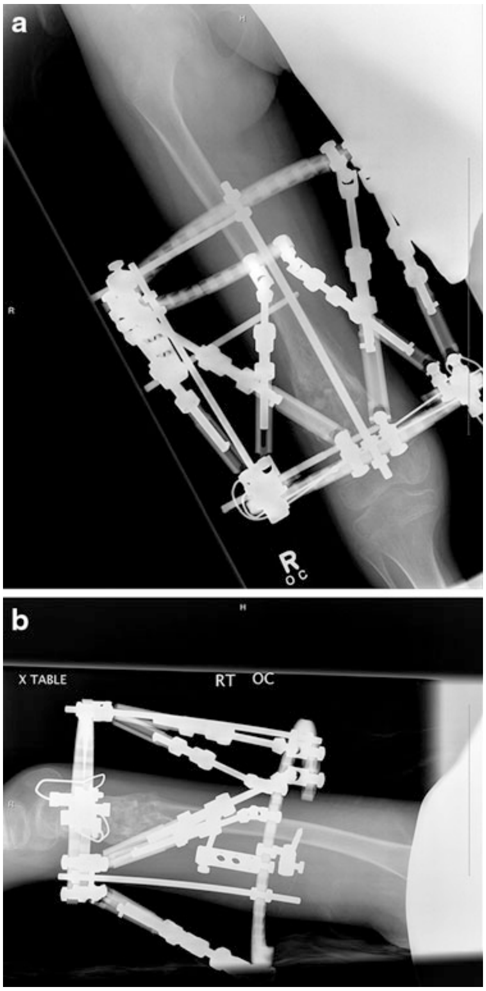

Fig. 3 Antero-posterior (**a**) and lateral (**b**) radiographs reveal periosteal new bone formation at the fracture site with maintenance of alignment. Note that threaded rods were added to the frame to increase its stability and prevent loss of reduction from occurring

Fig. 4 Antero-posterior (**a**) and lateral (**b**) radiographs after frame removal. The fracture has healed in excellent alignment. The femoral lesion shows consolidation compared to the injury radiographs. The distal femoral physis appears intact with no evidence of growth arrest or angular deformity

require a long duration of immobilization. External fixation with fine wires would allow the fracture to be stabilized and permit the range of motion of the knee to be preserved. The wires would have to be carefully placed in the metaphyseal bone to avoid injuring the physis. Wires could be placed in the epiphysis if necessary, but they would potentially increase the risk of septic arthritis. The external fixator would also allow early weight-bearing to occur.

5 Basic Principles

- All bone lesions should be biopsied and cultured for infection.
- The fracture site should be disturbed as little as possible. The lesion can be curetted and grafted through a percutaneous incision. The external fixator will allow an accurate closed reduction to be performed without having to open the fracture site.
- Multiplanar fixation should be applied to each fracture fragment. The long proximal fragment should have the fixation spread over the length of the bone. The surgeon should avoid clustering the pins close together.
- Due to the small size of the distal fragment, the surgeon may choose to bridge the fixation across the knee joint. Placing additional two or three half pins in the proximal tibia will create a stable ring block spanning the knee between the distal femur and the proximal tibia.
- The external fixator should be dynamized over the course of treatment. The bone must be trained to accept more weight as the healing advances.

- The subsequent growth of the limb will need to be monitored until skeletal maturity. Leg length discrepancy or angular deformities may develop over time due the injury or the treatment.

6 Images During Treatment

See Figs. 2 and 3.

7 Technical Pearls

- In order to fit fixation in a small space, a combination of wires and half pins can be used. This construct used a reference wire below the ring (lateral to medial), an opposing olive wire placed obliquely crossing from above the ring to below the ring (posteromedial to anterolateral), and a half pin placed directly on the proximal side of the ring through a pin fixation bolt.
- Fast fix struts assist in the reduction of the fracture but can become accidentally unlocked during the postoperative healing phase. Adding threaded rods to the frame can prevent loss of reduction from occurring if one of the struts becomes unlocked. Always remember to check that the locking sleeves are fully seated (pushed up all of the way) on each Fast fix strut.
- In order to make the frame construct more comfortable, two or three rings can be used. The distal ring should have the opening facing posteriorly, and the proximal ring should have the opening facing medially.

8 Outcome Clinical Photos and Radiographs

See Fig. 4.

9 Avoiding and Managing Problems

1. Pins and wires located near the joint have an increased risk of pin track infection. The skin should be stabilized with sponges or gauze dressings to decrease the movement around the pin. Before waking the patient, the knee should be placed through a complete arc of motion (full flexion to full extension) to evaluate the skin movement around each pin and wire. Any tension on the skin around the pin or wire should be released.
2. If the fixation in the small distal fragment seems insufficient, then the frame should have additional fixation added to the proximal tibia and span the knee.
3. External fixation of femur fractures is known to have the risk of refracture after frame removal. Dynamize the fracture during the treatment course by gradually removing fixation points. This will help the bone to accept progressively more load. The patient should be comfortably fully weight bearing before the frame is removed.

10 See Also in Vols. 1 and 2

Case 10: Distal Femoral Fracture Treated Initially with Internal Fixation Converted to Circular External Fixation due to Nonunion and Hardware Failure (Vol. 1)
Case 4: Computer Assisted External Fixation at Femur Malunion Accompanied with Complex Deformity (Vol. 2)

References and Suggested Reading

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Part XIII

Tumor: Reconstruction of Failed Initial Treatment

Case 74: Oncologic Defects: Reconstruction Following Initial Treatment Failure

George Cierny III

Contents

Abstract

Twenty-nine-year-old woman, 4.5 months post-radical resection and reconstruction of the left tibia for an adamantinoma at mid-shaft. Margins were clear of tumor. The initial reconstruction, a free fibula anastamosed to the posterior tibial artery (end to end), failed and suppurated (coagulase-negative staphylococcus [CNS]), requiring serial debridements and skin grafts to bone and soft tissues, anteriorly. Secondary reconstruction consisted of a (Companacci and Zanoli 1966) tibiofibular synostosis and long leg cast. At presentation, her extremity was flail and draining (*Serratia*, CNS). An angiogram disclosed tied off posterior tibial and peroneal arteries, an intact anterior tibial artery, and excellent runoff, distally.

1 Brief Clinical History

Twenty-nine-year-old woman, 4.5 months post-radical resection and reconstruction of the left tibia for an adamantinoma at mid-shaft. Margins were clear of tumor. The initial reconstruction, a free fibula anastamosed to the posterior tibial artery (end to end), failed and suppurated (coagulase-negative staphylococcus [CNS]), requiring serial debridements and skin grafts to bone and soft tissues, anteriorly. Secondary reconstruction consisted of a (Companacci and Zanoli 1966) tibiofibular synostosis and long leg cast. At presentation, her extremity was flail and draining (*Serratia*, CNS). An angiogram disclosed tied off posterior tibial and peroneal arteries, an intact anterior tibial artery, and excellent runoff, distally.

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Fig. 1 The anterior wound bed was ischemic and adherent

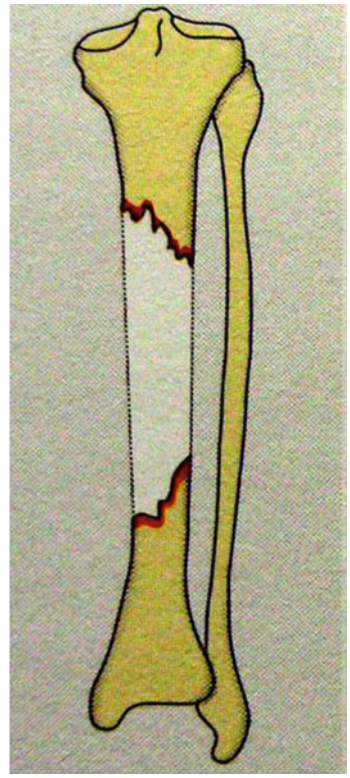

Fig. 2 X-rays demonstrated a 15 cm segmental defect of the left tibia, multiple screw holes in both metaphyses, a 10° varus deformity, and an *intact fibula*

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

(a) Fifteen-centimeter, composite, intercalary defect of the lower leg
(b) A single-vessel extremity (anterior tibial artery)
(c) Low patient confidence following multiple, failed treatments
(d) Nonunion, malalignment, and shortening

4 Treatment Strategy

(a) Establish a live, clean, manageable wound (Cierny 2011).
(b) Preserve existing vascular status.
(c) Increase "therapeutic options" with treatment, if possible.
(d) Strive for a 2-stage "clean reconstruction" (Cierny 2011).

5 Basic Principles

(a) *1st Stage*
1. Adequate and complete debridement
2. Dead space management with antibiotic depots (Cierny 2011)
3. Durable wound coverage (free-tissue transfer)
4. Stabilization

(b) *2nd Stage*: Follow the Reconstructive Ladder (Least to Most Morbid (Surgical))
1. *1st option*: Diaphyseal allograft/medullary fixation is contraindicated due to probability of cross contamination of canals (screws) and a prolonged (over 2 weeks) external fixation interval prior to implantation.
2. *2nd option*: Transport over nail (TON) (Kocaoglu et al. 2006).

Fig. 3 Initial treatment was an attempted proximal-to-distal transport utilizing a custom transport leash on the segment, a distal motor, and cables passing through the transport alley in order to avoid injury to the free flap and her residual vasculature. This method was aborted within the first 2 weeks of distraction due to increasing pain and distal blanching due, in part, to entrapment of the anterior bundle by heterotopic bone and/or callus attached to the transport segment

Fig. 5 At 3 years of follow up, she remained pain-free, infection-free, and WBAT without assistance despite an 8° varus "drift." At 7 years, new pain developed just below her knee with weight bearing

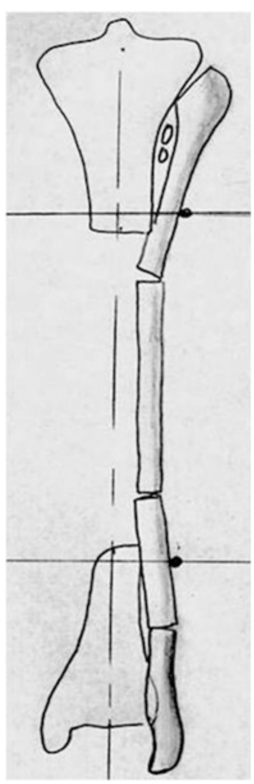

Fig. 4 The regenerate was compressed to decompress the vessel and a fibular centralization planned and executed utilizing the circular frame for fixation. She healed in 5 months, stayed in a frame for 8 months, and wore a custom-made PTB (clamshell) orthosis until the fibula hypertrophied sufficiently (2 years)

3. *3rd option*: Fibular centralization (Ilizarov) (Catagni et al. 2007; Companacci and Zanoli 1966; Huntington 1905).
4. *4th option*: Staged Masquelet grafting + IM nail (Donegan et al. 2011) is contraindicated due to compromised canals and osteoporosis (from disuse).

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

1. Avoid and anticipate cross contamination of canals from fixation pins when staging methods of internal fixation.
2. Obtain and be mindful of vascular studies when both planning and executing treatment options.
3. Educate your patients as to the signs and symptoms of ischemia during transport.

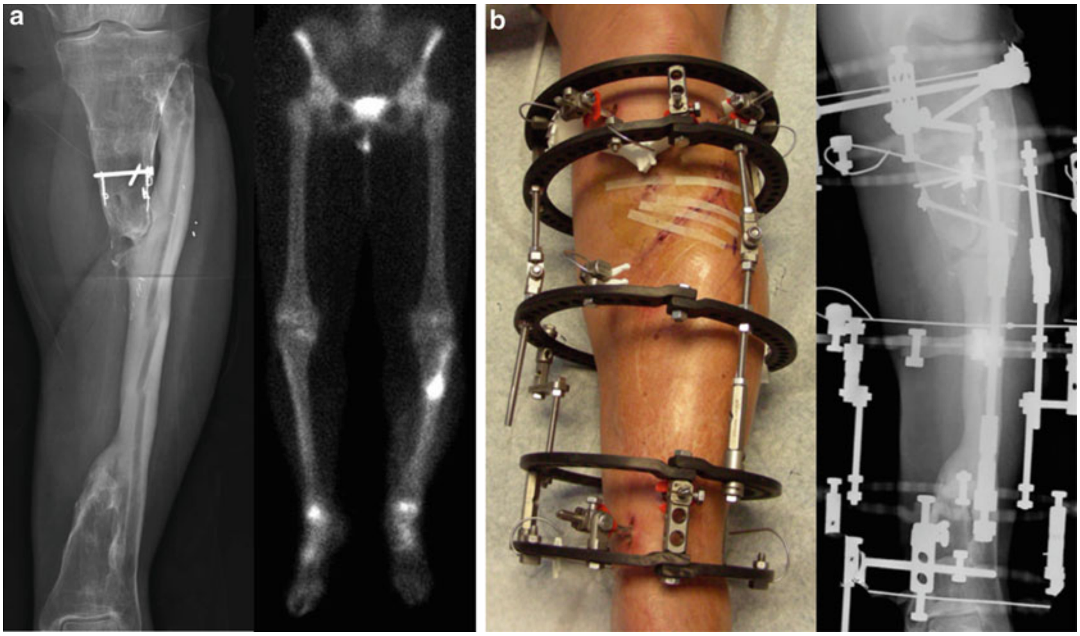

Fig. 6 (**a**, **b**) X-rays and bone scan disclosed a proximal pseudarthrosis, where the transposed fibula interfaced distal-most aspect of the proximal tibial segment

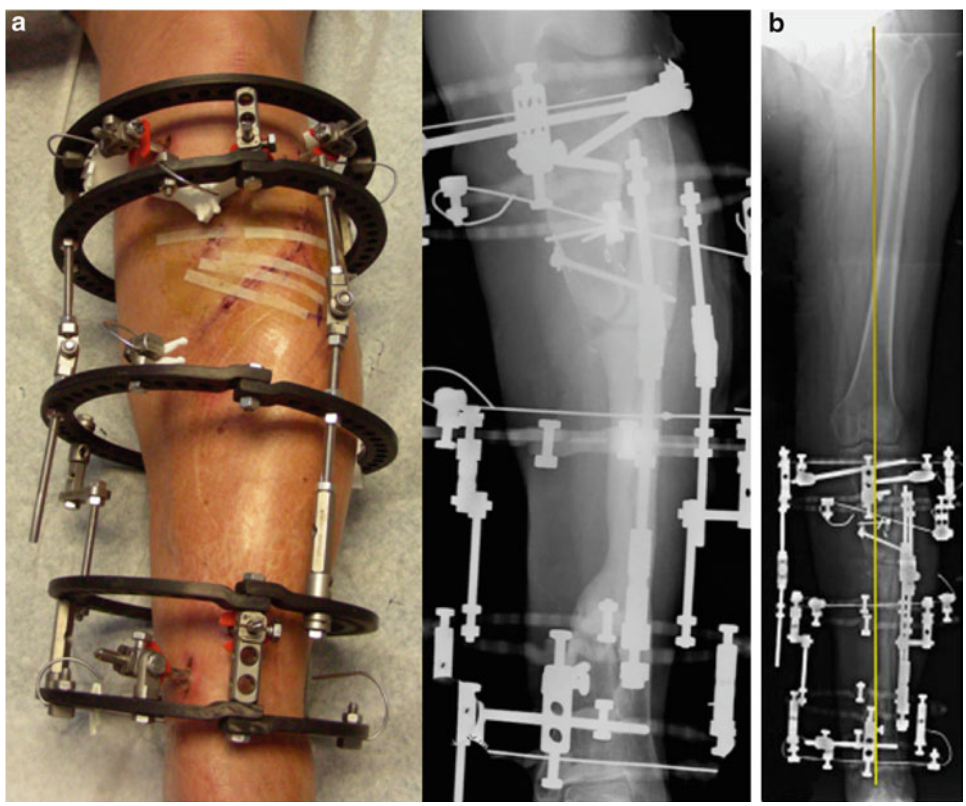

Fig. 7 (**a**, **b**) At retreatment, a circular frame and corticotomy were again used to restore her mechanical axis

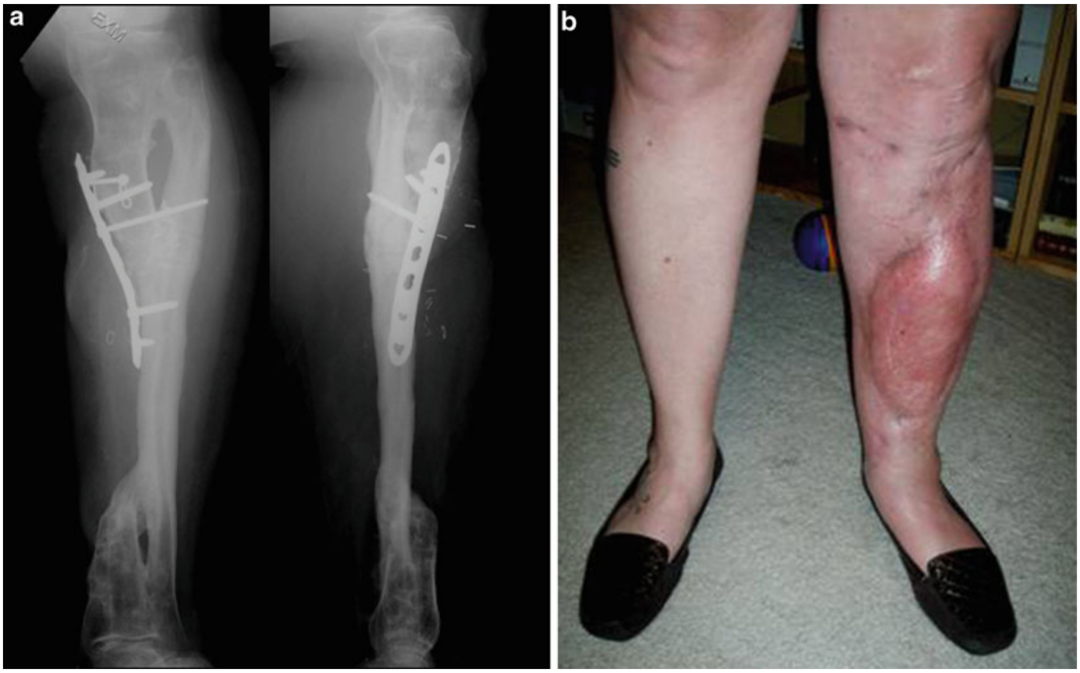

Fig. 8 (**a**, **b**) Following correction, a lag screw, used to stabilize the cross-union during distraction, was replaced with a percutaneous plate and the frame worn until union

4. Like Ilizarov's pelvic support osteotomy (Kocaoglu et al. 2002), fibular centralizations tend to be under-corrected (during) and drift (following) treatment. This reinforces the need for prolonged orthotic protection and emphasizes the need for advising patients that adjustments are common, down the line.

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

9 Avoiding and Managing Problems

1. Anticipate, be cognizant, and stay responsive to problems to both minimize their impact on outcomes and keep patients both informed and willing to move forward when the going gets tough. In this case, heterotopic bone moving with the transport segment placed traction and pressure on her anterior tibial vessels after just 12 mm of transport, forcing us to abandon this method and proceed with a centralization (safer). The retained hardware seen in Figs. 5 and 6a is reminiscent of a "leash" created to facilitate purchase of transport cables based distally.
2. When met with a recalcitrant nonunion (proximal tibial interface), we did not hesitate to move on to another method to obtain union, namely, ORIF/ex-fix assist. To decrease risk, we:
   (a) Moved pins out of the operative zone
   (b) Cultured/treated pin tract pathogens for 7–10 days prior to ORIF
   (c) Added antibiotic powder to the cancellous grafts at implantation

10 Cross-References

▶ Case 52: Bifocal Staged Bone Transport of a 30 cm Defect Including the Knee Joint
▶ Case 54: Deformity Correction (Tibial Bone Defect due to Osteomyelitis) in Lower Limb Using Taylor Spatial Frame
▶ Case 66: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Diaphyseal Tibia Using Circular External Fixator with Trifocal Bone Transport (Distraction Osteogenesis)
▶ Case 69: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proximal Tibia Using Taylor Spatial Frame (Distraction Osteogenesis)
▶ Case 72: Reconstruction of a Bone Defect, Following Resection of Chondrosarcoma in the Distal Forearm by Segment Transport Over Nail Technique Using Uniplanar Fixator

11 See Also in Vol. 1

Case 117: Chronic Osteomyelitis and 5 cm Bone Defect Treated with Masquelet Technique Followed by Ilizarov

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Case 75: Failed Allograft Reconstruction (Nonunion) for Malignant Bone

Austin T. Fragomen

Contents

Abstract

Reconstruction of bone defects after malignant tumor resection is often accomplished with fibular allograft. Fracture and nonunion are known complication of this technique. The following case will illustrate a method for treating a failed structural allograft utilizing autologous bone graft and external fixation. This is an alternative to salvage with a free vascularized fibular autograft.

1 Brief Clinical History

This is a 30 year old female who had resection of an osteosarcoma of the distal tibia as an adolescent. The defect was reconstructed with a fibular allograft which fractured and was augmented with bone graft and internal fixation. She presented with a long-standing deformity of the lower leg and a nonunion of the tibia.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Nonunion tibia and fractured fibular allograft with deformity
2. Retained hardware
3. Tibial shortening of 3 cm

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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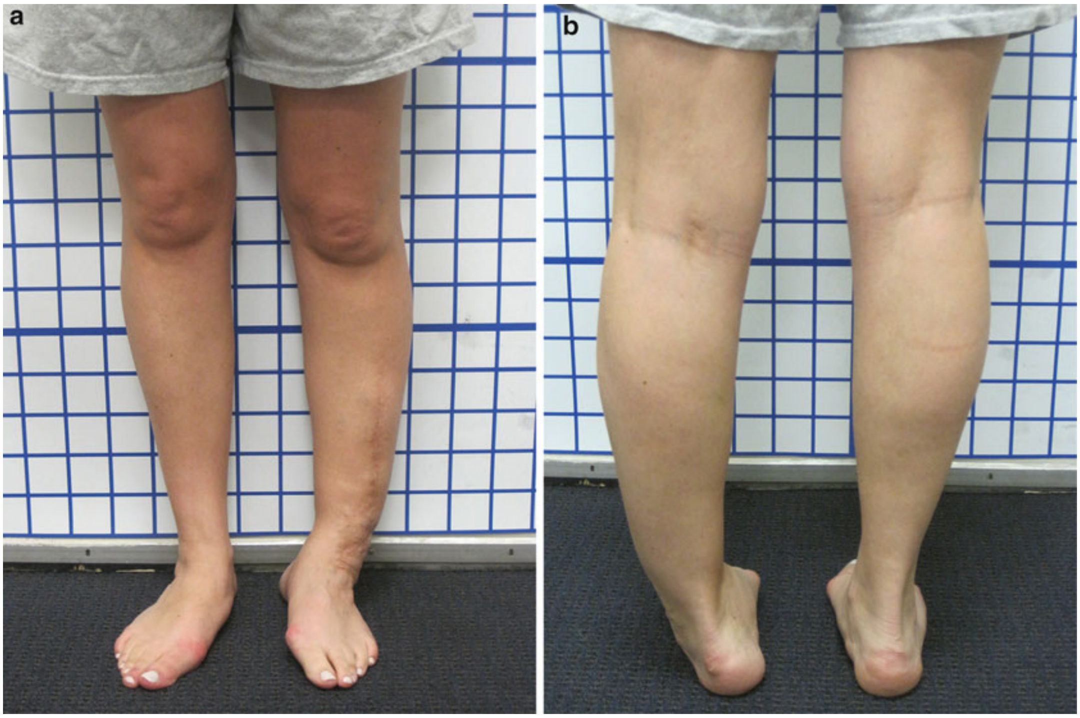

Fig. 1 (**a**, **b**) *Front* and *back* photos of the lower extremities show a deformity with varus, procurvatum, and shortening

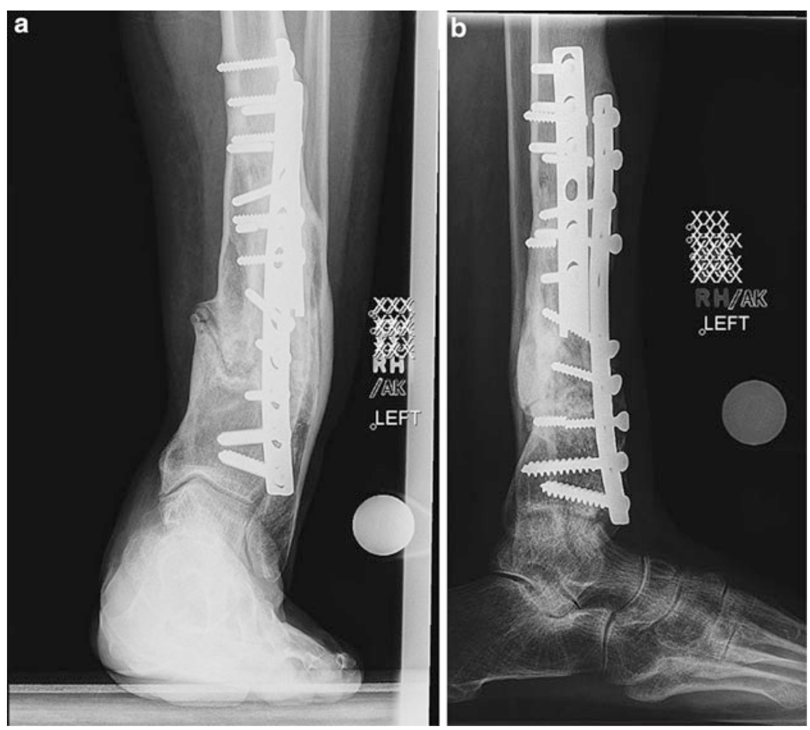

Fig. 2 (**a**, **b**) AP and lateral radiographs show a nonunion of the distal tibia with loosening of the hardware

Fig. 3 This 51″ standing X-ray shows 3 cm of tibial shortening

4 Treatment Strategy

The strategy was for a staged approach to limb salvage. The first stage was a reconstruction of the nonunion with acute deformity correction, preservation of the allograft as a structural device, removal of the internal fixation, bone grafting with autologous iliac crest bone graft, and fixation with a circular frame that provided constant compression. The second stage was extension of the external fixator to the proximal tibia and osteoplasty of the tibia and fibula for limb length equalization.

5 Basic Principles

Distraction osteogenesis requires adequate blood flow to the site of the osteotomy to ensure adequate regenerate bone formation. The proximal tibia provides an ideal environment for distraction to progress successfully. The distal tibia, in this patient, has been through multiple surgeries and the tibia is in a state of nonunion. These factors make attempting to distract through the same nonunion repair unlikely to heal. In

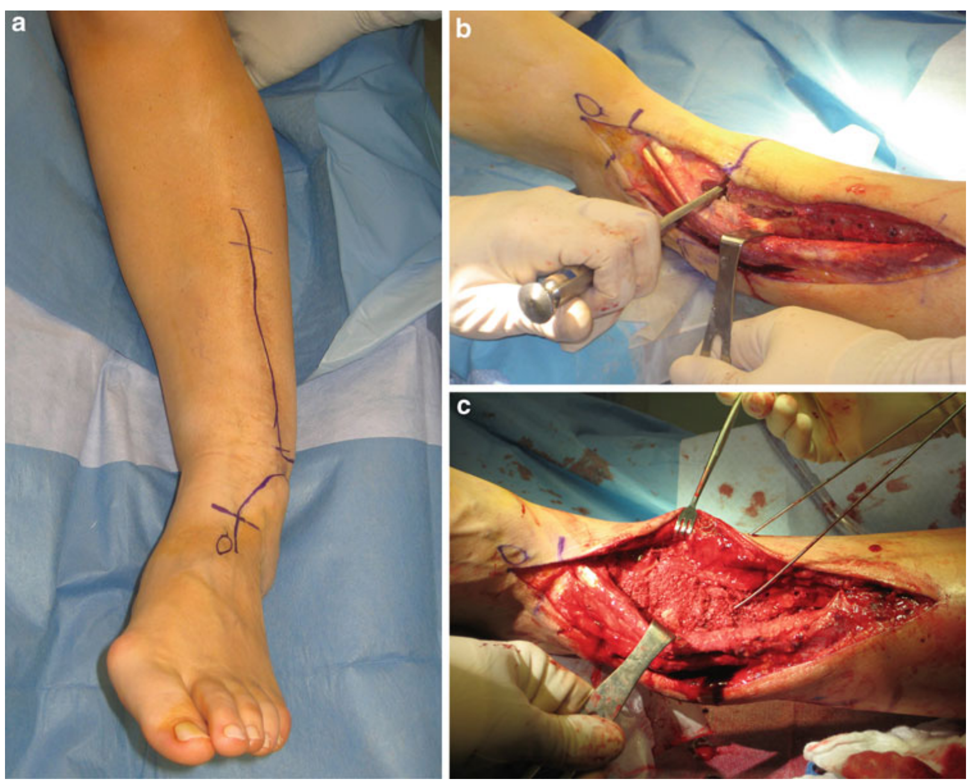

Fig. 4 (**a**–**c**) The previous incisions were used, the nonunion was mobilized and reduced, and the autograft was laid throughout the nonunion area

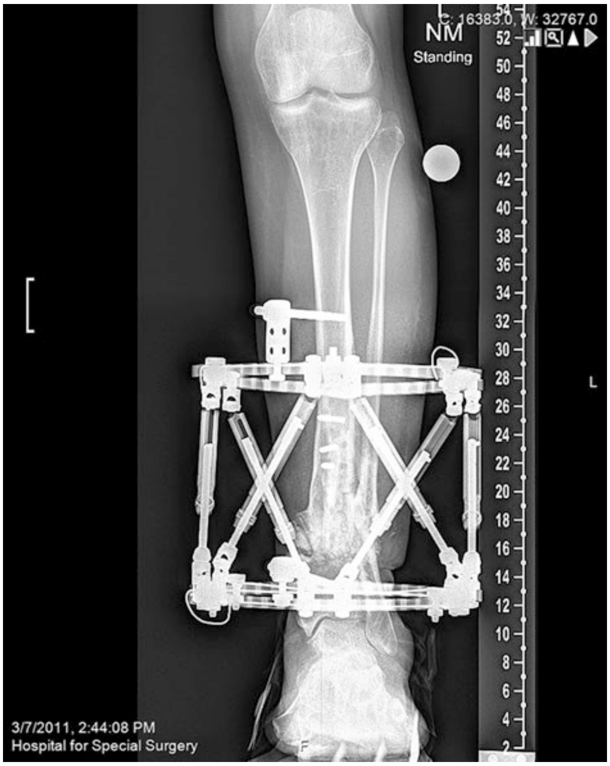

Fig. 5 The nonunion was compressed and alignment controlled with the circular frame

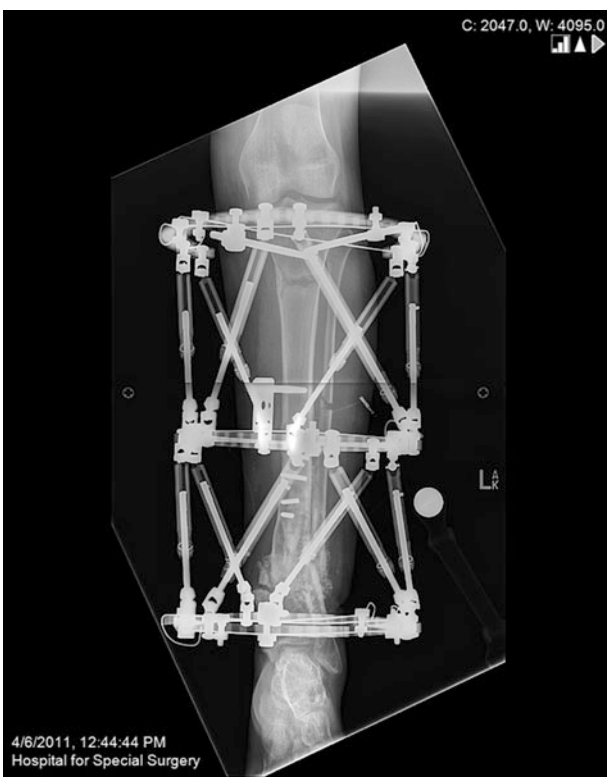

Fig. 6 The patient was returned to the OR for staged proximal tibial osteotomy

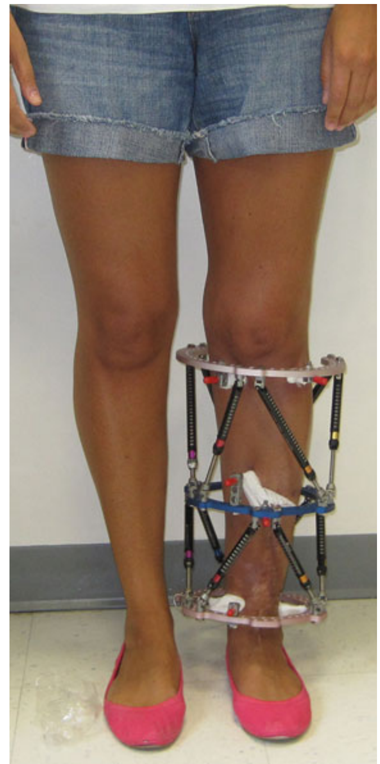

Fig. 7 The full, stacked external fixator is seen with equal leg lengths and no deformity

other words an osteotomy through the nonunion with gradual correction and lengthening would likely lead to a persistent nonunion. Therefore, proximal tibial osteotomy is preferred to ensure success.

6 Images During Treatment

See Figs. 4, 5, 6, and 7.

7 Technical Pearls

In order to obtain small morsels of iliac crest bone graft, the acetabular reamer was used on the outer table of the iliac crest. The crest was reamed down to the inner table. The reamings were collected and additional cancellous graft was harvested with curettes.

With correction of the varus-procurvatum deformity and debridement of poorly vascularized bone at the nonunion site, the extensor tendons became lax and a functional drop foot ensued. Later lengthening of the tibia re-tensioned these tendons and led to a full functional recovery.

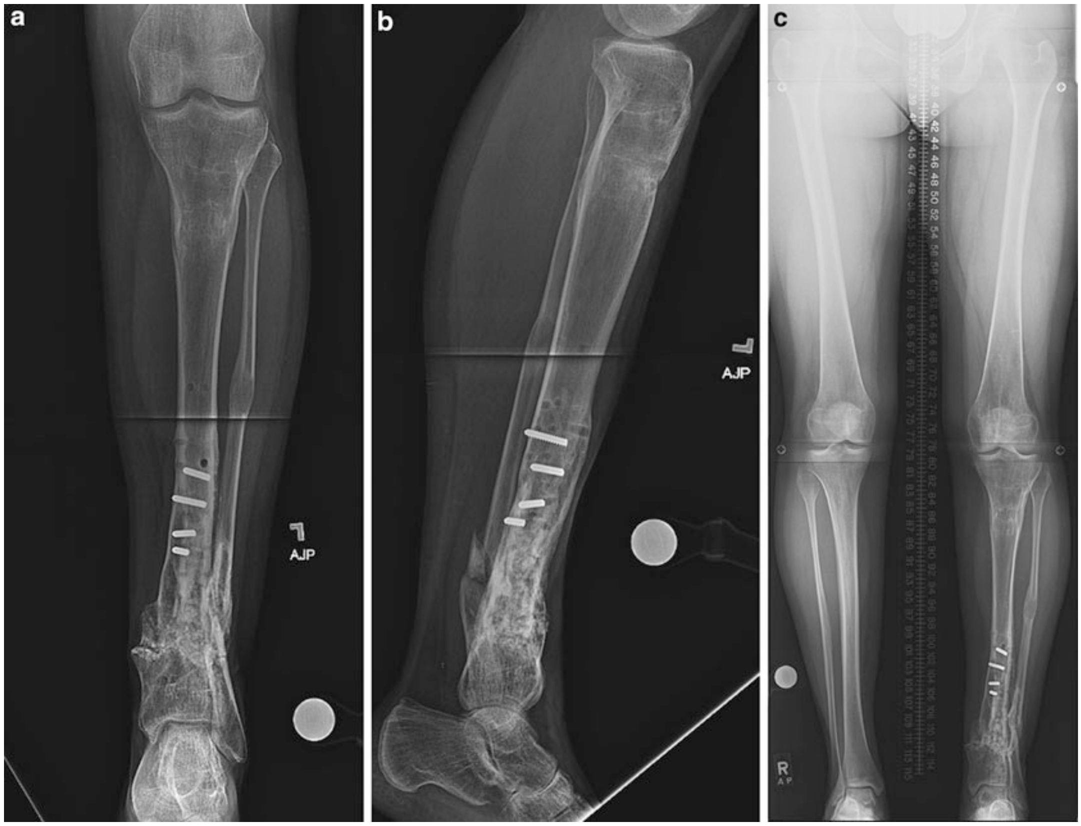

Fig. 8 (**a**–**c**) Final radiographs show full healing of nonunion and osteotomy sites and restoration of alignment

8 Outcome Clinical Photos and Radiographs

See Fig. 8.

9 Avoiding and Managing Problems

Infection of the retained fibular allograft through a pin site infection was a concern unique to this case. To prevent deep infection, the pins and wires were placed outside of the graft zone, and the patient was kept on oral antibiotics for the duration of the reconstruction.

When the patient developed dorsiflexor tendon laxity, the foot was protected with a neutral foot splint to prevent equinus contracture. Daily ankle and knee exercises helped ensure free joint motion during the lengthening.

Rh-BMP (Recombinant human bone morphogenic protein) was avoided due to the history of local bone cancer for fear of recurrence.

10 Cross-References

- ▶ Case 32: Acute Correction of Tibial Deformity and Plate Fixation, with Subsequent Lengthening Over Plate
- ▶ Case 54: Deformity Correction (Tibial Bone Defect due to Osteomyelitis) in Lower Limb Using Taylor Spatial Frame
- ▶ Case 69: Reconstruction of a Bone Defect (Malignant Bone Tumor) in the Proximal Tibia Using Taylor Spatial Frame (Distraction Osteogenesis)
- ▶ Case 77: Reconstruction of Failed Allograft Reconstruction with Combined Technique (Low-Grade Osteosarcoma)

11 See Also in Vol. 2

Case 34: Spatial Frame Correction of an Infected Distal Metaphyseal Tibial Nonunion/Malunion

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Case 76: Staged Reconstruction of a Failed Modular Knee Tumor Prosthesis

Levent Eralp and Ilker Eren

Contents

Abstract

Infection is one of the most common causes of the failure of tumor prosthesis. Low-quality soft tissue envelope, chemotherapy, and extensive soft tissue dissection are among the reasons responsible for this devastating complication. Removal of the implant is necessary to deal with the infection, and it is not always possible to reconstruct the joint with a functional implant, due to the poor bone stock or recalcitrant infection. We present a case with infected tumor prosthesis, which was salvaged with knee arthrodesis using two monolateral fixators, and subsequent lengthening of the femur and tibia with monolateral and circular external fixators respectively.

1 Brief Clinical History

A 29 year old male patient was referred to our clinic with a recurring synovial sarcoma of the knee joint. An arthroscopic intervention and biopsy were performed in another institution 6 years ago. He was diagnosed as having a synovial sarcoma of the knee joint and treated with chemotherapy alone. Two years later, following recurrence, an arthroscopic debridement was performed. He had a second recurrence and an open debridement was performed

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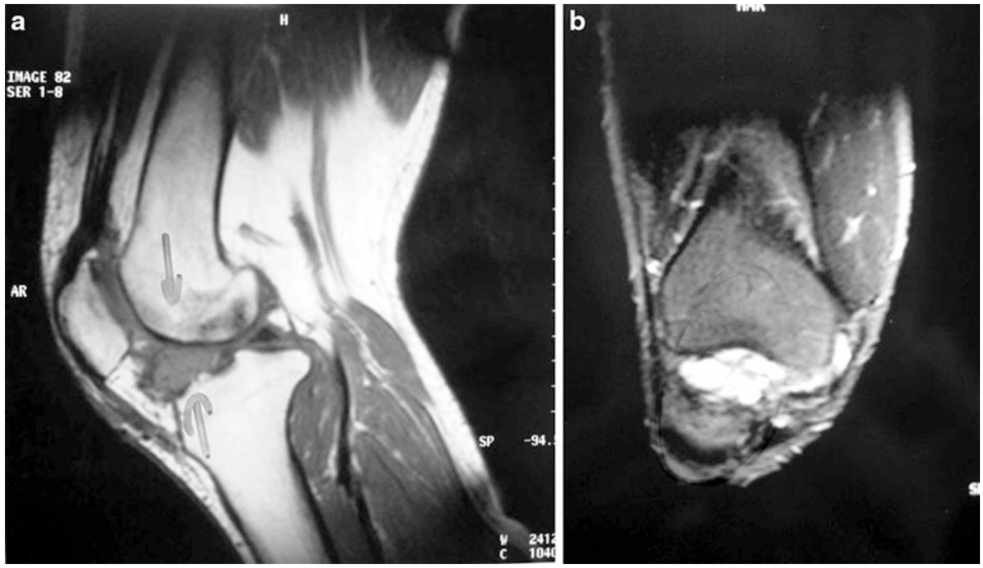

Fig. 1 Intra-articular lesion located at the retropatellar area extending throughout the joint. Sagittal (**a**) and coronal (**b**) MRI planes

Fig. 2 Preoperative planning. Arthroscopy portals and previous incision are included in the resection

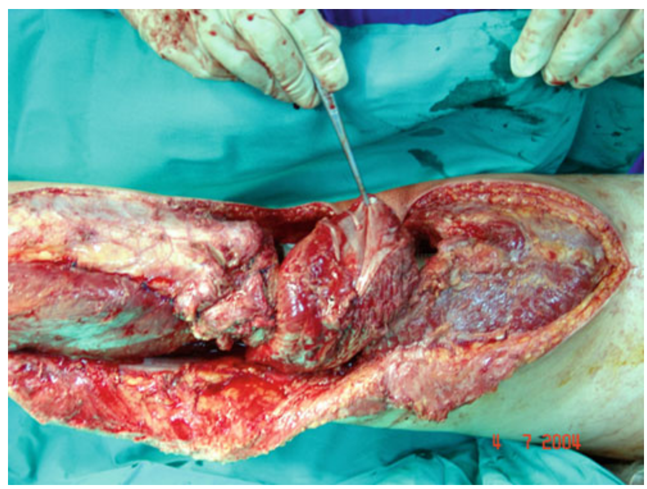

Fig. 3 Intraoperative photo demonstrating the gastrocnemius flap

in the same clinic. He was referred to our clinic a year later, with pain in the knee joint and progressive swelling. Diagnosis of synovial sarcoma was confirmed with a Tru-Cut biopsy. We performed a closed joint resection and reconstructed the knee joint with a modular tumor prosthesis. The soft tissue defect was closed and the extensor apparatus reconstructed with a medial gastrocnemius flap and split-thickness skin graft. The prosthesis became infected in the fifth postoperative month. Debridement and re-coverage by free muscle flaps failed three times.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, and 7.

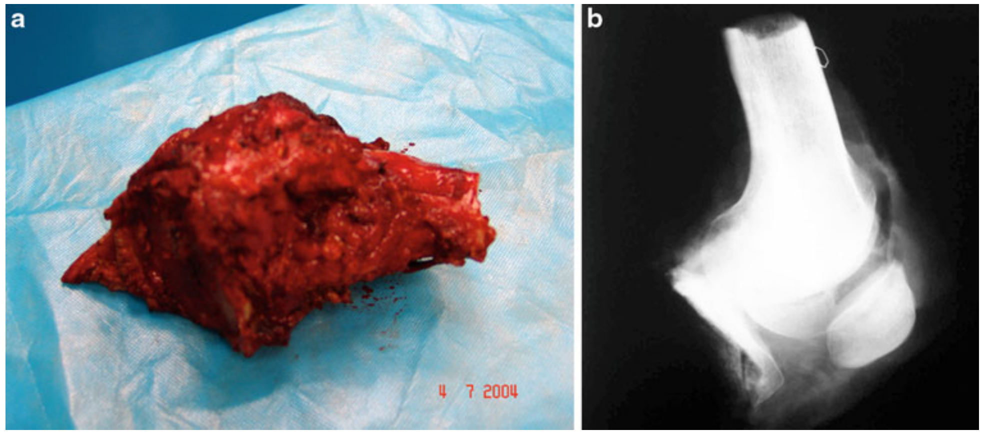

Fig. 4 Resected material (**a**). While performing tibial and femoral osteotomies, the joint capsule was protected. Proximal osteotomy was extended proximally due to the suprapatellar pouch (**b**)

Fig. 5 Early AP (**a**) and LAT (**b**) postoperative radiographs

3 Preoperative Problem List

(a) Infected and exposed tumor prosthesis, possible osteomyelitis
(b) Poor soft tissue coverage
(c) Decreased bone stock due to resection

Fig. 6 Joint subluxation at the 2nd month, which was reduced with arthroscopic visualization

4 Treatment Strategy

(a) Stage 1: removing prosthesis, debridement, and application of antibiotic-loaded cement spacer. Monolateral fixator application to preserve limb alignment and length.
(b) Stage 2: removing the spacer and evaluating the bone and soft tissues for infection. If there is persistent infection, repeat stage 1. Otherwise, external fixator should be applied for knee arthrodesis.
(c) Stage 3: Following solid union, limb lengthening is indicated with circular external fixator for the tibia and monolateral fixator for the femur.

5 Basic Principles

(a) Adequate debridement at the first stage is important to achieve an infection-free arthrodesis area.
(b) Altered knee joint anatomy requires careful dissection of the neurovascular structures.
(c) Series of cultures obtained before the second stage, C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) monitoring, and preoperative gram-staining are necessary steps during the first stage to ascertain that infection has been eradicated. Do not proceed to the second stage in case there is active infection.
(d) Double monolateral fixator was utilized to achieve knee joint fusion. Circular external fixator is also a viable option, however with inferior patient comfort. For the presented case, laterally and anteriorly placed monolateral fixators were preferred.
(e) The aim of the compression performed at the second stage is to bury the femoral shaft in the metaphyseal region of the proximal tibia. This will warrant a larger bony surface for solid union. Compression starts just after the surgery, without any latency period.

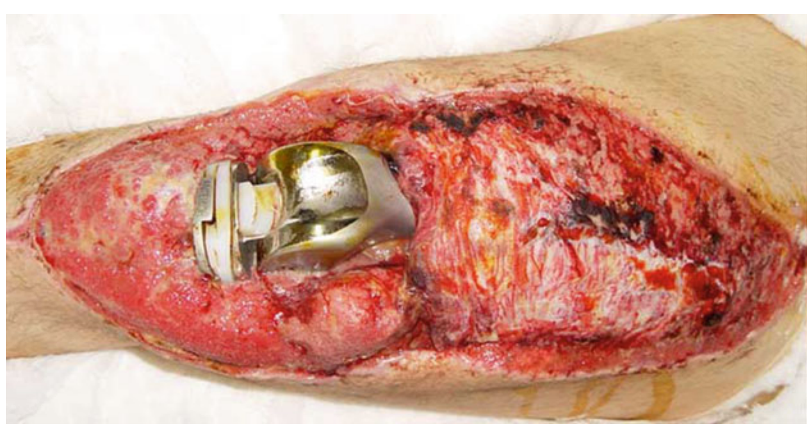

Fig. 7 The patient developed skin necrosis weeks after reduction. He was hospitalized and had several debridements for 5 weeks. Negative pressure wound therapy (NPWT) was used during this period. A free fasciocutaneous latissimus dorsi flap was utilized for wound closure. Unfortunately, the free flap also failed and the prosthesis was exposed again

Fig. 8 First stage of the treatment. Prosthesis was removed. After adequate debridement of bone and soft tissues, an external fixator was applied to preserve alignment

(f) Union will be evaluated with a series of radiographs obtained every month. After adequate union, the laterally placed fixator will be removed. As the remaining fixator is a short segment application, removing one and leaving the other fixator will serve as a dynamization, which should facilitate fusion.
(g) Initial compression is necessary and a long period of consolidation and union is expected.

6 Images During Treatment

See Figs. 8, 9, 10, 11, and 12.

7 Technical Pearls

(a) An infection-free limb and adequate soft tissue coverage are of vital importance for the success of the first stage. Do not proceed to the second stage until it is certain that the first stage has been successfully completed.
(b) Do not remove the fixators until bony union is radiologically evident. When removing the fixators, assess for pathological movement at the fusion site both clinically and radiologically. If there is any doubt, consider prolonged fixation or grafting. One month

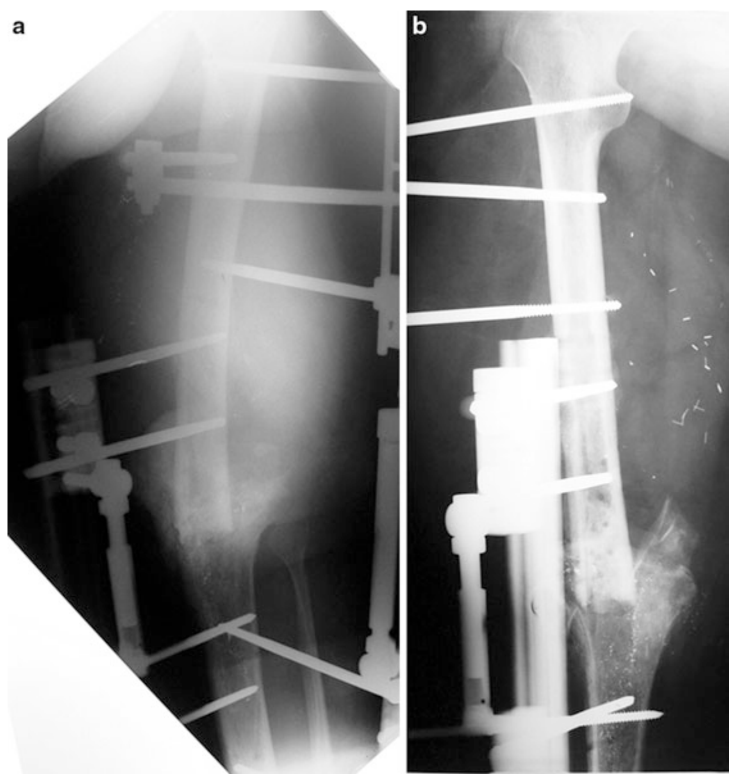

Fig. 9 The 2nd external fixator was used to achieve multi-planar stability, while leaving the first fixator in place. Also further debridement was performed. AP (**a**) and LAT (**b**) X-rays

Fig. 10 Clinical photo of the patient. Note the severe limb length discrepancy

prolonged fixation is much safer than one minute premature removal of the fixator.

(c) Inform the patient about the possible complications, specifically the long treatment period before (for eradication of the infection) and after the surgery, until bony union is achieved.

8 Outcome Clinical Photos and Radiographs

See Figs. 13, 14, 15, 16, 17, and 18.

9 Avoiding and Managing Problems

(a) Removing the tumor prosthesis will leave a huge bone defect, which is expected to increase with further debridements. Acute compression of extensive defects may lead to neurovascular problems. It is generally considered safe to acutely compress up to 5 cm of defect. However, after any acute compression, the neurovascular status of the limb has to be monitored closely. Patients with multiple operations or previous vascular reconstruction are more prone to such problems. For bigger defects, consider gradual compression if necessary.

Fig. 11 Following radiological assessment of the union, the laterally placed external fixator was removed at the 6th month postoperatively. AP (**a**) and LAT (**b**) X-rays

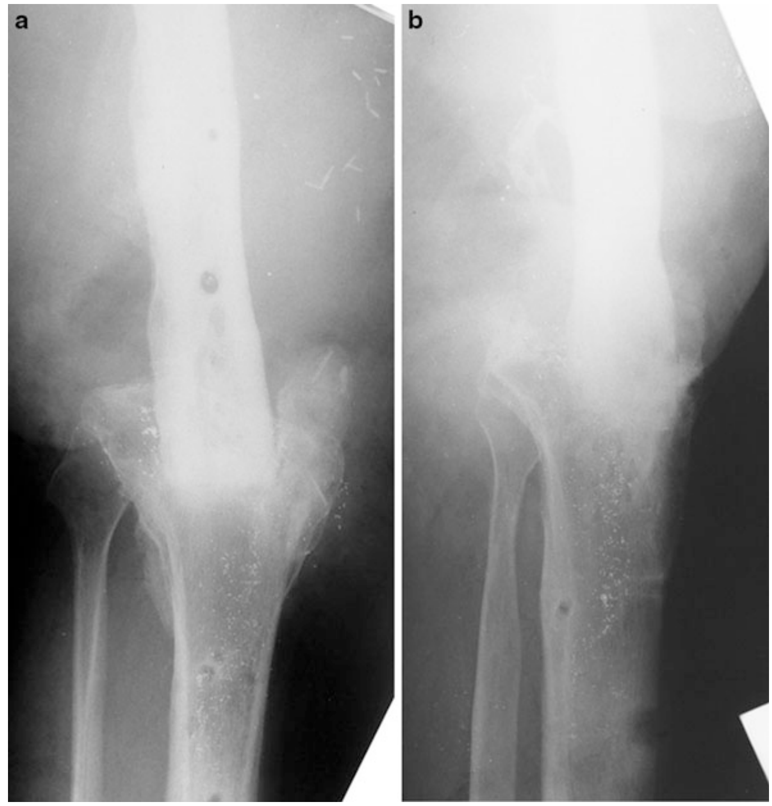

Fig. 12 The remaining anterior fixator was removed. Bone union was preserved with a soft cast application, which was removed a month later, and a long leg brace was utilized. AP (**a**) and LAT (**b**) X-rays

Fig. 13 Clinical photos of the patient at the end for the 2nd stage, following fixator removal. There was a 15 cm of limb length discrepancy (LLD). AP (**a**) and LAT (**b**) clinical photos

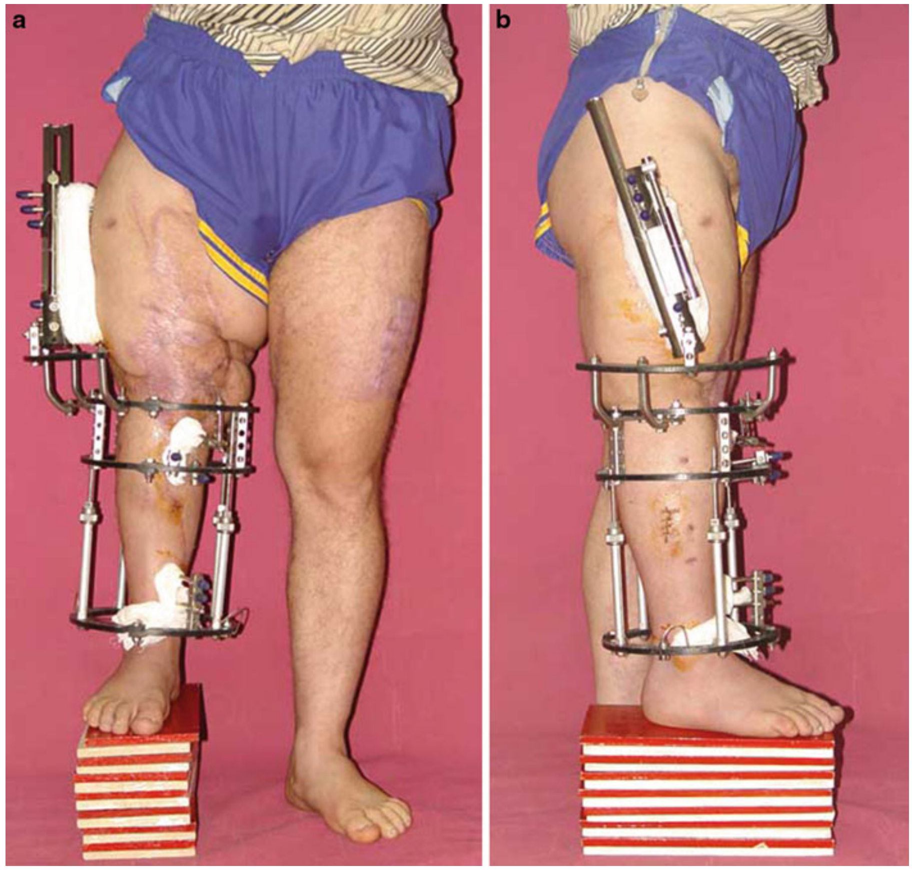

Fig. 14 We preferred monolateral fixator for femoral lengthening and a traditional circular external fixator for tibial lengthening. The two fixators were bridged at the knee level to create a stiffer construct. AP (**a**) and LAT (**b**) clinical photos

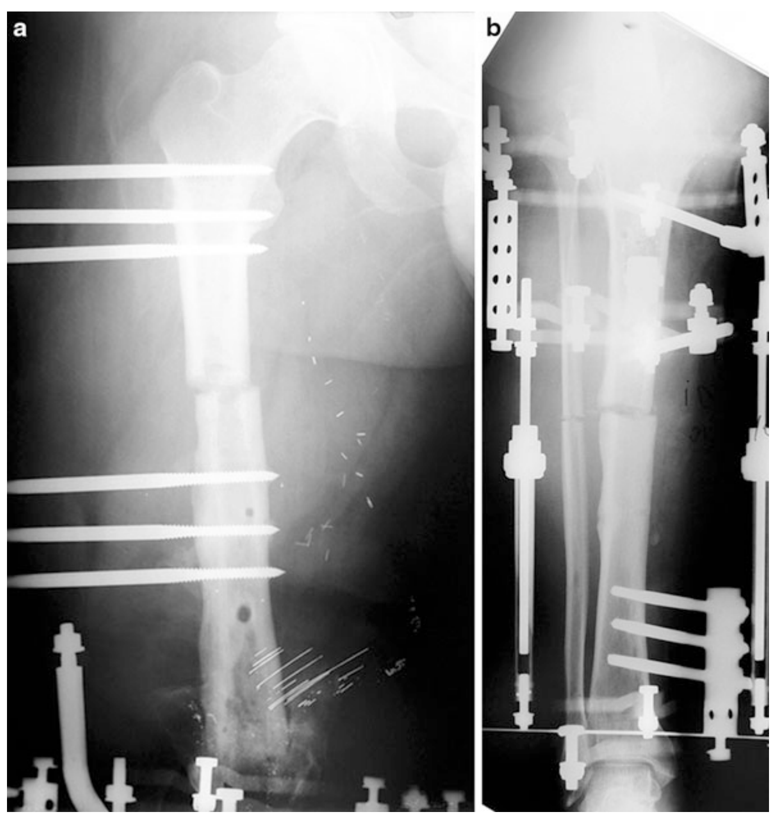

Fig. 15 Lengthening performed with a bifocal osteotomy. Considering previous problems, we initiated lengthening at a rate of 0.5–0.75 mm/day. Serial radiographs obtained every 2 weeks during follow-up. X-rays showing mid-diaphyseal femoral (**a**) and tibial (**b**) osteotomy

Fig. 16 At the end of the distraction period, 8 cm lengthening achieved from the femur and 6 cm from the tibia. One to 2 cm of LLD was intentionally left to facilitate gait. Clinical photo (**a**) and orthoroentgenogram (**b**) of the patient

Fig. 17 Orthoroentgenogram (**a**) and clinical photos (**b–d**) obtained at the end of the treatment, 4 weeks after fixator removal

Fig. 18 AP (**a**) and LAT (**b**) radiographs obtained 3 years postoperatively

(b) It is absolutely necessary to manage soft tissue problems before embarking on the second stage of reconstruction.
(c) Do not initiate lengthening at the usual rate of 1 mm/day. Neurovascular structures are more susceptible to injury and the quality of the bone regenerate is usually inferior.

10 Cross-References

▶ Case 47: Knee Arthrodesis for Failed Total Knee Arthroplasty
▶ Case 48: Knee Fusion and Lengthening for Failed Total Knee Replacement and Bone Loss
▶ Case 52: Bifocal Staged Bone Transport of a 30 cm Defect Including the Knee Joint

References and Suggested Readings

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Case 77: Reconstruction of Failed Allograft Reconstruction with Combined Technique (Low-Grade Osteosarcoma)

Mehmet Kocaoglu and F. Erkal Bilen

Contents

Abstract

Bone tumors in the long bones are successfully treated either with prosthetic replacement or with biologic reconstruction techniques. Following resection of all the tumoral tissues, the defect needs to be reconstructed with distraction osteogenesis and/or allografts.

1 Brief Clinical History

- A 33 year old male patient complaining of a progressing distal thigh mass referred to our clinic. The mass had been noticed early as the patient was himself a surgeon (Fig. 1a–d). Following initial radiological assessment, tru-cut biopsy had been performed. Low-grade osteosarcoma had been diagnosed after histopathologic evaluation. Three cycles of preoperative chemotherapy had been indicated. The initial surgical treatment had consisted of resection of the tumoral tissue and reconstruction with hemicylindrical allograft medially and stabilization via a retrograde intramedullary nail 3 years ago (Fig. 2a–c).
- The patient presented to our clinic with pain and limping at this stage. The plain X-rays revealed the IM nail was broken (Fig. 3a, b). At his point we wanted to differentiate between tumoral recurrence and atrophic nonunion. Thus, we obtained three-phase bone scans, which showed increased uptake (Fig. 4).
- The tru-cut biopsy was performed and the result was negative for tumoral recurrence.

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Fig. 1 (**a**) Preoperative X-ray (*AP view*) of the left femur depicting periosteal reaction. (**b**) Preoperative X-ray (*lateral view*) of the same patient. (**c**) Preoperative MRI scan (*frontal view*) showing the bone mass. (**d**) Preoperative MRI scan (*axial view*) of the same patient

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

- History of a low-grade osteosarcoma of the distal femur
- Atrophic nonunion of the distal 1/3 femoral diaphysis
- Instability due to broken IM nail
- Limb length discrepancy of 2 cm
- Valgus deformity

4 Treatment Strategy

1. Removal of the broken IM nail and the locking screws.
2. Resection of the atrophic nonunion site along with the allograft.
3. Retrograde insertion of a new IM nail with customized holes for locking of the transported bone segment at the second session.
4. Percutaneous corticotomy at the proximal 1/3 femoral diaphysis.

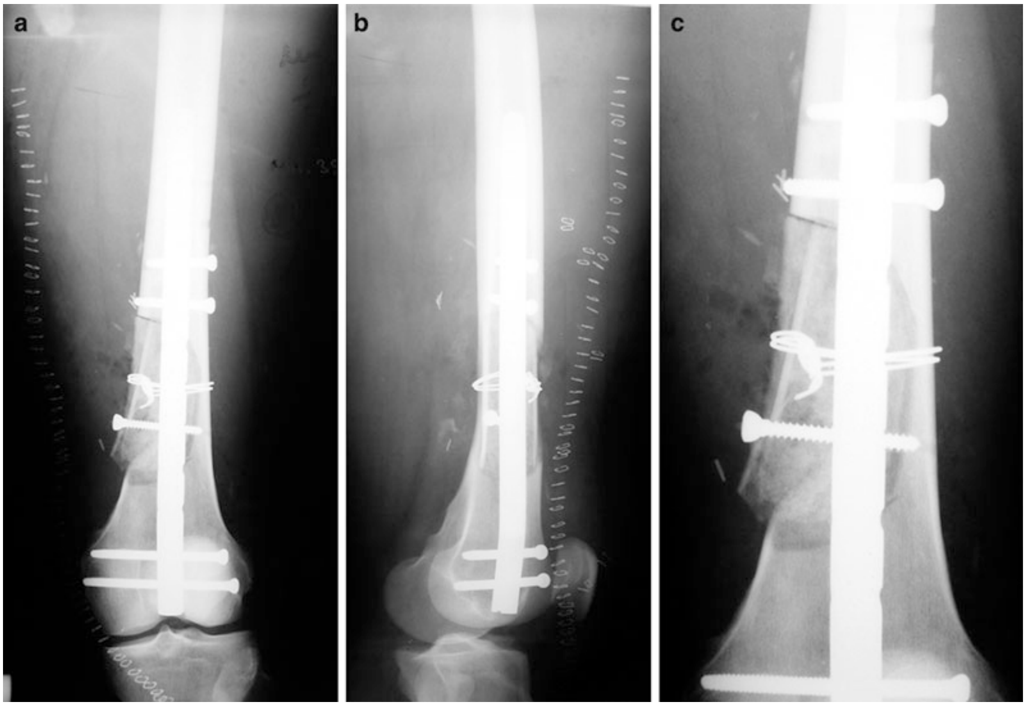

Fig. 2 (**a**) Immediate *AP view* following the initial reconstructive procedure consisting of resection of the tumoral tissue and reconstruction with hemicylindrical allograft medially and stabilization via a retrograde IM nail. (**b**) Immediate *side view* following the initial reconstructive procedure. (**c**) Close *AP view* of the same patient

Fig. 3 (**a**) Orthoroentgenogram of the patient showing the broken nail and the femoral valgus deformity. (**b**) *Side view* showing the broken nail and the nonunion. Note the periosteal activation at the posterior aspect of the nonunion

Fig. 4 Tc99 bone scan shows increased uptake at the nonunion site

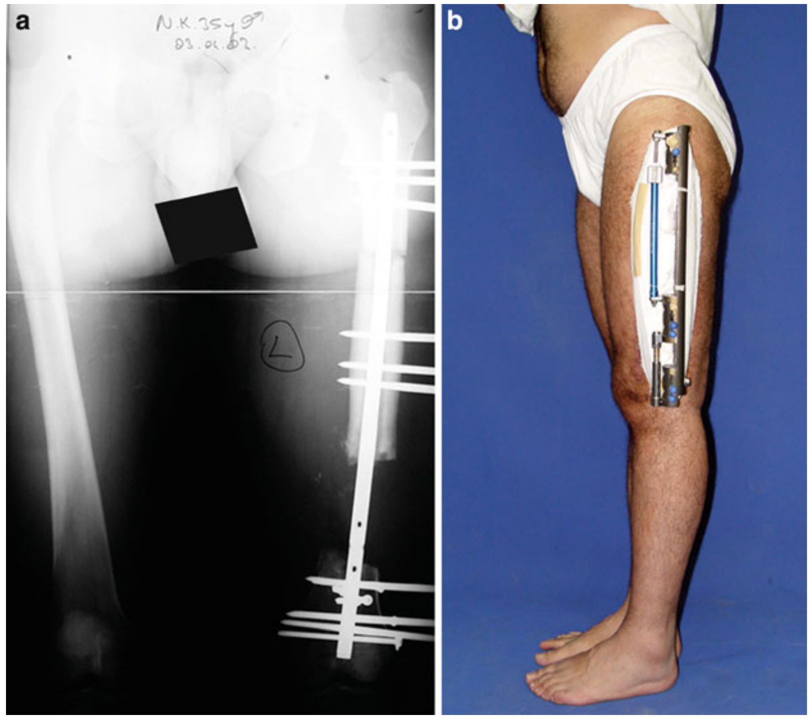

Fig. 5 (**a**) AP X-ray following the reconstruction consisting of wide resection of the nonunion side and retrograde IM nailing while preserving the current length of the femur. A proximal osteotomy is performed for bone transport and lengthening (bone transport via combined technique). (**b**) Clinical side view during ex. fix. period

Fig. 6 (**a**) Orthoroentgenogram after removal of the ex. fix. and locking of the IM nail. (**b**) AP X-ray showing the new bone formation 2 months later. (**c**) AP X-ray showing the new bone formation 3 months later. (**d**) *Side view* showing the bone formation

5. Application of a unilateral external fixator (Orthofix limb reconstruction system type) to all three segments of the bone (Fig. 5a, b).
6. When the desired amount of lengthening has been achieved, the remaining interlocking screws are inserted and then the external fixator is removed at a second session (Fig. 6a–d). Following removal of the external fixator, the patient is not allowed to bear full weight until consolidation is established radiographically (Fig. 7a–d).

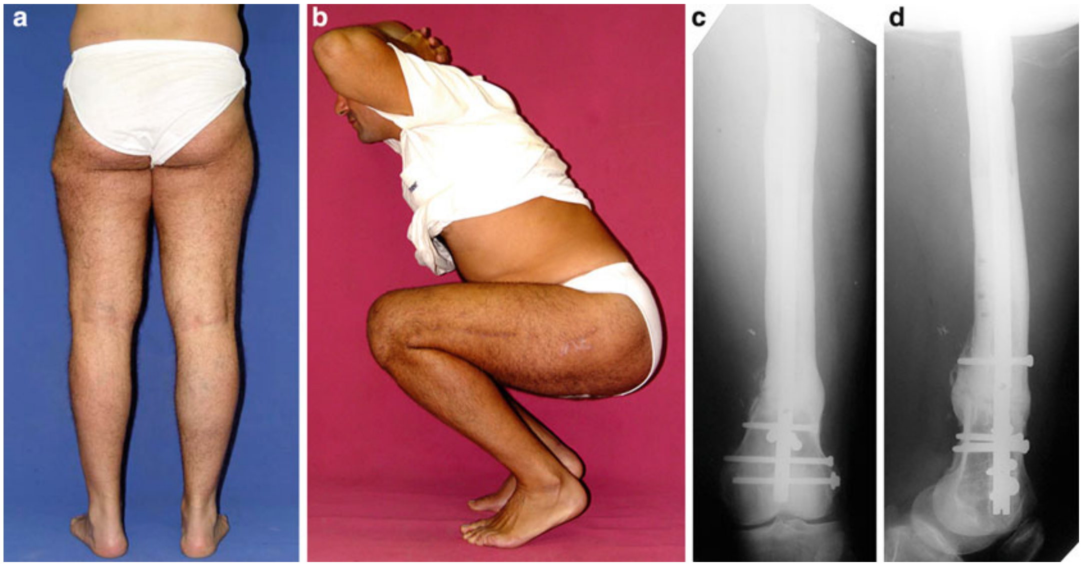

Fig. 7 (**a**) Clinical picture at the end of the treatment. (**b**) Functional clinical picture. (**c**) AP X-ray after complete bone healing. (**d**) Side view X-ray after complete bone healing

5 Basic Principles

1. All the nonviable avascular bones should be removed. This is established by the presence of the so-called paprika sign.
2. The medullary canal should be over-reamed by 2 mm larger than the IM nail.
3. A paper tracing is required to determine the customized holes on the IM nail for locking of the transported segment.
4. Usually the IM nail is introduced further through the piriform fossa proximally. This enables that enough length of the IM nail is still left inside the proximal segment after the bone transport and lengthening.

6 Images During Treatment

See Figs. 5 and 6.

7 Technical Pearls

- Over-ream the femoral canal by 2 mm to allow smooth sliding of the IM nail.
- Schanz screws are placed perpendicular to the IM nail (anatomical axis) on both planes.
- To prevent any contact between the Schanz screws and the IM nail, cannulated drill technique should be utilized for precision.
- Minimal invasive percutaneous corticotomy technique should be performed to obtain new bone formation of good quality.

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

9 Avoiding and Managing Problems

1. Over-reaming is of paramount importance as without its implication the transport system may stuck and not work.
2. Likewise, if the long axes of the IM nail and the external fixator are not parallel to each other on both planes, then the system will not work as well.
3. To avoid spreading of a pin tract infection into the medulla, the pins of the external fixator must not touch the IM nail. There should be at least 1 mm distance between the pins and the IM nail.

10 See Also in Vols. 1 and 2

Case 9: Adolescent with Segmental Bone Defect Secondary to Grade IIIB Open Tibial Fracture Treated by Oblique Wire Bone Transport (Vol. 1)
Case 7: A 12 cm Traumatic Femoral Defect Treated with a Long Oblique Diaphyseal Femoral Osteotomy and Lengthening Over a Nail (Vol. 2)

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Part XIV

Tumor: Reconstruction Following the Sequela of Resection

Case 78: Tibio-Talar Fusion to Treat Bone Defect and Ankle Arthritis Following Treatment of a Distal Tibial Giant Cell Tumour

Peter Calder

Contents

Abstract

A 23 year old secretary presents with right ankle stiffness and pain. A distal tibial giant cell tumor had been treated 9 years previously with curettage and cement implantation. Treatment included excision of the distal tibia and bone transport using a stacked Taylor spatial frame (TSF) to maintain leg length and achieve a tibiotalar fusion.

1 Brief Clinical History

A 23 year old secretary presented to the foot and ankle unit with right ankle pain and stiffness. At the age of 14, she presented with a giant cell tumor of the right distal tibia; a biopsy was performed and histology confirmed a typical giant cell tumor with no evidence of malignancy. She subsequently underwent curettage and insertion of cement into the cavity. Initially, she did well but gradually developed pain and stiffness with radiological changes of ankle arthritis. The pain was relieved by an injection of local anesthetic to the ankle joint. In view of the presence of the "cementoma" and reduced bone stock of the distal tibia, a referral was made to the limb reconstruction unit to consider excision of the affected distal tibia and fusion of the ankle.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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Fig. 1 (**a–d**) Plain radiographs demonstrating the tibia and ankle. The cement fills the whole of the distal tibial epiphysis and metaphysis. There is joint space narrowing consistent with ankle arthritis

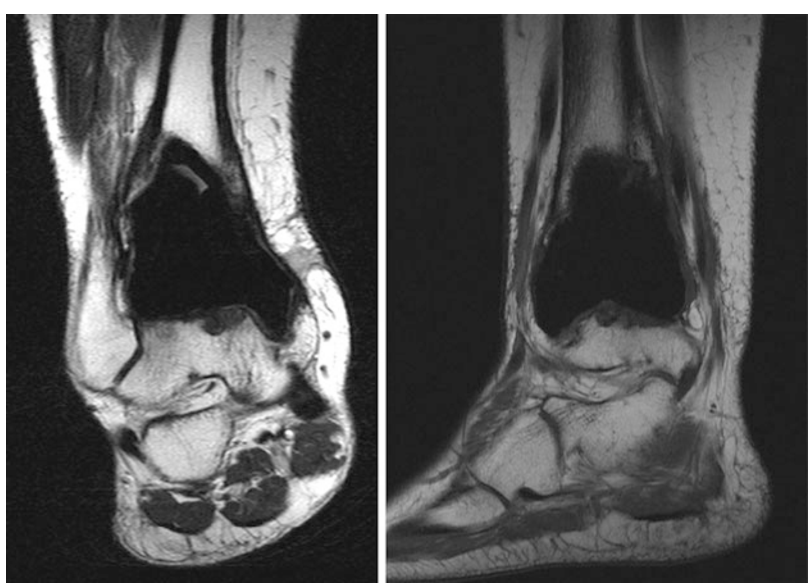

Fig. 2 An MRI demonstrates cysts within the top of the talus and lack of bone in the distal tibia between the cement and the joint

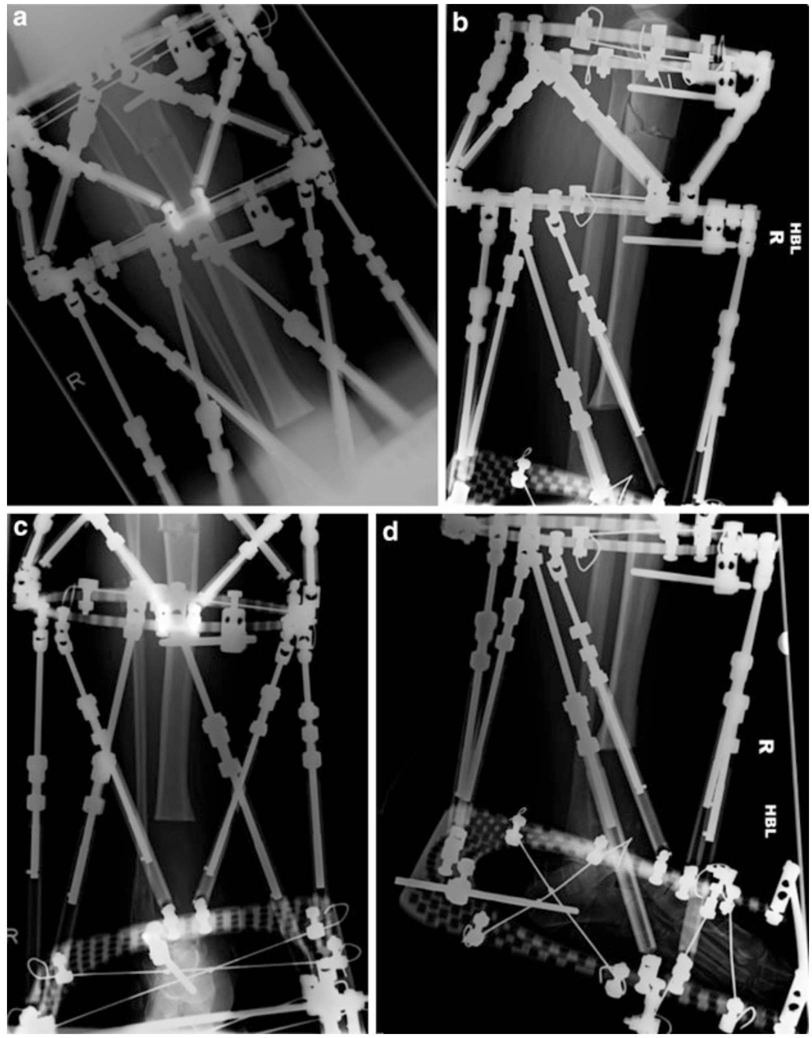

Fig. 3 (**a–d**) Initial radiographs following distal tibia excision, preparation of the talar dome, and proximal corticotomy

3 Preoperative Problem List

- Ankle pain and stiffness due to the arthritis
- Lack of bone in the distal tibia to achieve an ankle fusion
- Potential leg length discrepancy

4 Treatment Strategy

The preoperative plan was to produce suitable bone surfaces of the tibia and talus to achieve biological fusion. The distal tibia including the cement was excised back to the healthy bleeding bone at the metaphyseal/diaphyseal junction. The talar dome was also debrided back to the healthy bleeding cancellous bone, removing the sclerotic bone and cysts. The remaining bone defect was reconstructed using a bone transport technique. A Taylor spatial frame was constructed with a proximal ring, a central diaphyseal ring, and a distal foot ring. A proximal tibial corticotomy was performed and the central tibial segment transported through the tissues down to the talus after a latent period of 6 days. A secondary docking procedure was performed to ensure good bone contact and alignment. The frame was removed once the tibiotalar fusion and regenerate had consolidated.

5 Basic Principles

The aim of an ankle fusion in this case was to produce a stiff ankle with no pain. The ankle movement was already significantly reduced due to the arthritis. The principle required healthy biologically active bone surfaces to allow

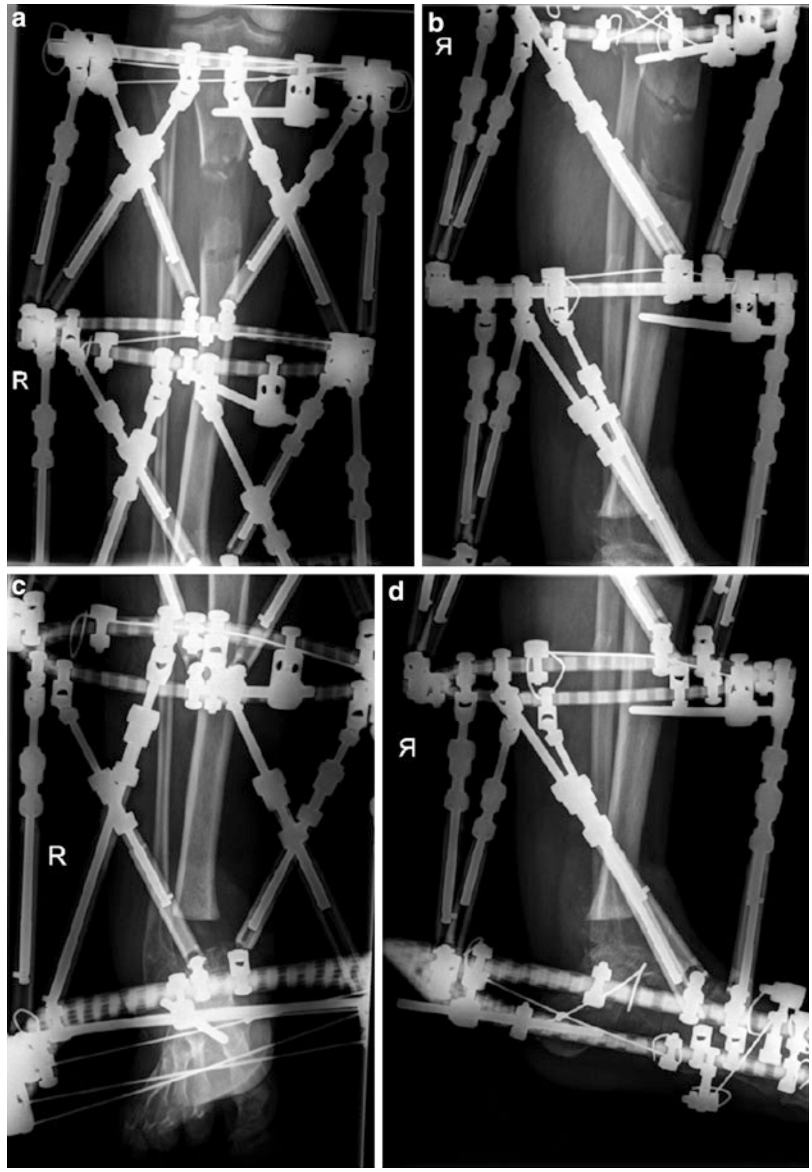

Fig. 4 (**a–d**) Radiographs during a lengthening process. Note the varus position of the foot in (**c**) which will need correction at docking procedure

the fusion to take place. Following debridement of the distal tibia through an anterior incision, a significant bone defect was created which was too large to allow simple shortening (due to soft tissue constraints and residual leg length discrepancy). By undertaking distraction osteogenesis through the proximal corticotomy, the central tibial segment is moved distally to fill the defect. The new regenerate bone fills in the proximal defect. The frame enables stable fixation of all the segments and the ability to control the rate and rhythm of the transport segment's journey. The hexapod system allows easier acute correction of residual deformity to produce an accurate docking position and compression of the tibia on the talus.

6 Images During Treatment

See Figs. 3, 4, 5, and 6.

7 Technical Pearls

Frame stability is essential to allow accurate transport of the bone and consolidation/healing of the bone regenerate and fusion site. The proximal ring includes a transverse reference wire and two further crossing wires which offer

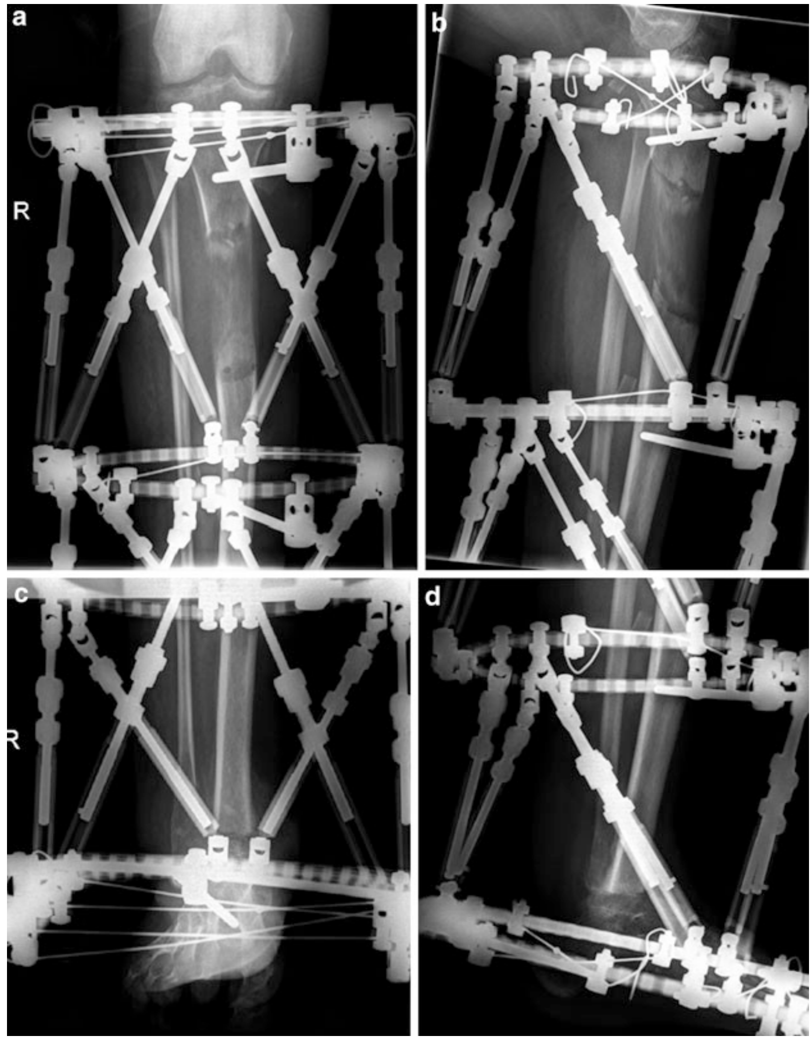

Fig. 5 (**a–d**) Docking procedure performed 14 weeks following initial procedure. Good alignment of foot and compression of the distal tibia to the body of talus achieved

good stability in the coronal plane. A hydroxyapatite-coated half-pin placed anteriorly offers further stability in the sagittal plane. An alternate construct could be all half-pins to include anteromedial and anterolateral pins. The transport ring has one wire and one half-pin. During movement, the wire and pin will cut through the skin. The wire is placed from anterolateral to posteromedial (a tibial face wire). An attempt to minimize soft tissue impalement is important as the wire passing through can be painful. The half-pin is perpendicular into the subcutaneous border of the tibia. Further stability either during transport or after docking can be achieved with further diaphyseal half-pins. The foot ring is attached by two calcaneal wires, two metatarsal wires, and a single half-pin placed into the posterolateral calcaneum. A talus wire through the talar neck could be considered to give further stability. The wire could be attached to the tibial ring as a “pull” wire to produce more compression at the docking procedure. At docking the anterior wound is reopened, the soft tissue covering the distal tibial stump is removed, and the cancellous bone of the talus is assessed for bleeding. By releasing the fast fix struts of the distal frame construct, acute compression is performed to ensure the foot is plantigrade. Cancellous bone graft insertion between the tibia and talus could be considered and may be harvested from the iliac crest. The fibula remains intact throughout treatment and is a guide for alignment and length.

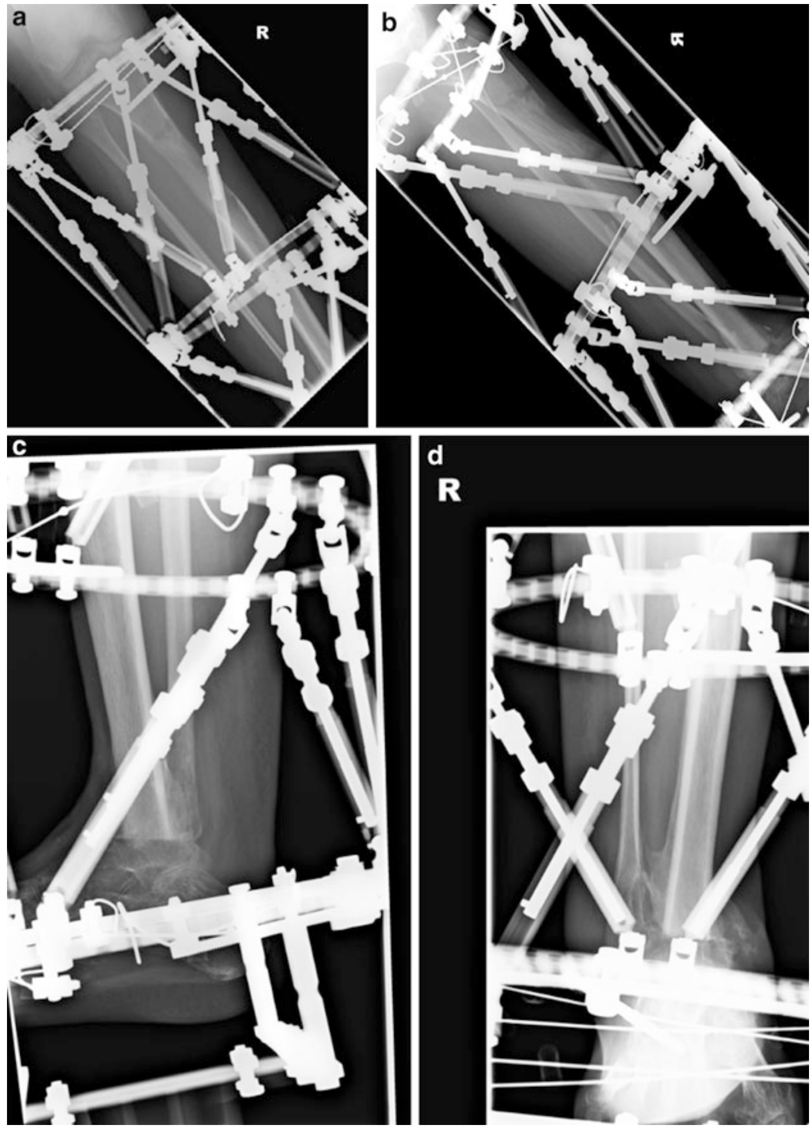

Fig. 6 (**a–d**) Final radiographs prior to frame removal exactly 1 year following initial surgery

8 Outcome Clinical Photos and Radiographs

See Figs. 7 and 8.

9 Avoiding and Managing Problems

The treatment process is very long and so preoperative counseling is essential with a multidisciplinary team. This should include specialist nurse practitioners, physiotherapists, and even psychologists and psychiatrists to help with low mood swings during the extended time in a frame. Physiotherapy concentrating on knee extension is required throughout the process to prevent a fixed flexion deformity. At rest the patient may lie with the leg up, but the frame will cause a flexion at the knee. Weight bearing can be painful due to the foot wires. A foot extension can be placed under the frame to allow load sharing with the frame and more comfortable weight bearing. Skin release may be required in painful inflamed pin sites during the transport phase. This can be done under local anesthetic. The leg is protected after frame removal initially with a Sarmiento weight-bearing plaster for 4 weeks followed by a removable gaiter splint. This is to provide additional support to the regenerate during the long remodeling phase. The frame is removed with 3 formed cortices, in this case, medial, lateral, and posterior. To protect the anterior cortex, a splint was used during weight bearing for approximately 9 months following frame removal.

Fig. 7 (**a**, **b**) Radiograph taken 3 months after frame removal. The ankle fusion is solid; there is good regenerate in the distraction gap but still remodeling needs to take place anteriorly

Fig. 8 (**a**, **b**) Final radiograph taken 30 months after initial surgery. Patient walking and cycling. Occasional discomfort over the midtarsal region but otherwise pain-free

10 See Also in Vols. 1 and 2

Case 8: Three Year Old Female with Segmental Bone Defect due to Grade IIIB Open Tibial Fracture Treated by Oblique Wire Bone Transport (Vol. 1)
Case 6: A 10 cm Traumatic Femoral Defect Treated with a Transport Technique Followed by a Lengthening Procedure. Sequential Use of a Monotube External Fixator and an Intramedullary Rod (Vol. 2)
Case 14: Double Level Bone Transport for Severe Bone Loss (Vol. 2)
Case 36: Distal Tibial Bone Defect Treated with Bone Transport Using Two Proximal Osteotomy Sites (Vol. 2)
Case 40: Acute Shortening and Arthrodesis Technique in Severe Irreparable Tibial Pilon Fracture (Vol. 2)

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Case 79: Combined Technique for Simultaneous Reconstruction of Ankle Instability and Tibial Lengthening Following Sacrifice of the Sciatic Nerve

Levent Eralp and Ilker Eren

Contents

Abstract

Peripheral nerve sheath tumors require extensive resections, usually with sacrifice of the nerve. Tumors originating from the sciatic nerve may lead to one of the most disabling conditions if associated with sacrifice of the nerve. Gait is altered seriously and patients usually require orthotics. The resulting muscle paralysis and imbalance may lead to ankle instability. We present the case of a patient with ankle instability and tibial shortening secondary to sacrifice of the sciatic nerve, who was treated with a combined technique to address both problems simultaneously. Tibia was lengthened proximally with a circular external fixator over intramedullary nail, while the intramedullary nail was used for a pantalar arthrodesis.

1 Brief Clinical History

A 17 year old male, who underwent three surgeries in the last 10 years for a malignant peripheral nerve sheath tumor, presented with a limb length discrepancy due to tibial shortening, an unstable ankle joint, and an equinus deformity. His last surgery required total sacrifice of the sciatic nerve and its branches, from the proximal plexus to cruris.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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Fig. 1 (**a**) Clinical photo of the patient, just before the last tumor resection 10 years ago. Note the extent of the resection. (**b**) Magnetic resonance imaging of the patient at that time

3 Preoperative Problem List

(a) An extremity operated extensively three times, resulting in soft tissue scarring
(b) Loss of sensory and motor function of the limb
(c) Shortening of the tibia
(d) Unstable ankle joint

4 Treatment Strategy

(a) Pantalar arthrodesis of the foot and ankle joints to achieve plantigrade foot
  - Utilization of retrograde nail for arthrodesis

(b) Tibial lengthening to address the limb length discrepancy
  - Lengthening over the arthrodesis intramedullary nail, using circular external fixation

(c) Immediately after achieving planned lengthening, removal of the fixator and locking of the nail preserve and allow consolidation of the regenerate

5 Basic Principles

(a) Preoperative planning is vital. Fixation for the arthrodesis and proximal locking after lengthening require special custom-made nails.

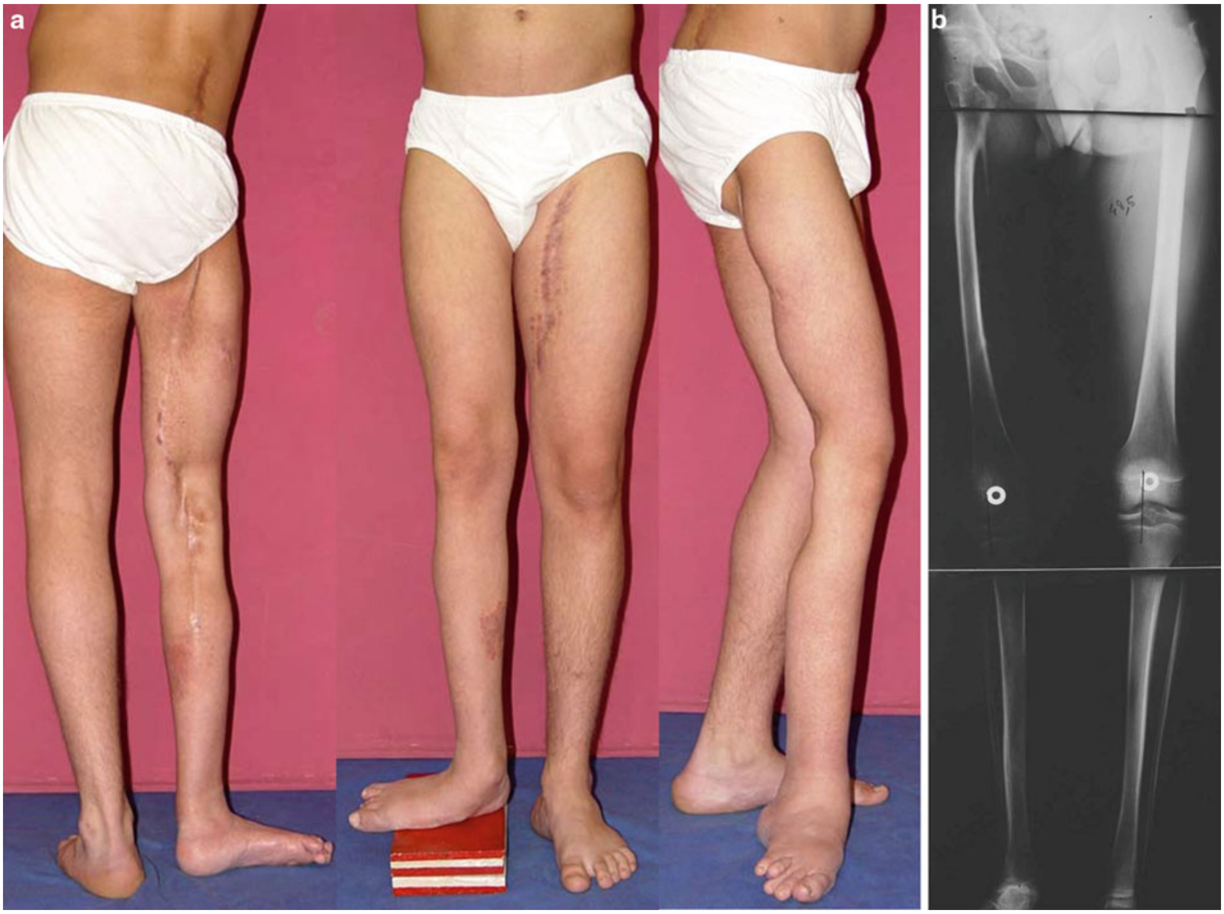

Fig. 2 (**a**) Current clinical status of the patient, 10 years following the last resection. He has a valgus instability of the ankle with tibial shortening. (**b**) Orthoroentgenogram of the patient

(b) Preparation of the circular external fixator is performed in a usual manner; however, insertion of the fixation elements requires special attention to avoid the nail.
(c) The condition of the soft tissues has to be taken into consideration in preoperative planning and throughout the treatment period. Dermal scarring and underlying fibrous adhesions may lead to skin breakdown during lengthening.
(d) Ankle instability is the major functional problem. Achieving a plantigrade foot is the cornerstone of success. Pantalar arthrodesis has to be planned and performed cautiously. The arthrodesis will be acutely compressed and fixed with the locking screws of the nail, and further compression will not be possible. Custom locking holes are needed in the distal tibial to maintain ankle compression during lengthening.
(e) Fine wire fixation is used around the nail in the distal tibia to achieve lengthening. Including the foot in the external fixation will further support the internal fixation and help prevent equinus flexion of the ankle arthrodesis during distraction.

6 Images During Treatment

See Figs. 3, 4, and 5.

Fig. 3 Clinical photos of the external fixator configuration

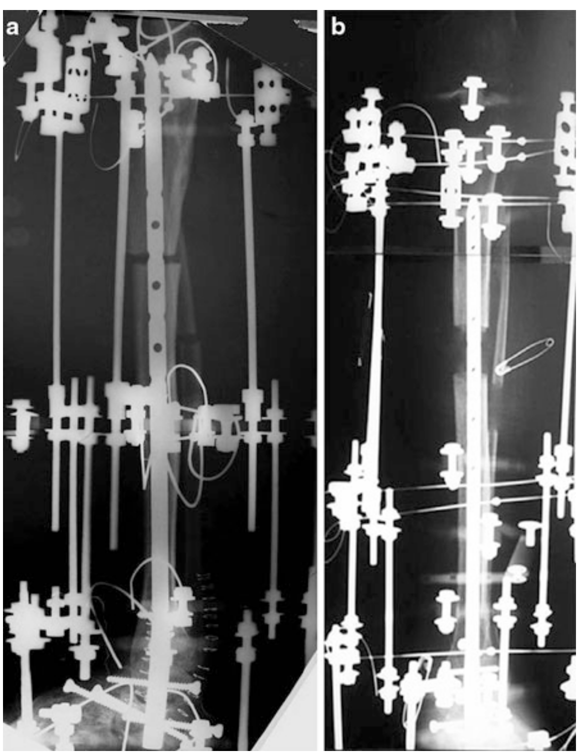

Fig. 4 (**a**) Lateral X-ray just after the surgery, before lengthening. Note the custom locking holes. (**b**) Anteroposterior view during lengthening. The locking holes will be at the intended final position after a short period

Fig. 5 Six weeks after surgery. The nail is locked and the fixator removed. An above-knee cast was used for 15 days with an additional 15 days of a below-knee cast to protect the lengthening and arthrodesis sites

7 Technical Pearls

(a) Placement of the wires and half pins is extremely important. Caution is necessary to avoid contact of internal and external implants. Pin tract problems and infections are easy to handle; however, an infected intramedullary nail is a devastating complication. It is advised to leave at least 1 mm of safe bone bridge between pins and the nail. An undersized intramedullary nail is used (1–2 mm narrower than the original canal diameter). Therefore, there is usually a safe zone in the diaphyseal region for bicortically placed K-wires. If necessary, wires can be introduced intracortically. Metaphyseal segments are wider, making it easier to place wires safely.

(b) Consider using poller screws for guiding the nail in the metaphyseal region if necessary.

(c) Carefully prepare the entrance point of the nail. It is slightly medial to the center point of calcaneus.

Fig. 6 Two months later following fixator removal. A plantigrade foot and full lengthening were achieved

Fig. 7 Four months after surgery. Patient can bear weight without any pain

8 Outcome Clinical Photos and Radiographs

See Figs. 6 and 7.

9 Avoiding and Managing Problems

(a) Meticulous preoperative planning is the keystone of the combined technique. The surgeon has to decide the amount of lengthening before surgery and prepare the custom nail templates according to it. The osteotomy site needs to be planned as well to allow adequate IM nail remaining in the proximal bone fragment.
(b) Consider primary grafting of the ankle if there is critical bone loss in the distal tibia.

10 Cross-References

▶ Case 77: Reconstruction of Failed Allograft Reconstruction with Combined Technique (Low-Grade Osteosarcoma)

11 See Also in Vol. 2

Case 41: Ankle Arthrodesis with Tibial Lengthening for Failed Pilon Fracture
Case 44: Complex Ankle Fusion and Tibial Lengthening Using the LATN Technique
Case 45: Ankle Fusion and Tibial Lengthening (LATN Technique) for Failed Ankle Replacement
Case 46: Failed TAR: Conversion to Ankle Fusion with Tibial Lengthening

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Upper Extremity: An Introduction

John E. Herzenberg

Ilizarov's method has revolutionized the orthopedic approach to complex limb deformities, limb length discrepancy, joint contractures, bone defects, and osteomyelitis. However, in practice, it would seem that the vast majority of "Ilizarov procedures" are done in the lower extremities.

This section of the case atlas demonstrates that there are a myriad of useful applications of the Ilizarov limb reconstruction methodology for upper extremity problems. The most obvious use is for humeral lengthening in cases of shortening due to achondroplasia, septic growth arrest, or Ollier disease. Our contributors also demonstrate remarkable cases of combined humeral angular deformity correction with lengthening. Off-label application of the lower extremity internal magnetic lengthening nail is also shown, as a glimpse into the future of humeral lengthening, avoiding the external fixator altogether.

For the forearm, our surgeons have devised clever techniques to address the complex deformities associated with multiple hereditary exostosis and radial clubhand. Even the hand is not immune, with brachymetacarpia being treated with mini-fixators, similar to the more ubiquitous applications in the foot for brachymetatarsia.

Ilizarov surgeons need to be aware that the healing of regenerate bone in the humerus is faster than the radius/ulna. This situation is analogous to the faster healing seen in the femur as compared to the tibia/fibula. For this reason, it is recommended to start lengthening at a slower rate of distraction (0.25 mm BID in adults and 0.25 mm TID in children) in the forearm. The humerus can typically sustain a rate of 0.25 mm QID in children and 0.25 mm TID in adults. Great care must be taken to avoid injury to the radial nerve in humeral applications, and the surgeon must be prepared to do a surgical decompression of the radial nerve if symptoms develop during lengthening. A thorough knowledge of the complex neurologic anatomy of the forearm is essential when applying external fixation of the radius and ulna.

The other category of challenging problems is complex trauma reconstruction for osteomyelitis and the mangled arm. The ingenuity and inventiveness displayed in the submitted cases will be an inspiration to the Ilizarov limb reconstructive surgeon to be open to new applications in the upper extremity. The cases shown in this section are by no means exhaustive or representative of all the potential upper extremity applications. The online nature of this Springer Atlas lends itself to incremental growth in the number of cases, and we are certain that even more upper extremity applications will be added to this already interesting and inspiring group of cases.

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Part XV

Upper Extremity: Humerus

Case 80: Humeral Deformity Secondary to Ollier Disease – Angular Correction and Lengthening with a Taylor Spatial Frame

Daniel Ruggles, Pablo Wagner, and John E. Herzenberg

Contents

Abstract

A 17 year old female presents with a chief complaint of a deformed left humerus. She has a diagnosis of Ollier disease. Secondary to her encondromas that altered physeal growth, she developed a short humerus and valgus deformity limiting her basic and advanced daily activities. A correction with a Taylor spatial frame (TSF) was performed achieving a good correction with a symmetric humeral length. An elbow flexion contracture developed during the treatment that resolved with physical therapy and a custom-made removable orthosis.

1 Brief Clinical History

A 17 year old female presents with gross deformity of her left humerus. She has a history of extensive enchondromas associated with her diagnosis of Ollier disease. She developed a 7 cm arm length discrepancy secondary to her pathologic short humerus and valgus deformity. This humeral deformity is a consequence of a growth arrest secondary to the enchondromas. She has limitations with her personal hygiene, feeding, and driving. A humeral lengthening and deformity correction was planned with a Taylor spatial frame.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

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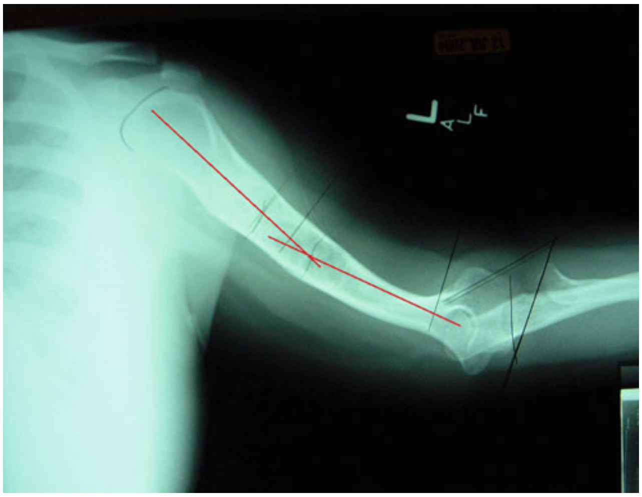

Fig. 1 AP view left humerus

Fig. 2 Lateral view left humerus

3 Preoperative Problem List

1. Short left humerus
2. Oblique plane deformity of the humeral shaft (valgus-procurvatum)
3. Functional deficit and poor cosmesis

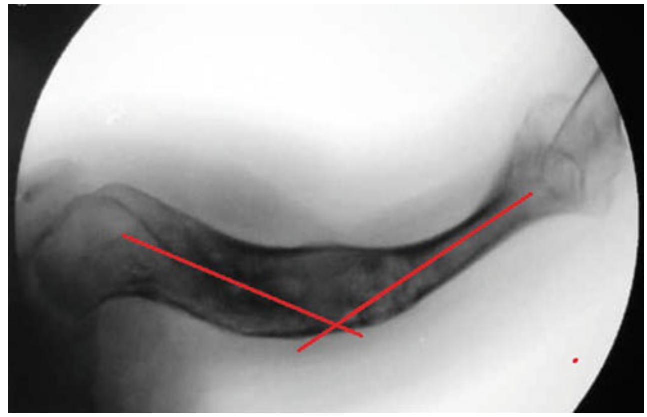

Fig. 3 Fluoroscopy left humerus: preoperative radiographs underestimate the magnitude of the deformity because of its oblique nature. The fluoroscopic image demonstrates the true oblique plane deformity that is consistent with the physical appearance. The apex of the deformity is anteromedial

Fig. 4 Clinical picture of left humerus

4 Treatment Strategy

Osteotomy of humerus with application of a hexapod circular frame for gradual angular correction and lengthening.

5 Basic Principles

A hexapod circular frame was utilized for this case because it enables accurate gradual correction of a complex deformity involving multiangular, rotational, and axial deformity. Pathologic bone in Ollier disease is not a contraindication for distraction osteogenesis as it has been shown that normal bone forms in the regenerate (Tellisi et al. 2008). This may be attributed to the belief that

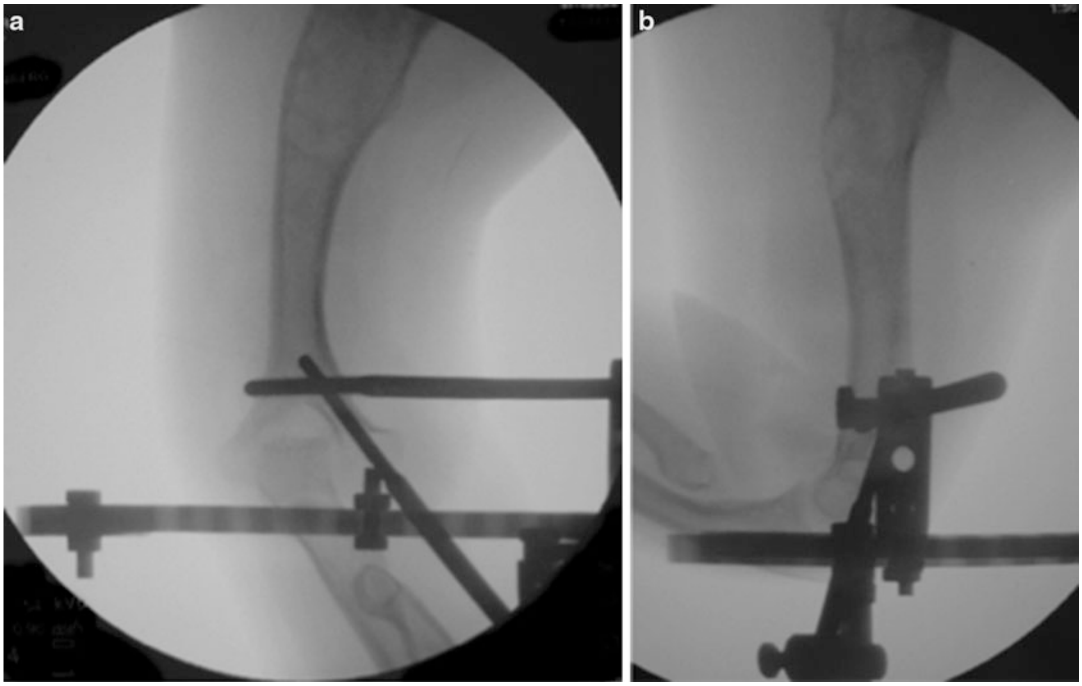

Fig. 5 (**a**, **b**) Perfect orthogonal fluoroscopic views were taken to measure mounting parameters for a distal ring reference

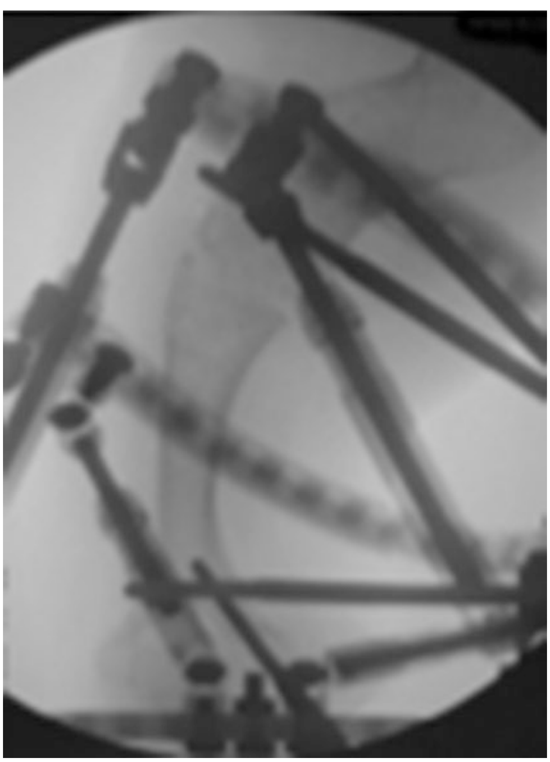

Fig. 6 The severity of the deformity precludes placing the proximal ring perpendicular to the axis of the proximal humerus; therefore, the ring is placed obliquely allowing for strut placement. The expected result is that the final corrected frame will have two parallel rings

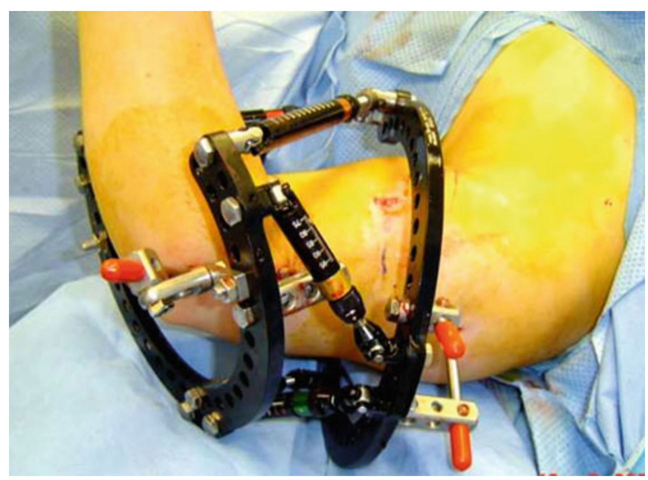

Fig. 7 Initial frame construct. Note that two-thirds of the rings are used: the distal ring is open volarly (anterior) to allow elbow flexion and the proximal ring is open medially for comfort (avoid frame contact with chest wall)

intramembranous ossification is primarily responsible for bone growth during distraction osteogenesis, whereas endochondromatosis is an abnormality of proliferation in endochondral ossification.

Osteotomy is performed at the apex of the deformity. Gradual correction of the deformity and lengthening follows using a hexapod frame.

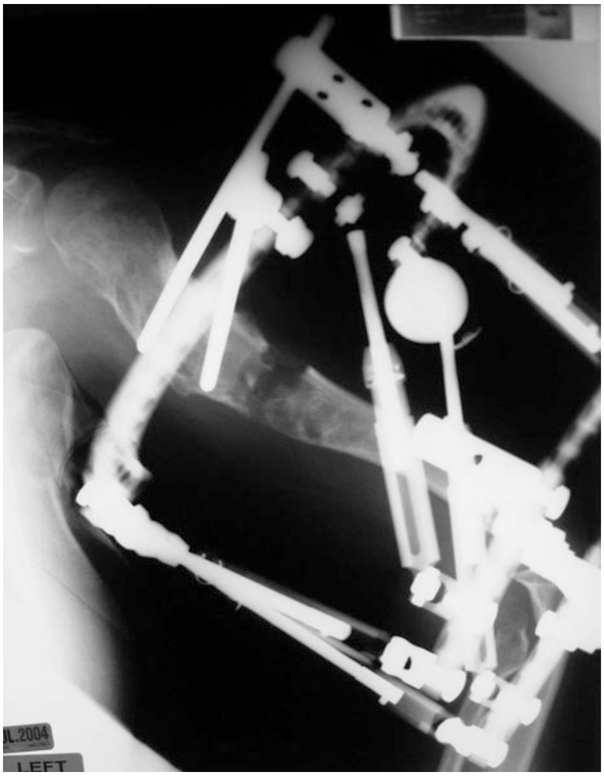

Fig. 8 After a 7-day latency period, the humerus is lengthened to 1 mm/day

6 Images During Treatment

See Figs. 5, 6, 7, 8, 9, and 10.

7 Technical Pearls

Position the distal ring (reference ring) perpendicular to the distal humerus. This increases the working distance of what would otherwise be a very tight frame. Place the proximal ring (non-reference ring) in a position that allows comfortable strut positioning. It is permissible not to place the non-reference ring in a manner that is not perfectly orthogonal to the bone axis in order to make the frame fit optimally.

While positioning the wires and pins, use always protective sleeves and avoid placing them close to the neurovascular structures.

8 Outcome Clinical Photos and Radiographs

See Figs. 11 and 12.

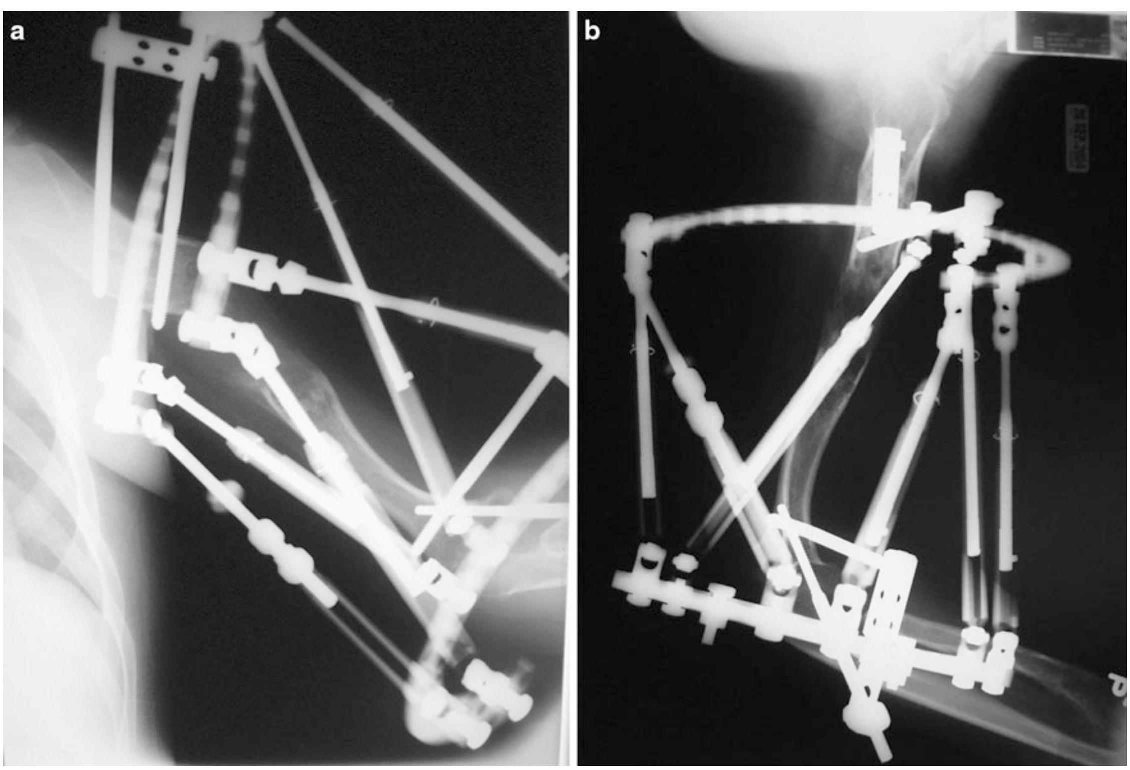

Fig. 9 AP (a) and lateral (b) radiographs after goal length and deformity correction are achieved

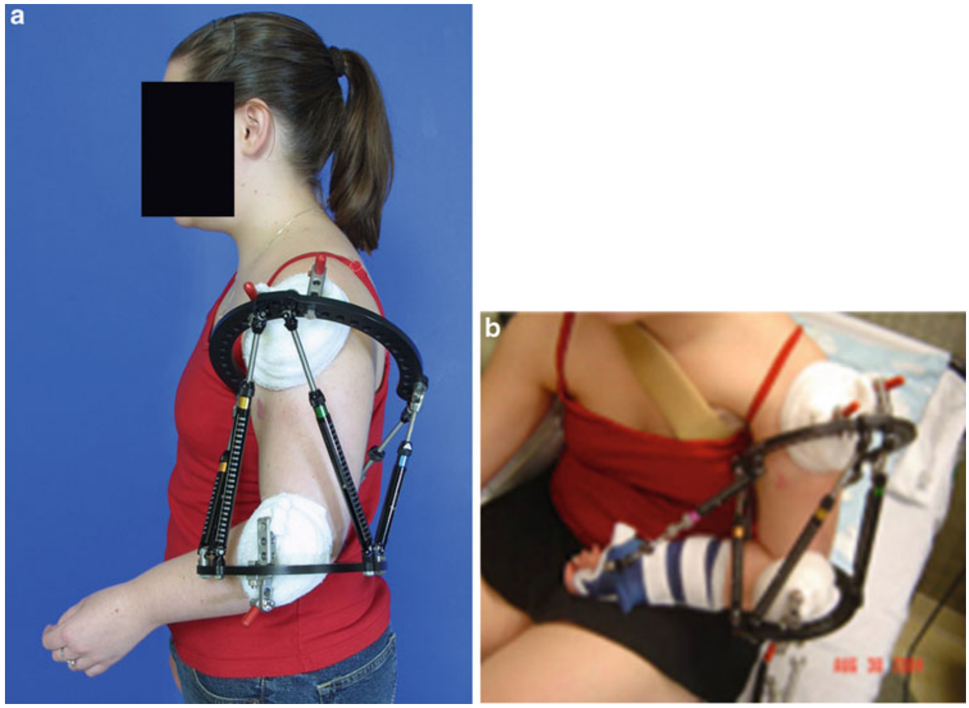

Fig. 10 (**a**, **b**) The patient did develop a significant elbow flexion contracture which was treated with aggressive physical therapy and a custom-built removable dynamic device

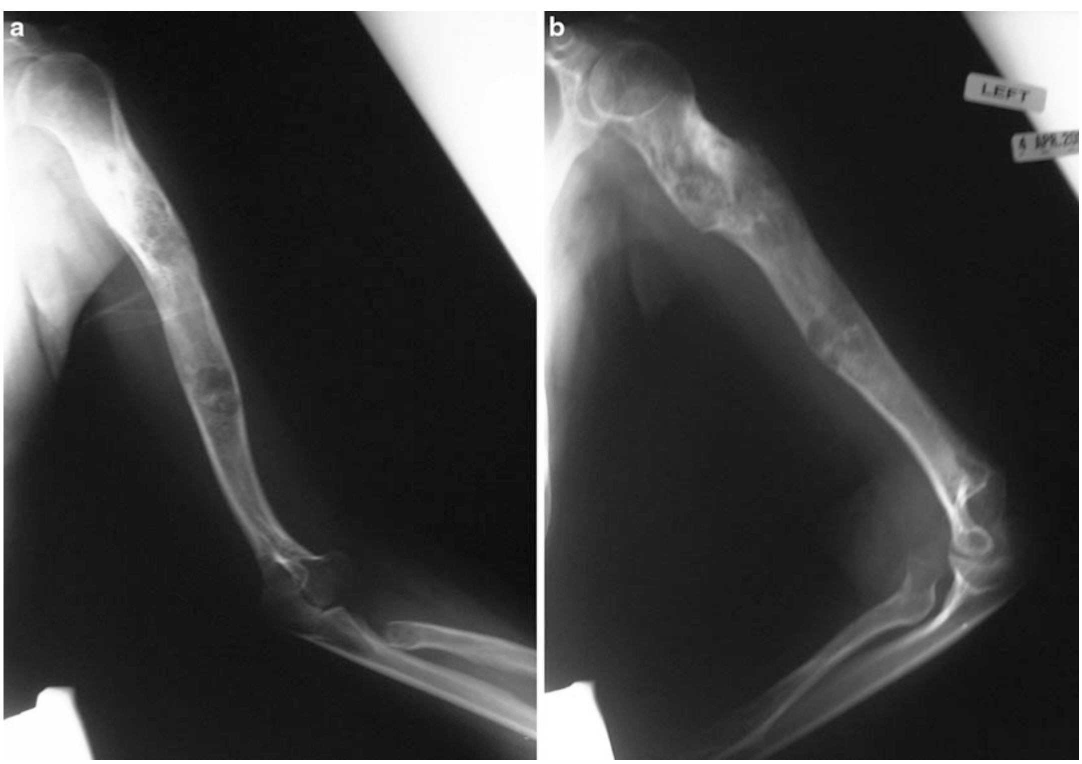

Fig. 11 AP (**a**) and lateral (**b**) XR showing normal-appearing bone regenerate within the diseased humerus

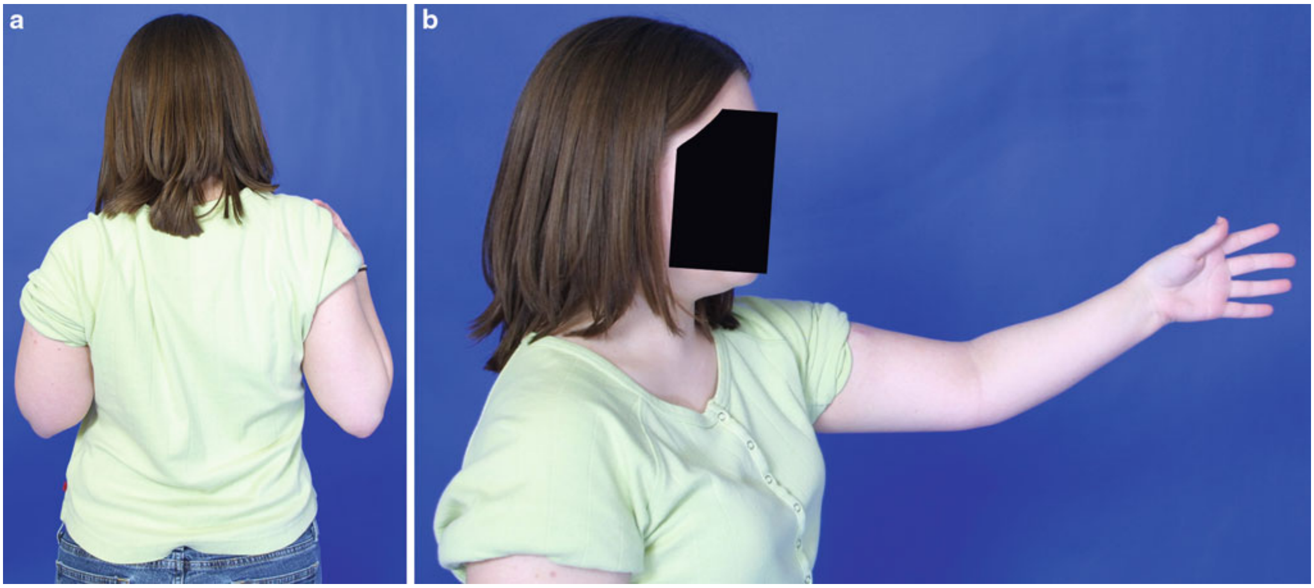

Fig. 12 (**a**, **b**) Clinical photos 8 months after surgery showing improved symmetry of humeral length and improving residual elbow contracture

9 Avoiding and Managing Problems

In case radial nerve symptoms appear, proceed with a radial nerve release. Some surgeons prefer to routinely perform a prophylactic radial nerve release prior to any humeral lengthening/deformity correction. As shown in this case, elbow contracture can be treated with a forearm splint that is incorporated into the TSF. The elbow contracture risk can be minimized with aggressive physical therapy or extending the fixator distal to the elbow.

10 Cross-References

- ▶ Case 81: Humeral Lengthening and Deformity Correction in Ollier's Disease: Distraction Osteogenesis with a Multiaxial Correction Frame
- ▶ Case 83: Adolescent with 15 cm Humeral Shortening from Osteomyelitis Treated by Humeral Lengthening via Circular External Fixation
- ▶ Case 87: Varus and Shortening of the Proximal Humerus
- ▶ Case 102: Fracture of the Humerus Treated Initially with a Flexible Intramedullary Nail and Later Converted to Circular External Fixation due to Non-union

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Case 81: Humeral Lengthening and Deformity Correction in Ollier's Disease: Distraction Osteogenesis with a Multiaxial Correction Frame

S. Robert Rozbruch

Contents

Abstract

A case of Ollier disease with deformity and shortening of the humerus is presented. Lengthening of 9 cm and deformity correction of 50° was accomplished with excellent functional and cosmetic results. Unique features of this case were the use of a multiaxial correction (MAC) monolateral frame (EBI, Parsippany, NJ) and the formation of normal bone within the region of the diseased Ollier bone.

1 Brief Clinical History

A 7 year old female with a short right humerus associated with deformity was referred by the hand tumor service at our institution. She was free of pain but was unhappy with the appearance resulting from the deformity and shortening and complained of inability to reach with the right arm due to short arm span. She carried a history of Ollier disease. She has no family history of the disease. The Ollier disease involved her humerus, radius, index finger, and scapula, all on the right side. She did have lower extremity involvement. She had undergone surgery on her radius for curettage and osteotomy with plating in at the age of 6 with satisfactory results. She had no significant medical history, and a review of systems was otherwise negative.

At presentation, the patient was noted to be 4' tall and weighed 56 lbs. The discrepancy in length between the humeri was 7 cm (Fig. 1a, b). There was full ROM and a normal neurovascular exam.

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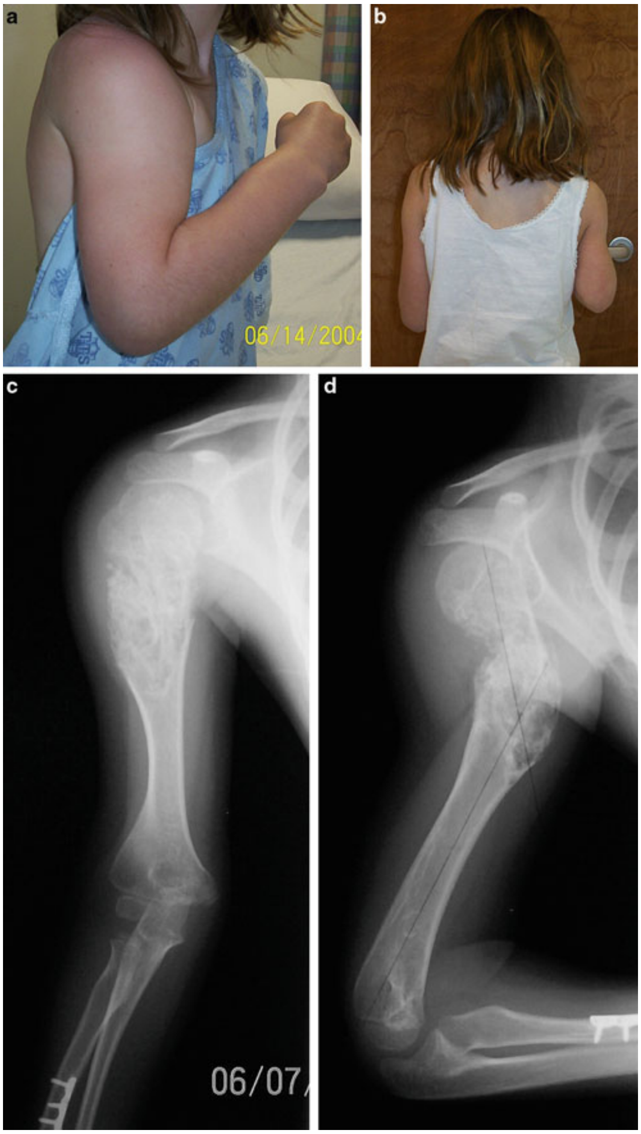

Fig. 1 (**a**) Preoperative *side view* showing the apex anterior deformity. (**b**) *Back view* showing the amount of shortening of the right arm span compared to contralateral side. (**c**, **d**) Anteroposterior (*AP*) and lateral views of right Humerus showing the extent of Ollier's disease and the 50° apex anterior deformity

1.1 Radiographs

She had a 50° apex anterior deformity at the proximal one-third of the humerus. The length of her normal humerus was 23 cm, and the length of the right humerus was 16 cm. There was evidence of Ollier disease at the proximal humerus, with possible involvement of the growth plate. The apex of the deformity was located within the region of the diseased bone (Fig. 1c, d). Based on an upper limb multiplier of 1.37 and the length of the left humerus, her projected left humeral length was calculated to be 31 cm. If the patient were to have no additional growth at the proximal growth plate in the right humerus, the projected discrepancy at maturity would be 14 cm. Growth is unpredictable.

1.2 Treatment

Gradual lengthening and correction of deformity was performed using distraction osteogenesis. The procedure was performed under regional block and sedation. The multiaxial correction frame (MAC) (EBI, Parsipanny, NJ, USA) was applied using two proximal and two distal half pins. The frame was mounted with 50° apex anterior parameter dialed onto the frame to mimic the humeral deformity, and the hinge was placed directly over the apex of deformity (Fig. 2a, b). The proximal pins were placed lateral and anterolateral using 4.5 mm hydroxyapatite-coated pins. The distal pins were placed from an anterolateral and posterolateral direction using 6 mm hydroxyapatite-coated pins. Percutaneous osteotomy just distal to the Ollier bone was performed. The rationale of choosing a distal location was to avoid lengthening through the Ollier bone. It was also felt that osteotomy location proximal to deltoid tuberosity may alter the shoulder biomechanics. Distraction started on the eighth day after surgery at the rate of ¼ turn corresponding to ¼ mm four times daily. Premature consolidation occurred at the osteotomy site, and the rate of distraction was increased to ¼ mm five times a day to overcome the problem. Spontaneous fracture occurred more proximally through the Ollier bone (Fig. 2b). This led to the decision to continue lengthening through the Ollier bone. We observed new bone regeneration within the region of the diseased bone.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. Ollier disease
2. Right humerus 50° apex anterior deformity (apex in diseased bone)
3. Limb length discrepancy 7 cm. Projected discrepancy at maturity 14 cm

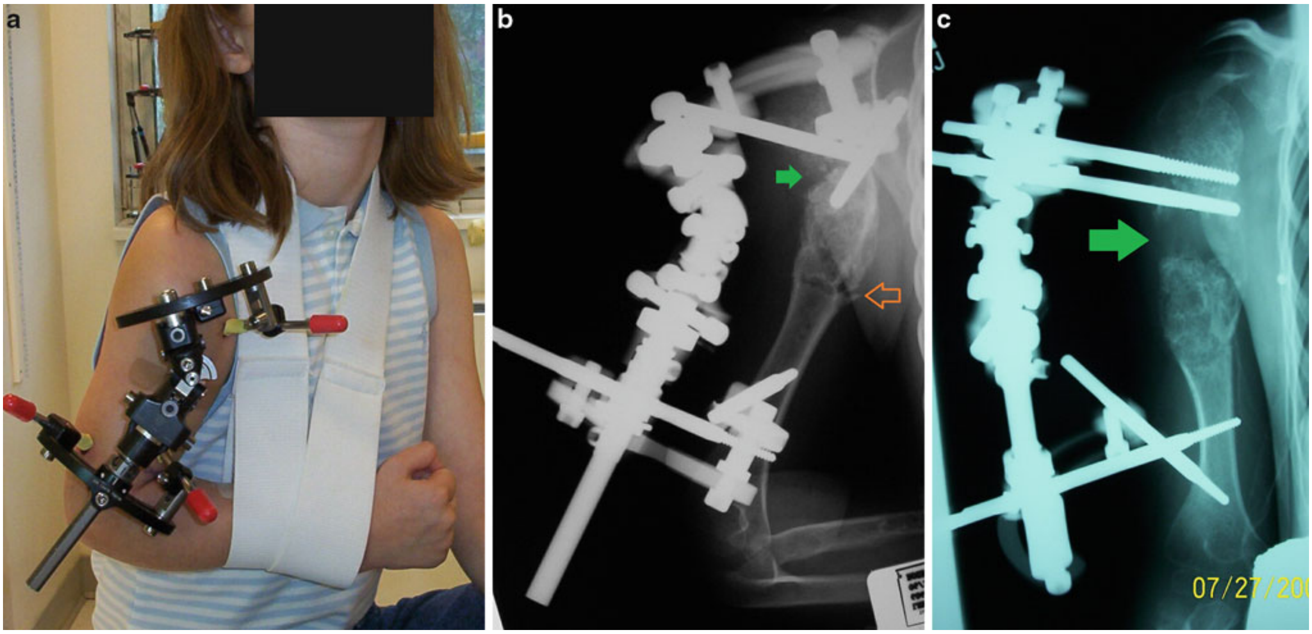

Fig. 2 (**a**) Early postoperative clinical picture showing how the frame mimics the deformity. Note the hinge at the level of the deformity. (**b**) Lateral X-ray showing fracture in the proximal humerus (*green arrow*) within the region of Ollier's bone and at the apex of deformity. The original osteotomy (*orange arrow*) developed a premature consolidation. (**c**) After lengthening of 2 cm through the fracture site (*green arrow*)

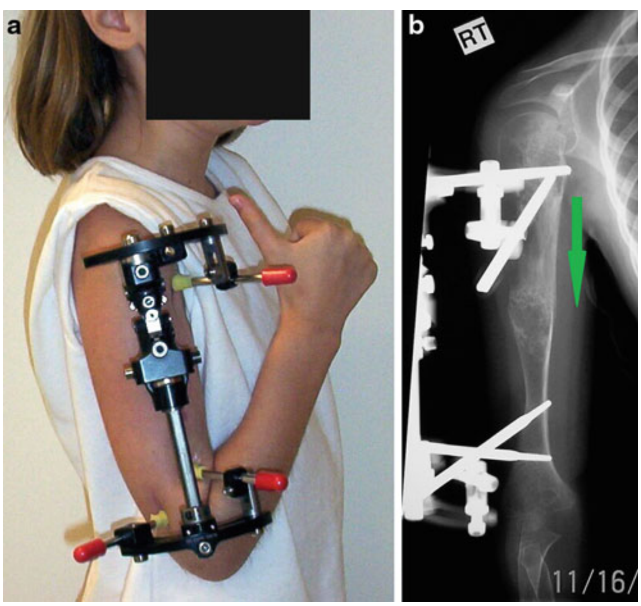

Fig. 3 (**a**) Clinical picture at the end of lengthening and correction. (**b**) AP X-ray showing correction of deformity and 9 cm regenerate (*green arrow*)

4 Treatment Strategy

1. Perform lengthening and deformity correction now. Do some additional lengthening now. Additional lengthening will likely be needed during adolescence or teenage years (see #4).
2. Perform osteotomy just distal to deltoid tuberosity to try and avoid lengthening the proximal humerus diseased bone and to avoid tightening of the deltoid.
3. Mount frame to match the deformity. Use a monolateral frame that has the capability of gradual multiaxial correction.
4. A second lengthening was done at age 15 for expected additional discrepancy and any recurrent deformity that may occur.

5 Basic Principles

1. Circular fixation is cumbersome on the upper arm. We opted to use a monolateral frame with capability for multiaxial correction. The MAC frame is a monolateral frame that has the capacity for multiplanar pin placement. It also can be used to gradually lengthen as well as correct angulation and translation in both the coronal and sagittal planes.
2. Osteotomy and lengthening the diseased bone in Ollier disease can lead to transformation of the enchondroma into normal bone. While this was not the initial plan, this is what happened after premature consolidation of the original osteotomy and fracture through the diseased bone.

6 Images During Treatment

See Figs. 2 and 3.

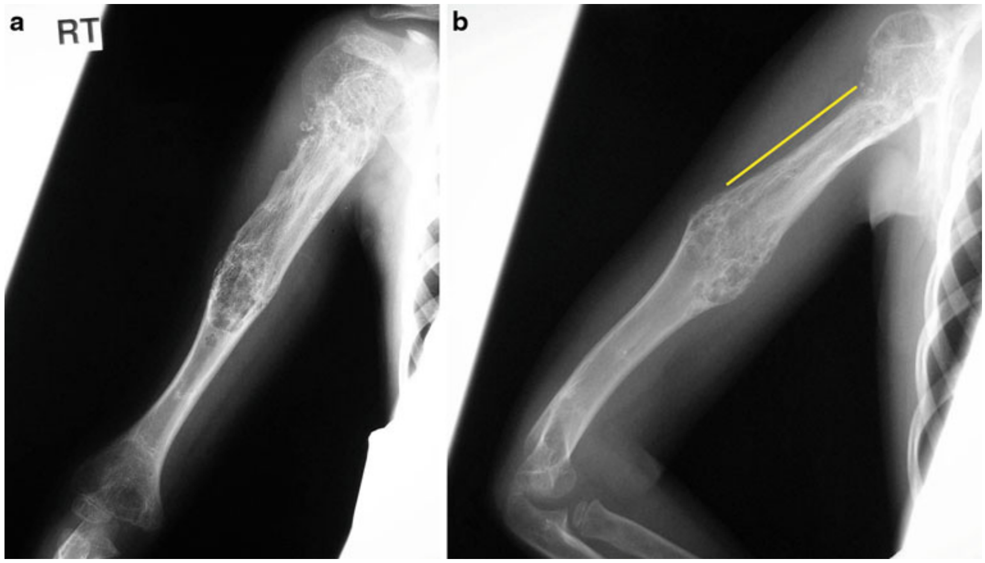

Fig. 4 (**a**, **b**) AP and lateral X-rays at 1 year follow up showing full correction of deformity. Normal appearing bone can be seen in the middle of the Ollier's affected area (*yellow line*)

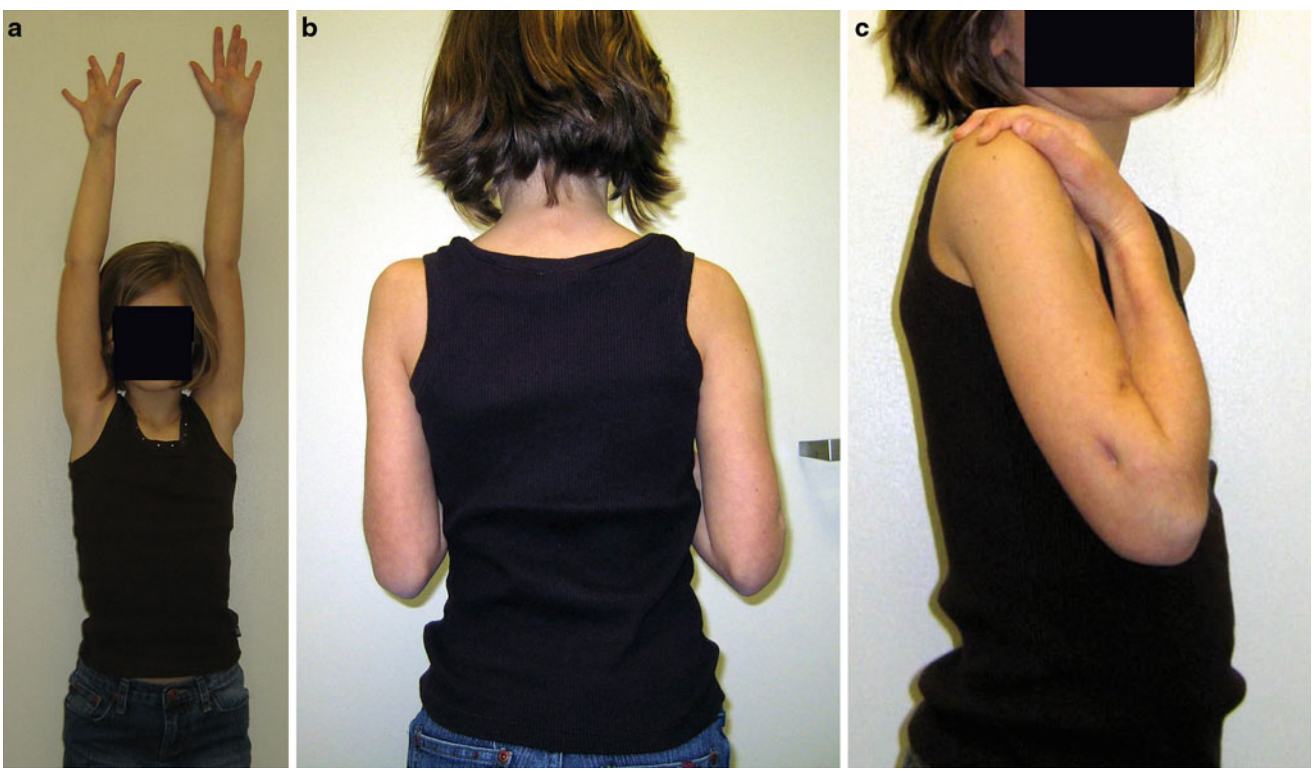

Fig. 5 (**a**–**c**) Clinical pictures at 2 year follow up (age 10) showing equal upper arm lengths and normal range movement of the right shoulder and elbow joints

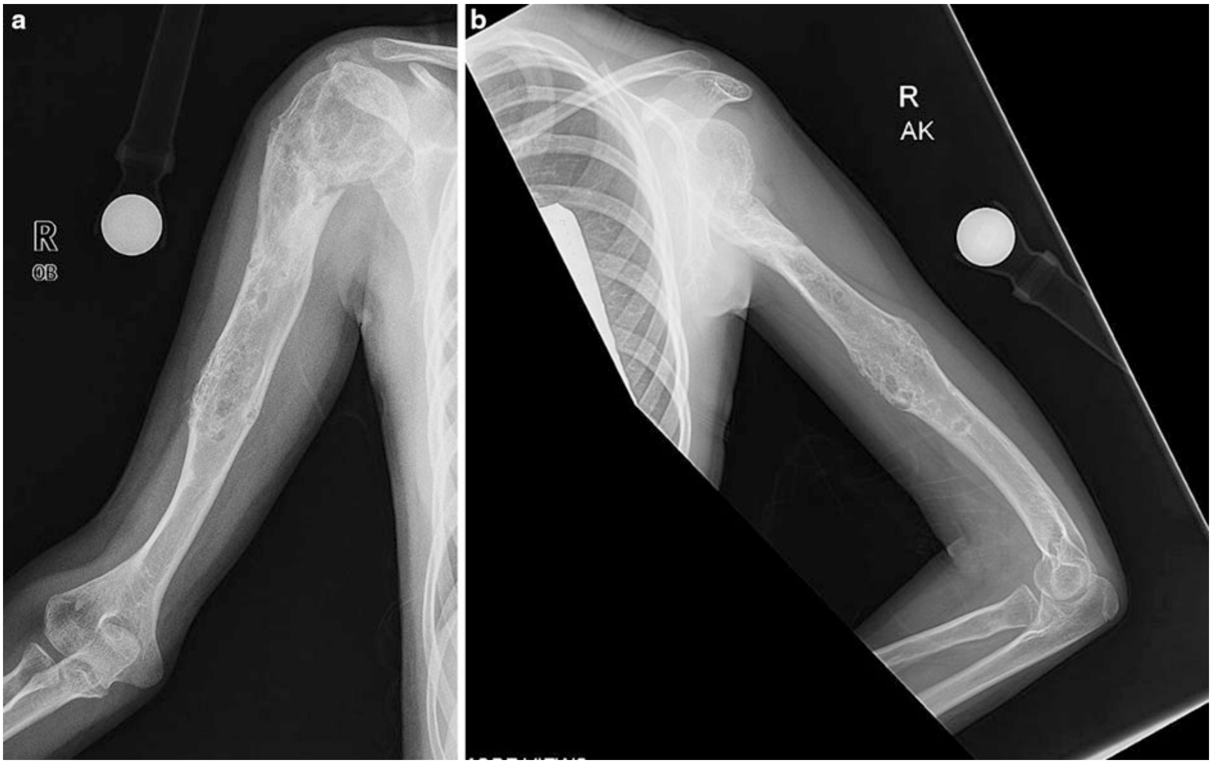

Fig. 6 (**a**, **b**) Final AP/lateral X-rays after completion of a second lengthening and residual deformity correction done at age 15. Recurrent apex anterior deformity was corrected and 5 cm of additional lengthening was done

7 Technical Pearls

1. The MAC frame is very useful here in that gradual multiaxial deformity correction is possible.
2. The arches allow multiaxial pin placement on a monolateral frame.
3. Pins are placed on a distal arch to avoid injury to the radial nerve. The cannulated wire technique is used for accurate pin placement. At the level where the radial nerve crosses the lateral humerus, the pin is placed in a posterolateral to anteromedial direction, maintaining a safe distance from the radial nerve.

8 Outcome Clinical Photos and Radiographs

See Figs. 4, 5, and 6.

9 Avoiding and Managing Problems

1. Prevent injury to the radial nerve when placing distal pins. Make sure the patient is not paralyzed, so a hand twitch would be noticed if the nerve were touched with a wire. Use the cannulated wire technique (first insert wire; then use cannulated drill over the wire; then insert half-pin) and soft-tissue protectors. The pin on the distal arch that is at the level of the radial nerve is directed from posterolateral to anteromedial, maintaining a safe distance from the radial nerve.
2. Premature consolidation can be avoided by performing a complete osteotomy, starting distraction sooner with a faster rate than 1 mm/day
3. Continue distraction in the setting of premature consolidation, and in most cases, the osteotomy will "pop" and separate.

10 Cross-References

▶ Case 87: Varus and Shortening of the Proximal Humerus
▶ Case 94: Correction of Forearm Deformities in Hereditary Multiple Exostosis (MHE)

11 See Also in Vol. 1

Case 90: Correction of Lower Limb Deformities in Multiple Hereditary Exostosis (MHE)

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Case 82: Humeral Lengthening for Septic Growth Arrest

Pablo Wagner, Daniel Ruggles, and John E. Herzenberg

Contents

Abstract

This 20 year old female developed humeral growth arrest secondary to neonatal osteomyelitis of the proximal humerus. Her main complaint was a limitation to perform her basic daily activities that required reaching with her affected arm. She underwent a 7 cm humeral lengthening using a monolateral external fixator. There were no significant complications in this case. A successful final outcome was achieved.

1 Brief Clinical History

This patient is a 20 year old healthy female with a history of neonatal sepsis. Secondary to this infection, she developed a proximal humeral septic growth arrest. She developed an arm length discrepancy of 7 cm. Initially a conservative treatment was chosen by the family and patient. In her teenage years, a functional limitation in her daily activities became evident. Impaired function related to compromised reach and concern about the abnormal appearance were the main reasons to proceed with surgical treatment. A lengthening using a monolateral external fixator was proposed.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Left humeral shortening
2. Left humeral head deformity
3. Radial nerve at risk

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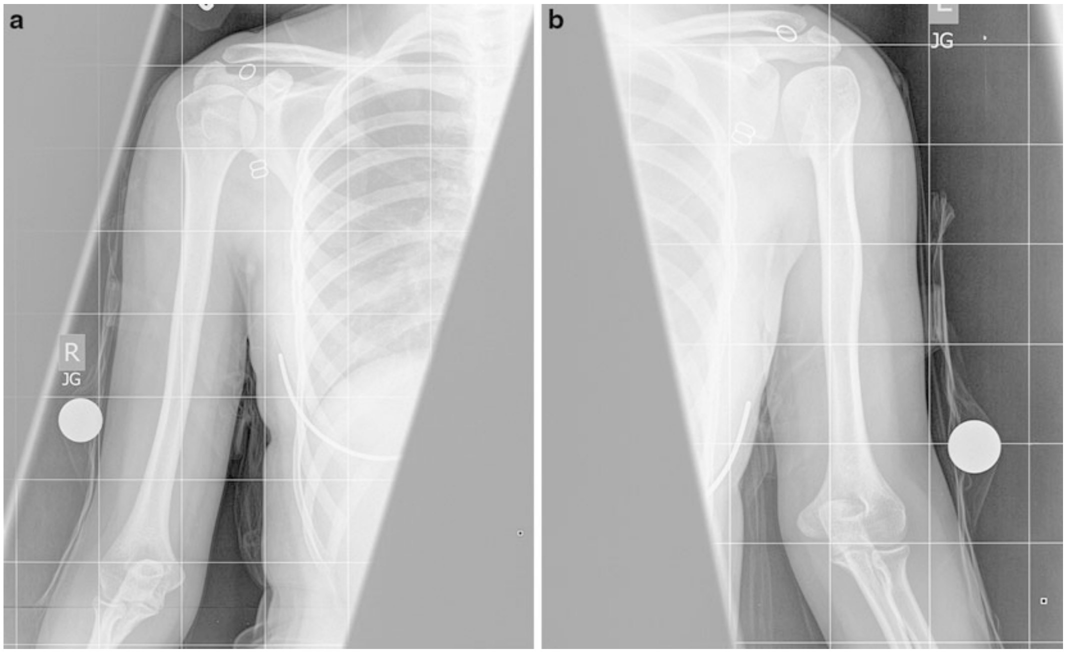


Fig. 1 (**a**, **b**) AP X-ray of the right and left humerus, showing left-sided shortening

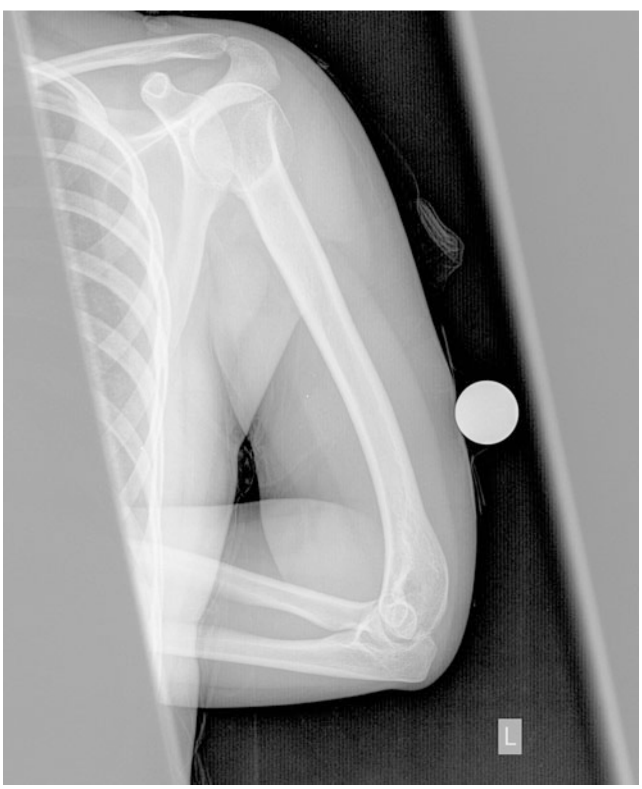


Fig. 2 Lateral X-ray of the left humerus

Fig. 3 Clinical picture showing arm length discrepancy (left-sided shortening)

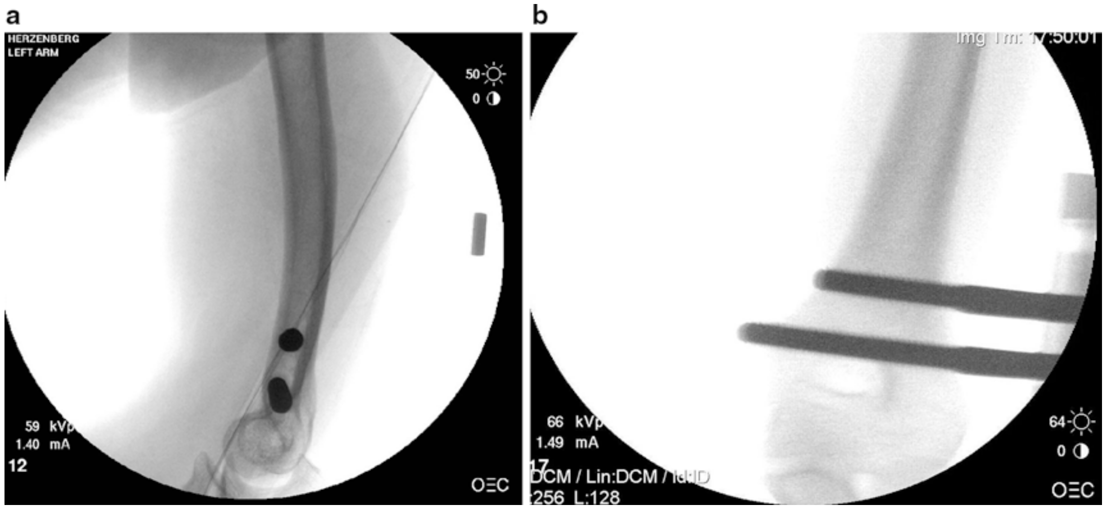


Fig. 4 (**a**, **b**) Distal pin placement on a lateral and AP intraoperative X-ray

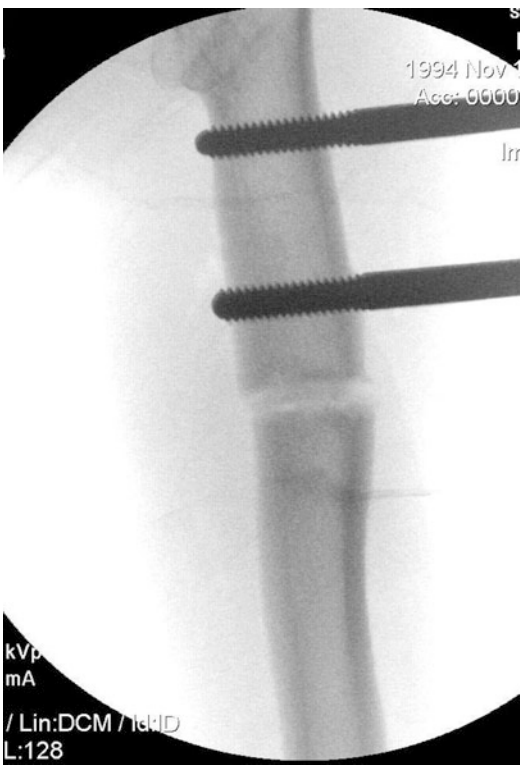


Fig. 5 AP intraoperative X-ray of the proximal pins

Fig. 6 AP X-ray showing early separation of the osteotomy

4 Treatment Strategy

Lengthen the humerus using a monolateral frame. Perform osteotomy just distal to the deltoid tuberosity.

In this case, accept the proximal humerus deformity and avoid reconstruction in that area. This is not expected to change preoperative shoulder ROM limitation related to proximal humerus deformity.

Frame application: Place distal pins first, as distal as possible, perpendicular to the anatomic axis.

Then place proximal pins at the level of the deltoid tuberosity and proximal to it.

Fig. 7 AP X-ray showing 7 cm distraction gap, good bone formation, and mild varus angulation

5 Basic Principles

Distal pins should be located as distal as possible to avoid radial nerve path. The most distal pin should be placed just proximal to the olecranon fossae and the second pin just proximal to it. Proximal pins should be located proximal to the deltoid tuberosity, but not within 4 cm of the acromion which would put the axillary nerve at risk during pin insertion. Osteotomy should be performed just distal to the deltoid tuberosity.

6 Images During Treatment

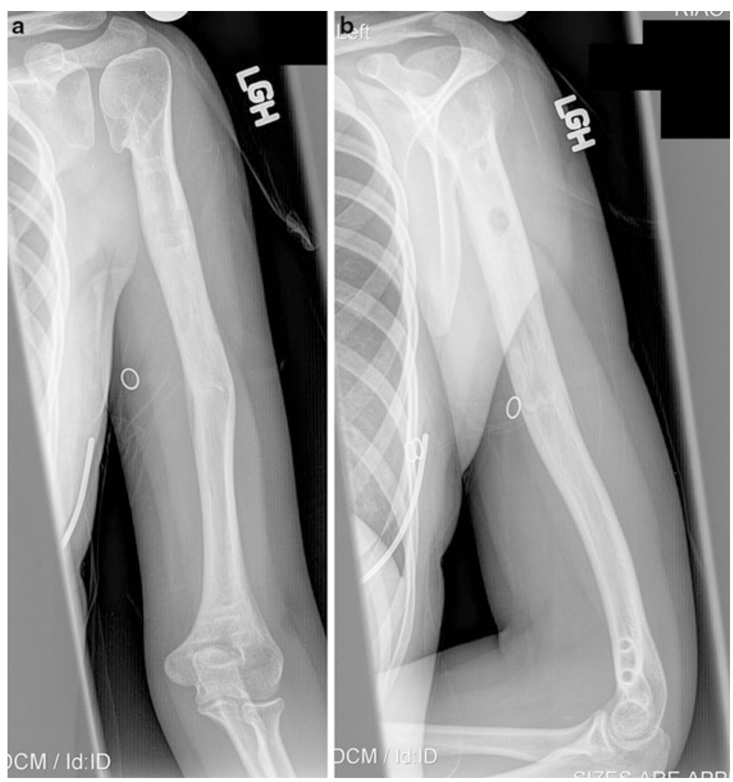
See Figs. 4, 5, 6, and 7.

7 Technical Pearls

Locate the distal pin just above the olecranon fossae. Start with a K wire, then drill over it using a cannulated drill bit. The second distal pin should be located immediately proximal to the first one. Use the clamp from the external fixator to determine the minimum distance between these two pins.

Many surgeons prefer to release the radial nerve prophylactically. To do that, release the radial nerve starting

Fig. 8 (**a**, **b**) AP and lateral X-rays after bony union and external fixator removal



distally, anterior to the pins, and follow it proximally to the radial groove and intermuscular septum. In this particular patient, this release was not performed. We do not perform nerve release routinely.

8 Outcome Clinical Photos and Radiographs

See Fig. 8.

9 Avoiding and Managing Problems

Physical therapy is necessary to avoid elbow and shoulder contractures. A close follow-up is necessary to check the radial nerve status. If the radial nerve was not released, keep a close follow-up on patients particularly during the lengthening period. At the first sign of nerve compromise, a nerve release should be performed. During humeral lengthening, varus angulation (see Fig. 5) is very common. It is only necessary to correct it in cases of progressive malalignment and pin loosening. Mild varus may be accepted.

10 Cross-References

- ▶ Case 83: Adolescent with 15 cm Humeral Shortening from Osteomyelitis Treated by Humeral Lengthening via Circular External Fixation
- ▶ Case 87: Varus and Shortening of the Proximal Humerus

References and Suggested Reading

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Case 83: Adolescent with 15 cm Humeral Shortening from Osteomyelitis Treated by Humeral Lengthening via Circular External Fixation

John Birch, Alexander Cherkashin, and Mikhail Samchukov

Contents

Abstract

Fifteen year old male with a multifocal osteomyelitis presumably due to neonatal sepsis resulted in varus deformity of the proximal tibia with internal rotation and shortening, which were corrected previously, and varus-procurvatum deformity of the left humerus with 15-cm shortening. Patient underwent 14-cm humeral lengthening after midshaft osteotomy and acute deformity correction using circular external fixation.

1 Brief Clinical History

The patient is a 15 year old male known to have multifocal septic arthritis as an infant with resultant joint disruption and physeal growth disturbance of the knee, proximal tibia, shoulder, and proximal humerus, all on the left (Fig. 1). Previously, he had undergone tibial angular deformity correction and lengthening with an excellent clinical outcome. His current complaints include significant glenohumeral intra-articular shoulder pain, markedly reduced shoulder abduction (50°), and limited external/internal rotation (20°), with a cosmetically displeasing substantial shortening (15 cm) of the humerus (Figs. 2 and 3). He has limitation of ipsilateral elbow flexion to approximately 100°, which is asymptomatic. He is neurovascularly intact and in good general health.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

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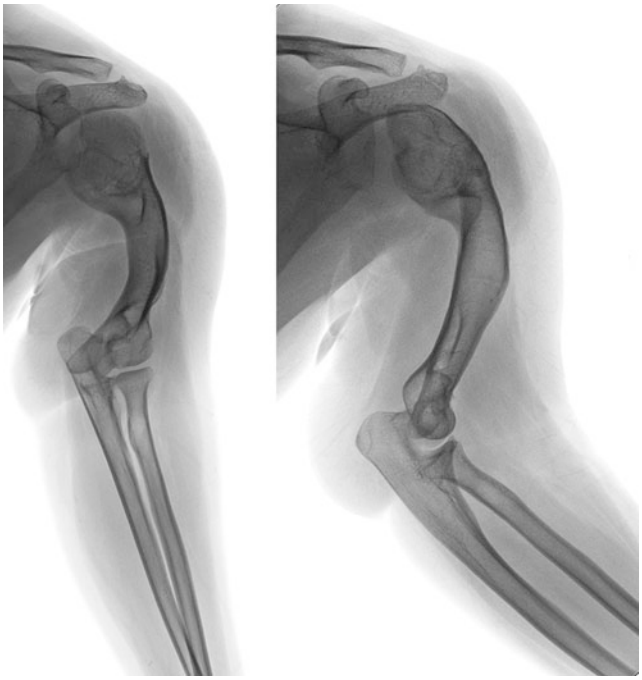

Fig. 1 Preoperative AP and LAT radiographs of the humerus demonstrating significant distortion of the glenohumeral joint and proximal humerus. Note varus-procurvatum deformity (40°) of the humeral diaphysis (asymptomatic) and the severe (15 cm) shortening

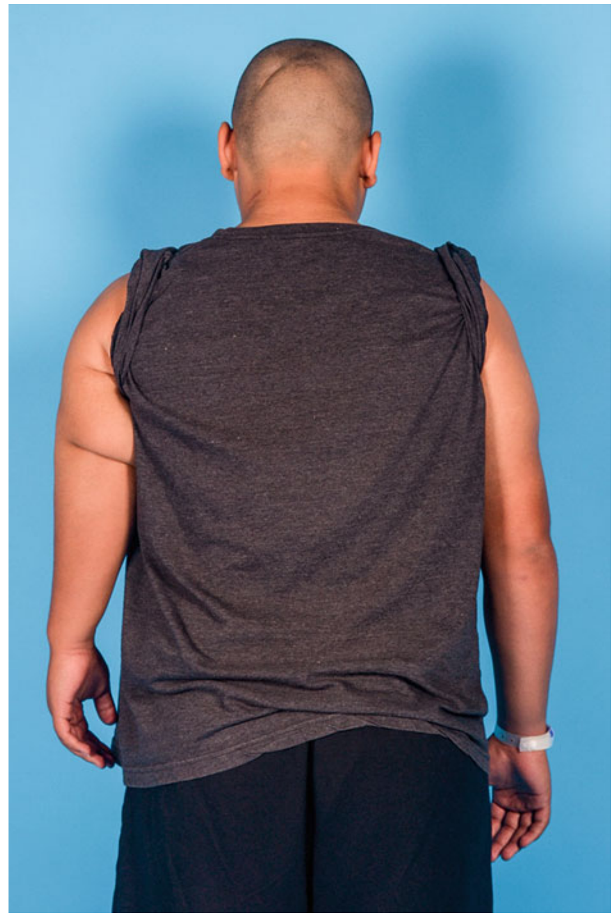

Fig. 2 Preoperative view from behind showing substantial shortening of the left humerus

3 Preoperative Problem List

- Cosmetically displeasing 15-cm humeral shortening
- Asymptomatic 40° varus-procurvatum deformity of the affected humerus
- Glenohumeral post-septic degenerative arthritis with significant pain and very limited shoulder range of motion
- Limited elbow flexion to approximately 100°

4 Treatment Strategy

Because of the extreme shortening associated with angular deformity, circular external fixation was elected to effect humeral lengthening. The patient was carefully evaluated by upper extremity specialists before the surgery with respect to the glenohumeral pain and significant limitation of shoulder motion. In the context of the severity of the articular deformity, he was considered a candidate for shoulder arthrodesis. The patient was counseled that humeral lengthening would have no positive and, possibly, a detrimental effect on shoulder pain and range of motion (ROM). He elected humeral lengthening to correct the cosmetic deformity, knowing that shoulder arthrodesis could be performed subsequently if symptoms warranted. To preserve shoulder and elbow ROM and prevent potential joint subluxation, systematic exercises and periodic evaluation during the course of lengthening were included in the treatment strategy.

5 Basic Principles

Fixation strategy for long-distance humeral lengthening is based on hybrid bone fragment stabilization utilizing a combination of wires and half-pins proximally and cross wires only distally (Cattaneo et al. 1990, 1993; Lee et al. 2005; Pawar et al. 2013). This approach maximizes longevity of the interosseous fixation and dimensional flexibility in correction of existing deformity of the humerus as well as an opportunity to correct secondary deformities that could develop during lengthening. After frame application, a humeral osteotomy is carried out by multiple drill holes connected using a narrow osteotome just distal to the deltoid insertion after subperiosteal dissection through an anterior approach to the humerus. Humeral lengthening in pediatric patients is accomplished using standard Ilizarov protocol (Ilizarov 1992) comprising of 0.25 mm of distraction four times daily after a 5-day latency period.

Fig. 3 Preoperative side view photograph illustrating apex-anterior bow of the humerus

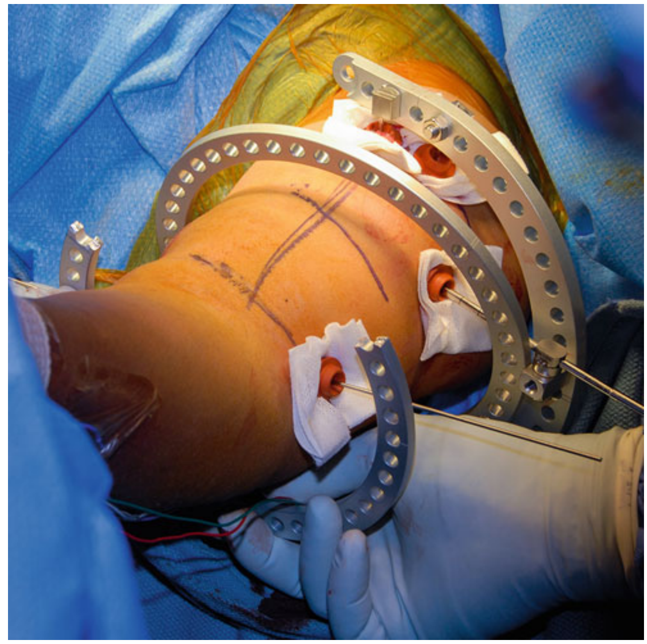

Fig. 4 Intraoperative photograph of the humerus during application of TrueLok external fixator. Note that ends of the aluminum 5/8 rings can be easily cut at the surgery to increase the anteriorly oriented opening and provide space for elbow flexion during the lengthening

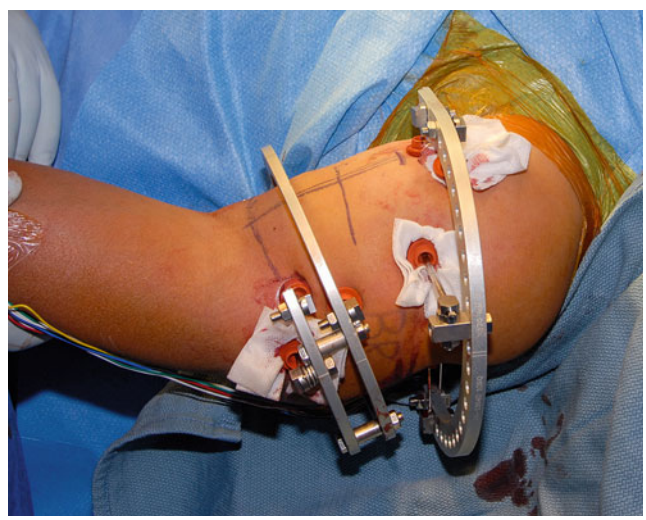

Fig. 5 Intraoperative photograph demonstrating position of external supports with the angle opened anteriorly prior to osteotomy and acute procurvatum deformity correction

Regenerate bone tends to form well in the distraction gap during humeral lengthening, and the surgeon must monitor the new bone formation carefully, altering the rate of distraction as indicated. As a generality, patients undergoing upper extremity lengthening do not have as much pain or interference with mobility as those undergoing lower extremity lengthening. Activities of daily living, however, may be significantly impacted by the upper extremity fixator, and consultation with an occupation therapist is very helpful.

6 Images During Treatment

See Figs. 4, 5, 6, 7, 8, 9, 10, and 11.

7 Technical Pearls

Frame configuration and bone fixation pattern for humeral lengthening must be carefully selected to allow safe application of the device to a short and often deformed humerus without compromising stability of bone fragment fixation. Our standard fixation of the proximal humerus in those cases consists of two posterior-to-anterior 1.8-mm diameter olive crossing wires and one lateral 4-mm diameter half-pin inserted proximal to the deltoid tubercle and

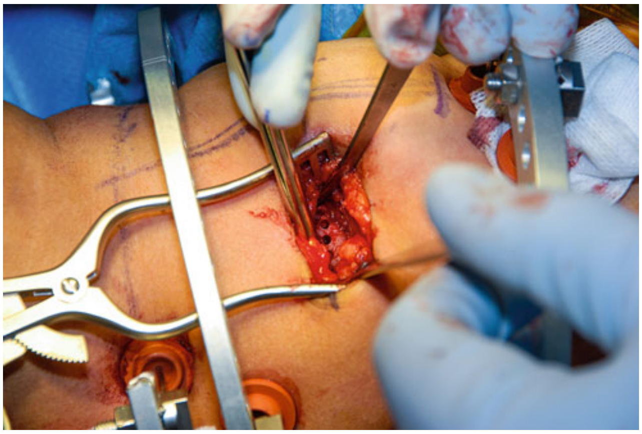

Fig. 6 Intraoperative photograph illustrating midshaft humeral osteotomy. Note multiple drill holes that will be connected using narrow osteotome followed by rotation osteoclasis to complete the osteotomy

Fig. 7 Intraoperative photograph showing elbow ROM at the end of the surgery. Note sufficient opening on the distal external support anteriorly maximizing joint flexion

attached to a semicircular external support (Fig. 4), which is shaped as a half ring with an elongated ends (e.g., Ilizarov “Omega” ring, TrueLok foot plate). Fixation of the distal humerus is usually achieved by three transverse 1.8-mm diameter wires including two cross olive wires located the most distally and one smooth drop wire positioned at some distance more proximally secured to a full and 5/8 ring block (Fig. 5). Following osteotomy, proximal and distal external supports are interconnected by telescopic distraction rods allowing gradual lengthening. In cases when the distance between the external supports does not allow for the shortest telescopic rods, we use regular threaded rods and special TrueLok square nuts with attached concave washers (Fig. 7) that can be turned together by a double wrench for gradual compression or distraction.

8 Outcome Clinical Photos and Radiographs

See Figs. 12, 13, and 14.

9 Avoiding and Managing Problems

The most important challenge of circular external fixation on the short and deformed humerus is providing sufficient stabilization of the bone fragments, while avoiding a peripheral nerve injury. Unfortunately, anatomical constraints and pathological changes in bone and soft tissue structure do not allow the application of the most rigid external support configuration such as full ring and limit the utilization of such parameters as maximum wire crossing angles and wire tension in achieving satisfactory bone fragment stabilization. Therefore, the addition of the lateral half-pin to two wires crossing at the very obtuse angle (15–20°) or replacement of those two wires with two to three half-pins similar to proximal femoral fixation is employed for proximal humeral fixation. The use of posterior olive wires will also help in preventing anterior

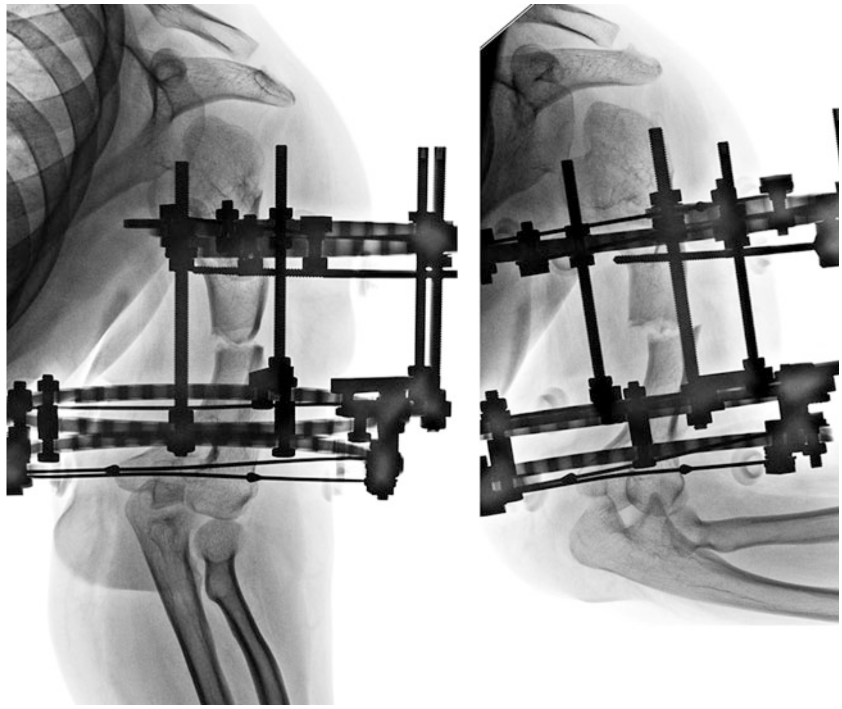

Fig. 8 Postoperative AP and LAT radiographs at 5 days of distraction. Note correlating inter-fragmentary gap and bone fragment orientation after acute deformity correction

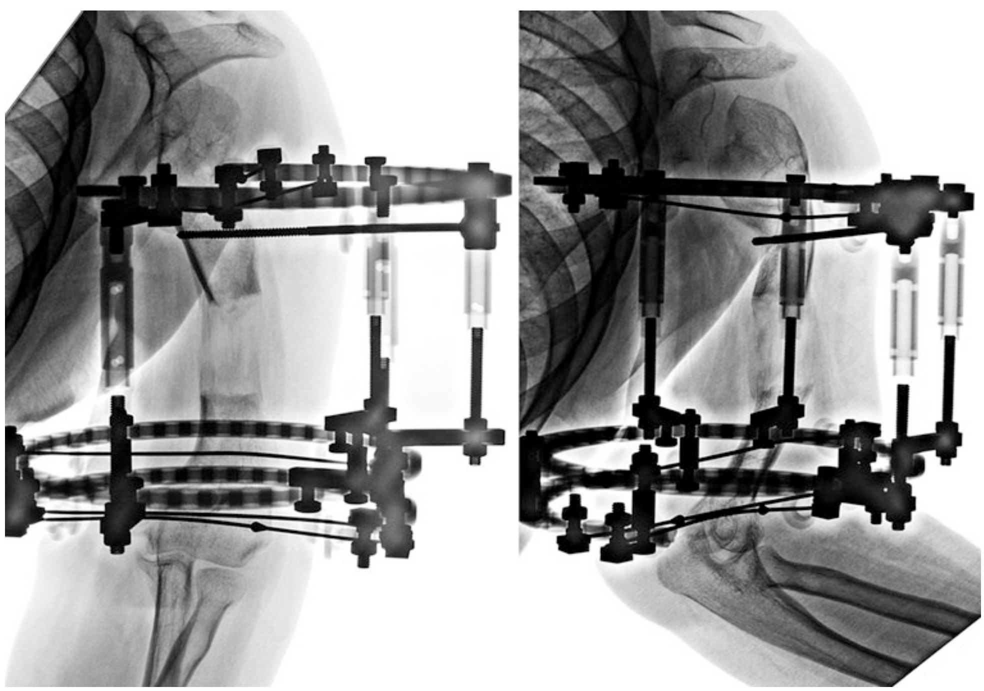

Fig. 9 Postoperative AP and LAT radiographs at 2 months of distraction. Note typical three-zonal distraction regenerate and maintenance of bone fragment orientation during the lengthening

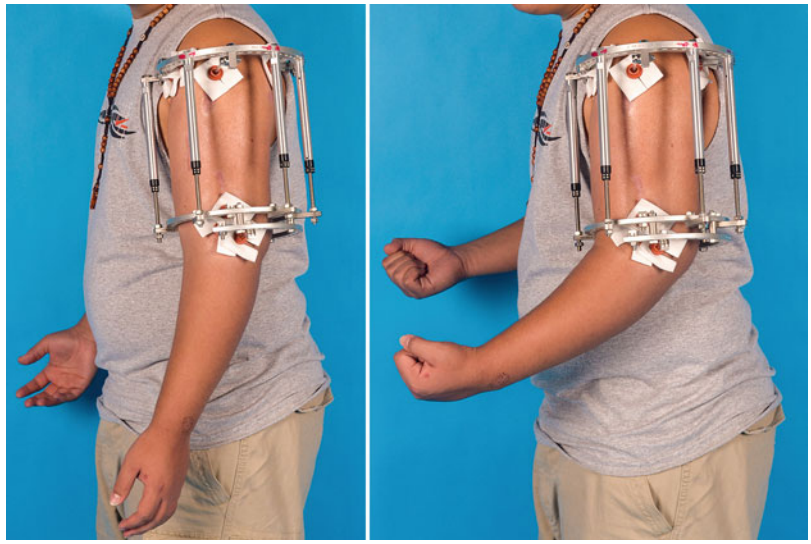

Fig. 10 Lateral view photographs demonstrating elbow ROM during the lengthening

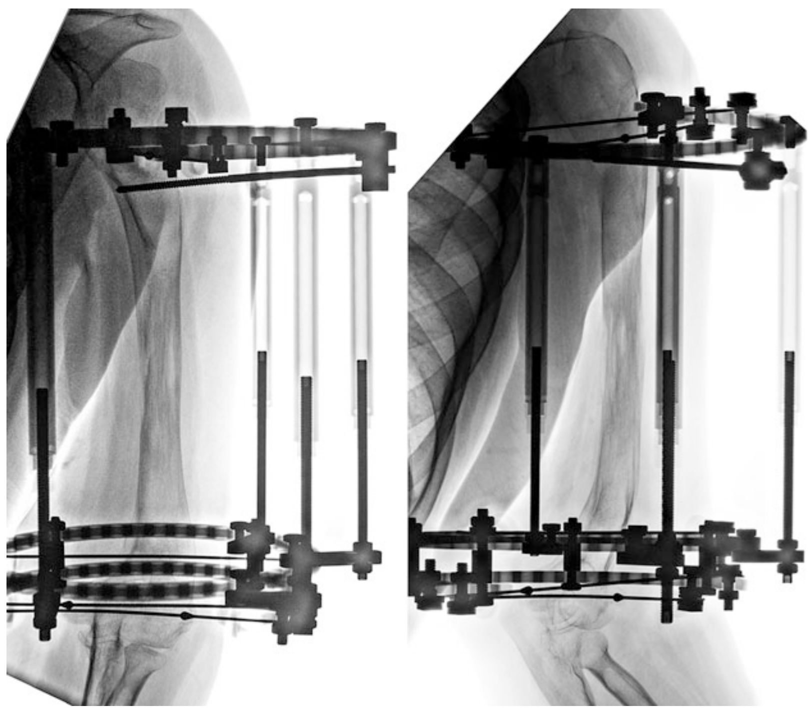

Fig. 11 AP and LAT radiographs after completion of 14 cm of humeral lengthening after 4 months of consolidation. Note homogeneous column of newly formed bone in the distraction gap. The fixator was removed 1 month later (total treatment time in the frame was 10 months, including 5 months of distraction and 5 months of consolidation)

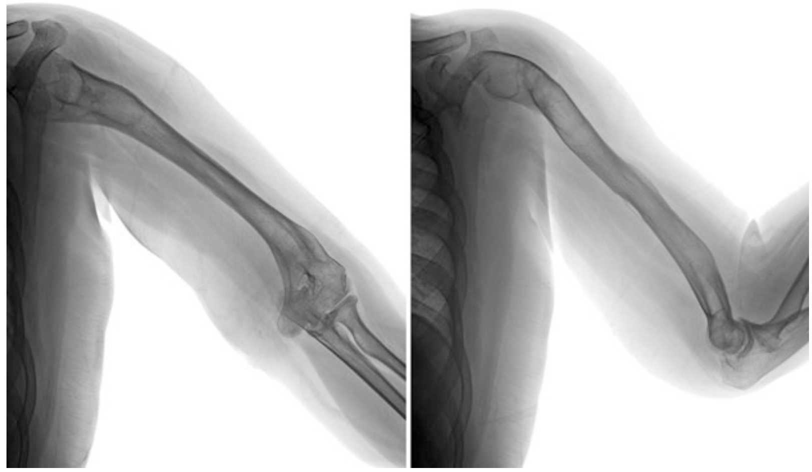

Fig. 12 AP and LAT radiographs of the humerus 2 years after frame removal demonstrating excellent alignment, complete remodeling of the newly formed bone with reconstitution of the medullary canal, and no deterioration of the deformed humeral head

Fig. 13 Back view photograph 2 years after frame removal. Note that humeral length is equal to the opposite side. Patient is skeletally mature. He complains of some moderate pain in the shoulder, related to cold weather

translation of the apparatus by the patient leaning on the back of the apparatus when reclined. Distally, the angle between the two crossing wires is even smaller (10–15°), requiring addition of the drop wire to enhanced anterior/posterior bending stability. Sometimes, the length of the distal humeral fragment is too short, thereby preventing the insertion of the drop wires. In those cases, two olive wires can be used, crossing each other at a larger angle in the coronal plane and attached to the external support using connection posts/cubes. To avoid nerve injury during wire/half-pin insertion and acute manipulation with bone fragments, somatosensory evoked potential (SSEP) monitoring of peripheral nerves is utilized in our institution during frame applications on upper extremities (Makarov et al. 1997, 2012). Finally, the surgeon should have no hesitation in performing limited exposures of the bone and/or neurovascular structures during wire and half-pin placement if deemed appropriate.

10 Cross-References

- ▶ Case 80: Humeral Deformity Secondary to Ollier Disease – Angular Correction and Lengthening with a Taylor Spatial Frame
- ▶ Case 81: Humeral Lengthening and Deformity Correction in Ollier’s Disease: Distraction Osteogenesis with a Multiaxial Correction Frame
- ▶ Case 82: Humeral Lengthening for Septic Growth Arrest

Fig. 14 Lateral view photographs illustrating preserved elbow ROM (from full extension to 90° of flexion). Patient remains with restricted motion at the shoulder but totally satisfied with the outcome and not desiring of a shoulder fusion for symptoms at this time

► Case 84: Humeral Lengthening in Erb's Palsy
► Case 85: Deformity of the Humerus in a Four Year Old Boy with Osteogenesis Imperfecta
► Case 86: Humeral Lengthening with a Motorized Intramedullary Lengthening Nail

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Case 84: Humeral Lengthening in Erb's Palsy

Gamal Ahmed Hosny

Contents

Abstract

A 10 year old girl presented with a deformed right humerus. The patient had weakness of the muscles due to the Erb palsy. There was a history of having undergone a previous osteotomy of the proximal humerus to derotate the arm, which resulted in malunion of the humerus in the form of anteromedial angulation, and shortening of 8 cm. There was marked limitation of shoulder abduction and external rotation and neurologic deficit consistent with the Erb palsy. An Ilizarov external fixator was applied to the humerus, and corticotomy was performed through the scar of the previous operation at the apex of the deformity. After a latency period of 1 week, distraction was begun at a rate 1 mm per day in divided doses. At the end of gradual lengthening and correction of the angulation, she then had an acute derotation procedure done by adjusting the external fixator acutely in the clinic. The only complication encountered was pin tract infections, which were treated by parenteral antibiotics. Follow-up after 3 years revealed improvement of the abduction and external rotation range of motion.

1 Brief Clinical History

This girl was initially treated at age 4 years. The diagnosis was right Erb's palsy with marked internal rotation contracture. She was treated with derotation osteotomy of the upper humerus without internal fixation. The osteotomy had been stabilized with a shoulder spica cast, but lack of stability of the fragments led to shortening and malunion.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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3 Preoperative Problem List

1. Shortening and anterolateral angulation, right humerus
2. Internal rotation deformity, right humerus
3. Limitation of right shoulder abduction and external rotation
4. Erb's palsy

4 Treatment Strategy

There was an oblique plane angular deformity and rotational deformity. We decided to use the circular frame as it is more effective in treating complicated deformities than a unilateral frame. We applied an Ilizarov frame that included a 90° Italian

Fig. 1 (continued)

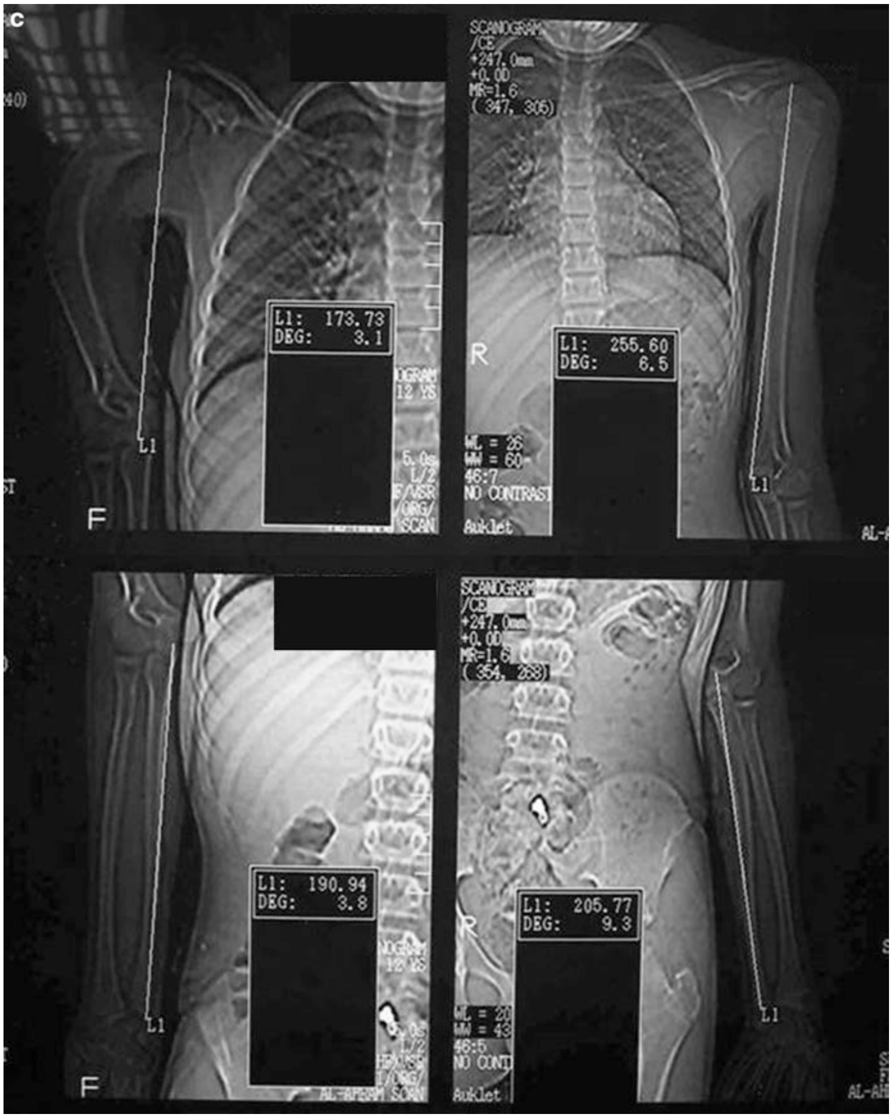

Fig. 1 (**a**) Preoperative photo showing the deformity and shortening of the right humerus. (**b**) Preoperative radiographs of the right humerus. (**c**) CT scanogram of both upper limbs

arch, two rings, and a 5/8th ring. The osteotomy was performed in the upper humerus at the apex of the angular deformity. The arch was fixed to the bone above the corticotomy site with three 4 mm Schanz pins and was attached to a "dummy" ring which was placed below the apex of the deformity. Then, a 5/8th ring was applied above the olecranon fossa using two 1.8 mm K-wires and linked to a full ring connected to the bone with 4 mm Schanz pin. Ilizarov hinges were positioned above the "dummy" ring at the level of the apex of the deformity.

5 Basic Principles

Lengthening of the humerus is indicated if shortening exceeds 5 cm. Complex deformities in different planes can be dealt with from a single corticotomy using a circular frame and gradual treatment. Correction of severe humeral deformities in Erb's palsy can improve the range of shoulder movement and cosmetic appearance.

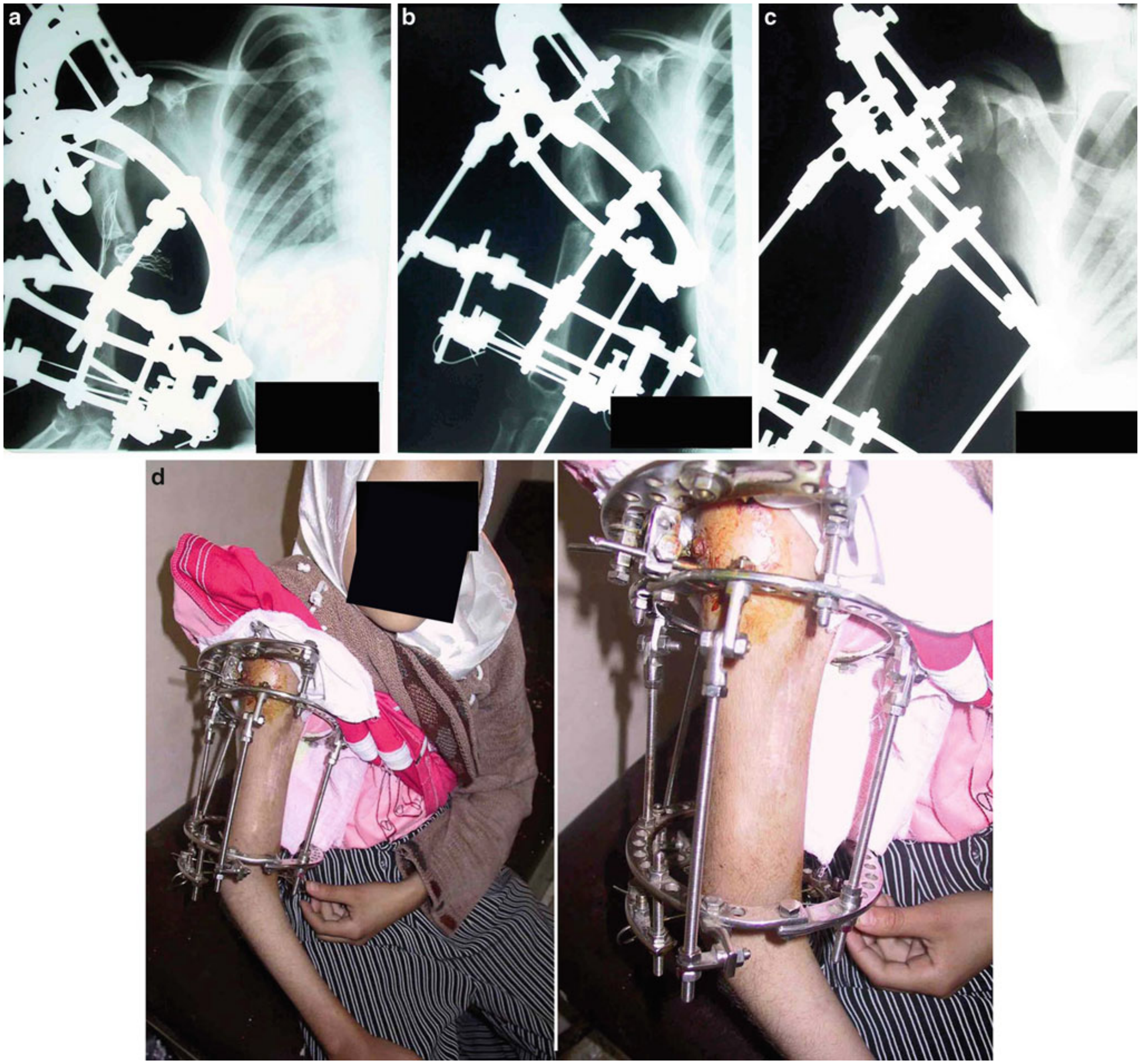

Fig. 2 (**a**) Immediate postoperative radiograph. (**b**) Radiograph during distraction showing correction of the deformity. (**c**) Radiograph at the end of lengthening. (**d**) Photos at the end of lengthening

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

It is better to use the old scar to perform the corticotomy. In severe postsurgical deformities, the apex of the deformity lies at the site of malunion. Control of severe deformities is better using a circular frame than a monolateral frame.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

Hybrid fixation of the humerus is important to avoid the neurovascular complications.

Fig. 3 (**a**) Radiograph after fixator removal. (**b**) Photo after fixator removal. (**c**) Follow-up radiograph after 2 years

Note There is a potential neurologic risk from doing an acute derotation in the clinic as was described in this case report. An alternative strategy is to do a gradual derotation of the humerus after angular correction and lengthening. This is done by building a derotation construct into the Ilizarov apparatus, a difficult and cumbersome task. Another option is to use a six-axis correction device such as the TSF to do simultaneous lengthening, angulation, and derotation.

10 Cross-References

▶ Case 82: Humeral Lengthening for Septic Growth Arrest

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Case 85: Deformity of the Humerus in a Four Year Old Boy with Osteogenesis Imperfecta

Elizabeth Ashby, Reggie C. Hamdy, and François Fassier

Contents

Abstract

This is a case of severe deformity in the right humerus of a 4 year old boy with osteogenesis imperfecta type III. Surgical correction was achieved using multiple osteotomies and insertion of a telescopic Fassier-Duval rod.

1 Brief Clinical History

A 4 year old boy with osteogenesis imperfecta type III had received medical treatment for osteopenia in the form of intravenous bisphosphonates since the age of 5 months. He developed lower limb deformities and at the age of 2 years underwent staged bilateral femoral and tibial osteotomies with intramedullary rodding. Upper limb deformity hindered his rehabilitation due to difficulty using walking aids. For this reason, it was decided to correct the deformity in both humeri. Multiple osteotomies were performed together with insertion of telescopic Fassier-Duval rods. The right humerus was more deformed than the left and will be discussed here.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

1. There is severe deformity of the right humerus.
2. The deformity is present along the entire length of the bone. It is not localized to one segment.
3. The bone is small and osteopenic. This precludes the use of plates. Any fixation must be performed with an intramedullary device.

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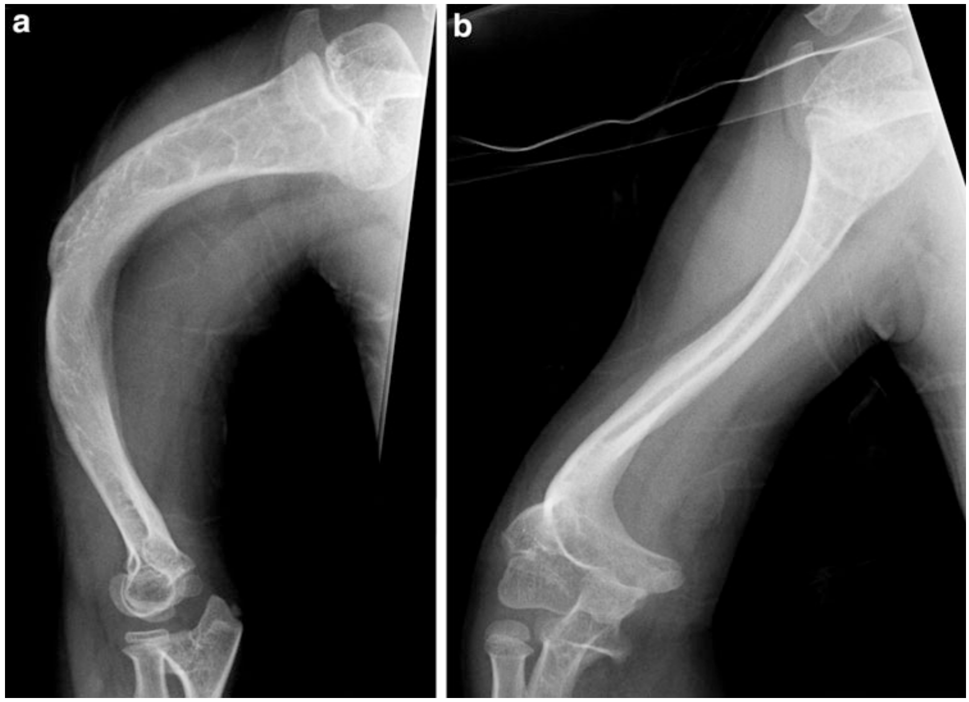

Fig. 1 Anteroposterior (**a**) and lateral (**b**) radiographs of the deformed right humerus

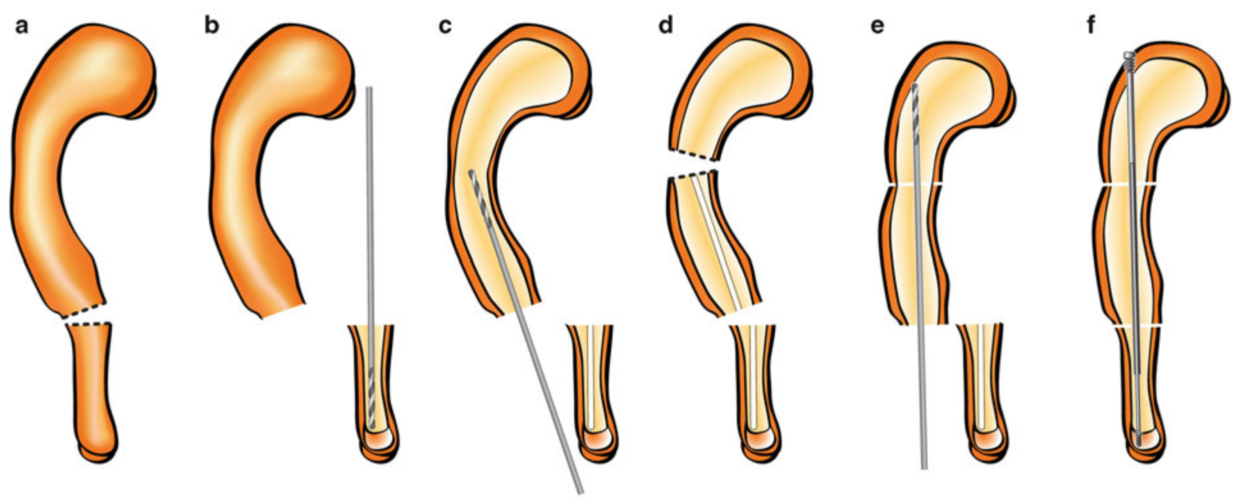

Fig. 2 Surgical stages of insertion of a Fassier-Duval rod into a humerus. Anteroposterior images of the humerus are shown since this plane had the greatest deformity

4 Treatment Strategy

1. To obtain a clinically straight humerus
2. To stabilize the osteotomies and reduce the risk of further fracture by inserting a telescopic Fassier-Duval rod
3. To maintain reasonable movement in the shoulder and elbow by minimizing surgery involving the joints and ensuring no metalwork penetrates the joint

5 Basic Principles

The basic principles are to correct deformity, maintain joint movement, and prevent fractures in the future. These are achieved in several ways:

1. The humerus is straightened by performing as many osteotomies as necessary. Two osteotomies were needed in this case.

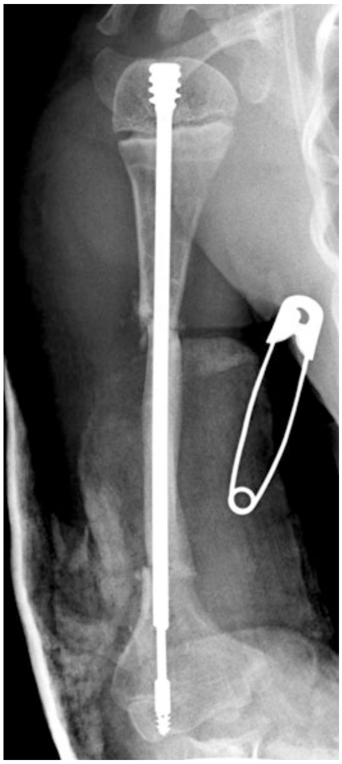

Fig. 3 Immediate postoperative anteroposterior radiograph of the humerus with the Fassier-Duval rod in situ

Fig. 4 Anteroposterior radiograph of the right humerus 6 months after surgery showing healing of the osteotomy sites

2. The elbow joint is not entered at any point during surgery. The shoulder joint is only entered to insert the male driver and female part of the Fassier-Duval rod. The insertion of reamers is performed through an osteotomy site (not across a joint). Thus iatrogenic joint damage is kept to a minimum helping maintain joint motion postoperatively.
3. A telescopic Fassier-Duval rod is used. This protects the entire length of the growing humerus. Careful preoperative planning of the length and width of the rod is necessary.
4. Rehabilitation is very important with minimal postoperative immobilization (4 weeks in this case).

6 Images During Treatment

A. Perform the distal osteotomy first (at the apex of the distal deformity). Remove a wedge of the bone to correct the deformity at this level (Fig. 2).
B. Ream the distal fragment to an appropriate size for the chosen rod.
C. Ream proximally until the lateral cortex is reached and it is not possible to ream any further.
D. At this site perform a second osteotomy (at the apex of the proximal deformity). Remove a wedge of the bone to correct the deformity.
E. Realign the osteotomy site and continue reaming into the humeral head and through the cortex.
F. Insert the Fassier-Duval rod. To do this, insert a male-size wire through the distal osteotomy site and advance proximally. Make an incision over the shoulder to allow the wire to exit. Advance the male driver over the wire to the distal osteotomy site. Remove the wire and load the male rod to the driver. Advance the male rod into the distal fragment. Once the physis is reached, screw the male rod into the lateral condyle. Remove the male driver and insert the female rod.

7 Technical Pearls

1. Position the endotracheal tube in the opposite side of the mouth to the operated arm.
2. Do not use an Esmarch bandage. It may cause fractures.
3. Although careful preoperative planning of osteotomy sites is important, X-ray images obtained in several planes in the operating room may lead to changes in the plan.
4. If the medullary canal is too narrow for the smallest Fassier-Duval rod (3.2 mm), K-wires should be used.
5. When removing the male driver, keep the pushrod or a small-diameter K-wire in contact with male rod to prevent back out and facilitate introduction of the female part.
6. Ensure that the threaded portions of the Fassier-Duval rods are completely buried within the epiphyses in all planes on intraoperative imaging.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

9 Avoiding and Managing Problems

1. Mobilize and protect the radial nerve if performing an osteotomy in the mid-third of the humerus. The periosteum should be incised at least 1 cm from the nerve and the flap of the periosteum used to protect the nerve.
2. The male part of the rod is cut to an appropriate length prior to insertion. The male rod should not protrude beyond the articular cartilage of the humeral head to avoid damage to the rotator cuff.
3. Elbow preoperative range of motion has an impact on the healing potential of the distal humerus osteotomy site. The more limited the elbow motion is, the greater the likelihood of pseudarthrosis formation. Keep this in mind when planning osteotomy sites.
4. Avoid giving bisphosphonate treatment until osteotomy sites have healed. We usually allow bisphosphonate treatment 4 months following surgery providing radiographic evidence of bone healing is satisfactory.

10 Cross-References

▶ Case 97: Forearm Deformity in a Fourteen-Year-Old Boy with Osteogenesis Imperfecta

11 See Also in Vol. 1

Case 85: Eleven Year Old Child with Osteogenesis Imperfecta Type III and Multiple Severe Deformities, Treated with Telescoping Fassier-Duval Rods
Case 86: Coxa Vara in a Nine-Year-Old Boy with Osteogenesis Imperfecta

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Case 86: Humeral Lengthening with a Motorized Intramedullary Lengthening Nail

Søren Kold

Contents

Abstract

The patient is a 19 year old male with a 5 cm unilateral humeral shortening. The patient had back and neck pain and was cosmetically dissatisfied. The humerus was lengthened 4 cm with a motorized intramedullary lengthening nail (FITBONE®, WITTENSTEIN Intens GmbH, Igersheim, Germany) which is primarily used for lower limb lengthening. At the latest follow-up 1 month after nail removal, the patient did not have back or neck pain or cosmetic complaints. The patient was very satisfied with the result. However, shoulder abduction was reduced from a preoperative range of 100° to a postoperative range of 80°.

1 Brief Clinical History

A 19 year old male presented with unilateral humeral shortening caused by Erb-Duchenne-type obstetric palsy. At the age of 12 years old, the proximal humerus was corrected into valgus through a proximal osteotomy fixed with a locking plate, subsequently removed. When the patient was 18 years old, the left humerus was 10 cm short, and the humerus was lengthened 5 cm with an external fixator. The left humerus remained 5 cm short and the patient complained of back and neck pain and was dissatisfied with the cosmetic appearance. The patient was offered lengthening with an intramedullary lengthening nail, as the patient did not want another lengthening with an external fixator. The motorized intramedullary lengthening nail (FITBONE®, WITTENSTEIN Intens GmbH, Igersheim, Germany) has previously been described for lower limb lengthening (Krieg et al. 2011).

Søren Kold and Knud Stenild Christensen did the preoperative planning, surgery and postoperative follow-up of the presented case in collaboration.

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Fig. 1 Preoperative X-ray of the left humerus. Note the dysplastic humeral head

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

- In order to insert a straight nail, the humerus had to be osteotomized at the center of the diaphyseal angulation of the humerus (Fig. 1).
- The dimensions of the humerus allowed for implantation of a nail with a diameter of 11 mm and a length of 225 mm. This nail has a maximum stroke length of 60 mm (Fig. 2).

4 Treatment Strategy

Through a minimal lateral approach, the planned osteotomy site was predrilled. Access to the humeral canal was made through an anterolateral transdeltoid approach for antegrade

Fig. 2 Picture of the FITBONE lengthening nail with fixation screws. Energy is transmitted from a transducer placed over the skin to a subcutaneously placed receiver connected to the motor unit inside the nail

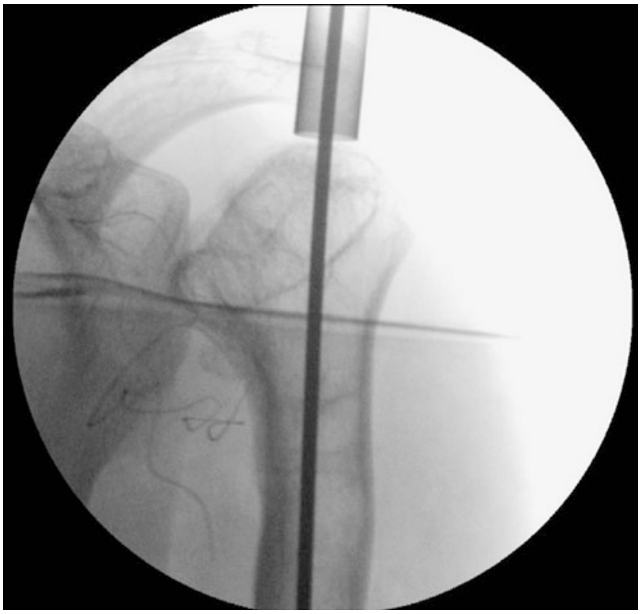

Fig. 3 Intraoperative fluoroscopy showing the protection sleeve placed through the supraspinatus tendon prior to antegrade reaming

humeral nailing where the supraspinatus tendon was spit in line with its fibers. A protection sleeve was passed through the split supraspinatus tendon prior to reaming (Fig. 3). Reaming was performed up to size 12 mm diameter straight reamers to the planned osteotomy site. The humeral osteotomy was completed with a chisel through the lateral approach. Antegrade reaming was carried out distal for the osteotomy to size 11.5 mm diameter straight reamers. The FITBONE nail (WITTENSTEIN Intens GmbH, Igersheim, Germany) was fixed distally with one locking screw and proximally with two locking screws. The motor unit inside the nail was connected to a subcutaneously placed receiver by a wire passing through the split in the supraspinatus tendon. The patient held a transducer over the receiver to activate the motor unit inside the telescopic lengthening nail. Lengthening was started at the eighth postoperative day at a maximum rate of 1/3 mm three times daily.

Fig. 4 Immediate postoperative X-ray

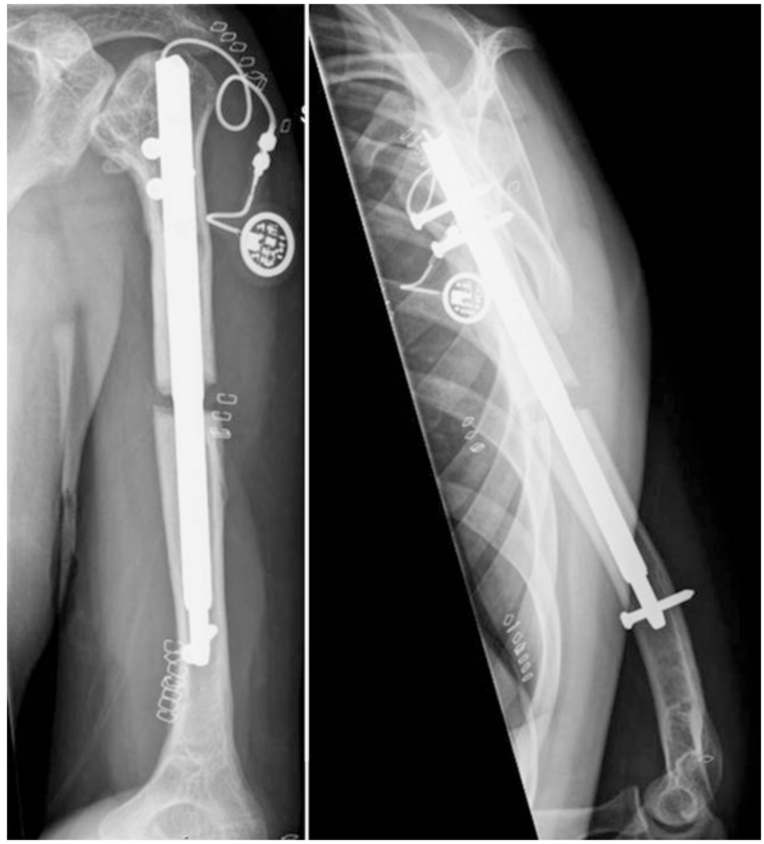

Fig. 5 X-ray taken 6 days after the start of lengthening

Fig. 6 Frontal (*left*) and lateral (*right*) X-rays taken 9 months postoperative showing healing of the bone regenerate. Note the proximal migration of the humeral head

Fig. 7 Frontal (*left*) and lateral (*right*) X-rays taken 1 month after removal of the humeral nail

5 Basic Principles

The rate of lengthening was adjusted according to weekly radiological signs of bone formation in the regenerate. Physiotherapy was carried out on a regular basis to try to preserve range of motion of the shoulder and elbow joint. After 4 cm of intramedullary nail lengthening (total of 9 cm lengthening), the proximal humerus began to migrate proximally and the amount of shoulder abduction declined. Therefore lengthening was terminated leaving the left humerus 1 cm short compared with the right side.

6 Images During Treatment

See Figs. 3, 4, and 5.

7 Technical Pearls

In order to insert a straight nail, the humerus had to be osteotomized at the center of the diaphyseal angulation of the humerus (Fig. 1).

Fig. 8 Clinical picture 1 month after removal of the nail showing the 80° abduction on the treated left side compared with a preoperative abduction of 100°

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7, and 8.

9 Avoiding and Managing Problems

It is possible to perform bone lengthening on the humerus only by the use of an intramedullary lengthening nail. However, in the reported case, shoulder abduction declined from a preoperative range of 100° to a postoperative range of 80° as the humeral head migrated proximally.

10 Cross-References

- ► Case 81: Humeral Lengthening and Deformity Correction in Ollier's Disease: Distraction Osteogenesis with a Multiaxial Correction Frame
- ► Case 82: Humeral Lengthening for Septic Growth Arrest
- ► Case 84: Humeral Lengthening in Erb's Palsy

References and Suggested Reading

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Case 87: Varus and Shortening of the Proximal Humerus

Hae-Ryong Song and Kwang-Won Park

Contents

Abstract

Neer and Horowitz in 1965 wrote that fractures of the proximal humeral epiphysis comprise 3 % of all epiphyseal injuries. Considering that the proximal humeral physis contributes 80 % of the longitudinal growth of the bone, it is no surprise that complications of neglected fractures include shortening, as well as potential varus deformity, and restricted shoulder movement. Kohler in 1935 provided criteria for humerus varus: (Ugwonali et al. 2007) proximal humeral neck-shaft angle of less than 140°, a greater tuberosity elevated above the superior margin of the humeral neck, and a reduced distance between the articular surface of the humeral head and the lateral cortex of the humerus (Ellefsen et al. 1994). This deformity causes limitation in active abduction and forward flexion. The shortening is also cosmetically unsightly and may cause limitations in function. A number of techniques have been used to correct this kind of deformity, including a valgus osteotomy and fixation using tension band wiring, plates, and the Taylor Spatial Frame (Malot et al. 2013; Lucas and Gill 1947). We present a case of a patient with varus and shortening of the humerus corrected using an external fixator.

1 Brief Clinical History

A 14 year old male patient, who suffered a right proximal humerus fracture and was treated conservatively about 1 year ago, visited our clinic. He has a history of hydrocephalus at birth and pyogenic arthritis of his right shoulder. At the time of visit, he complained ofshoulder joint motion and 8 cm of limb length discrepancy.

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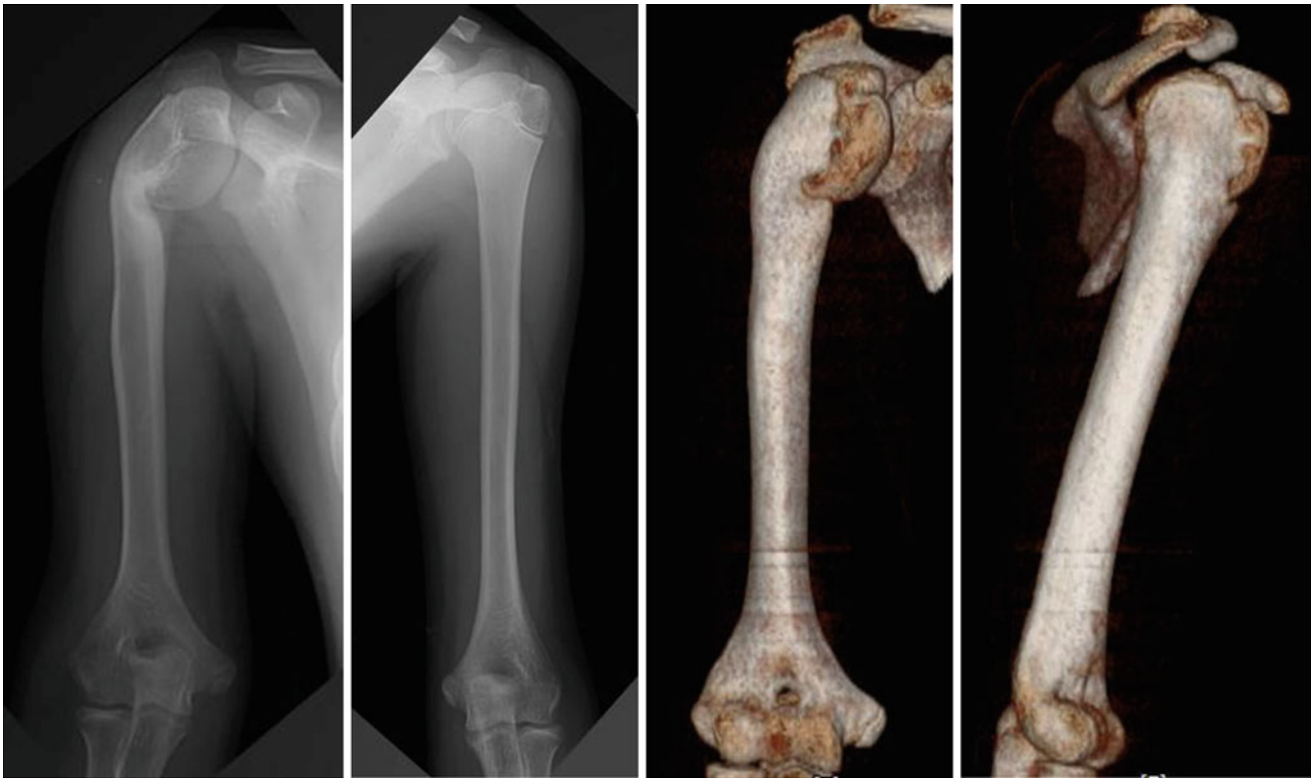


Fig. 1 Right humerus AP at the time of initial visit (14 years). Varus angulation, 42°. No flexion or extension angulation. Humerus length, *Rt*. 243 mm/*Lt*. 323 mm

Fig. 2 Clinical photos of the patient. Range of right shoulder joint motion: abduction 50° and forward flexion 80°

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

I. Varus deformity of the right proximal humerus (physeal arrest of the medial aspect and resultant notching)

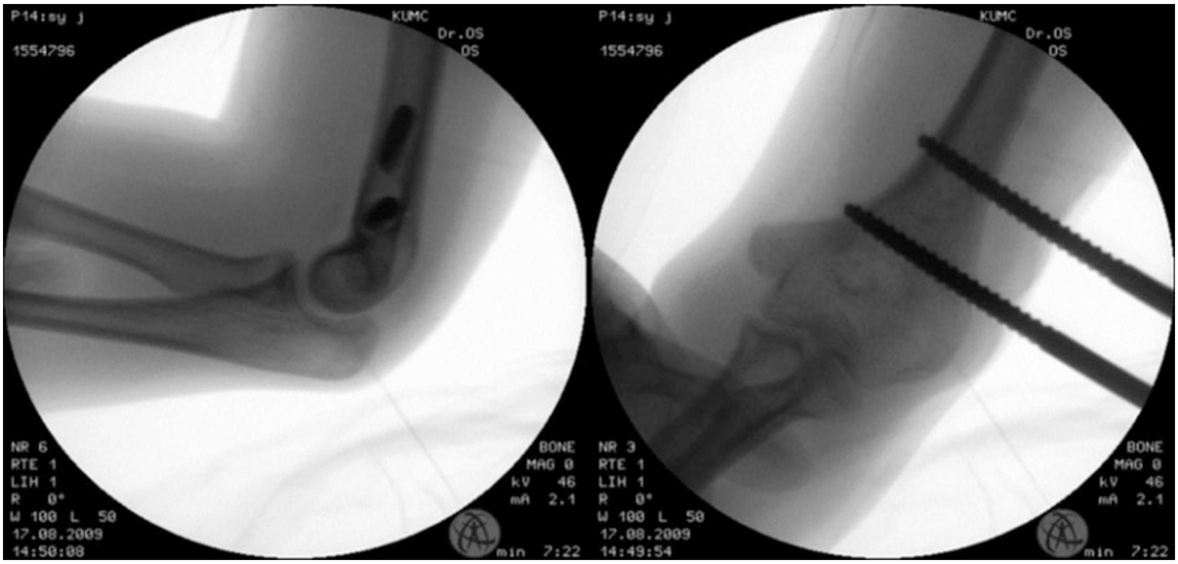


Fig. 3 Intraoperative image of proper pin location. Pin point contact of the pin indicating proper location of the Schanz screw in lateral position

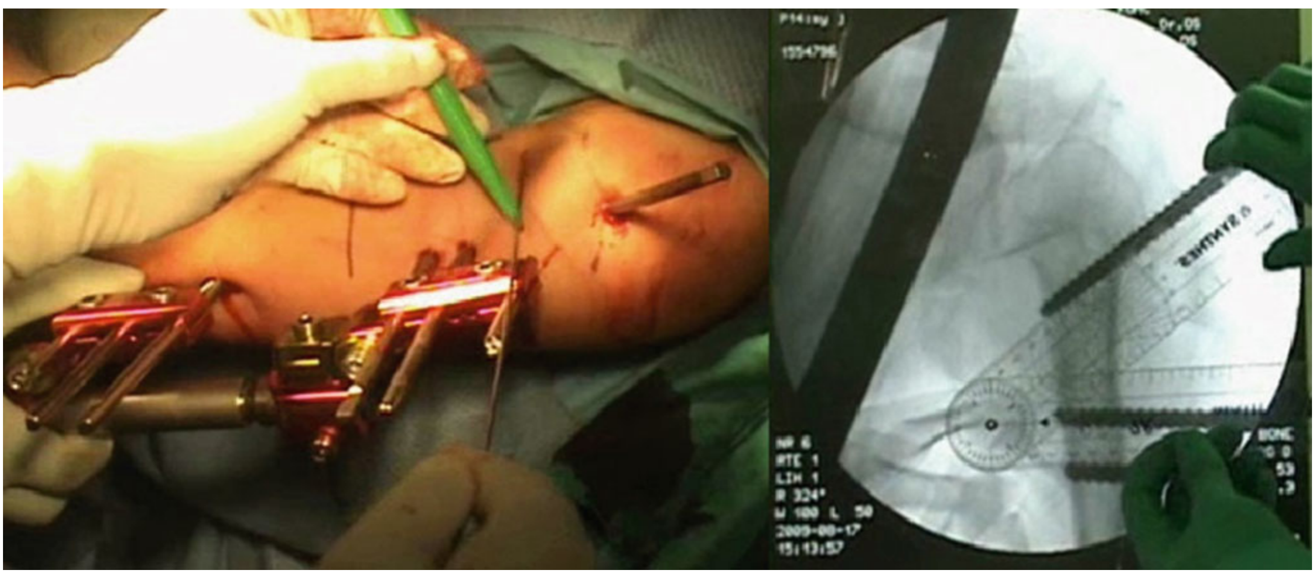


Fig. 4 Intraoperative image of determining the amount of correction and proper level of osteotomy

II. Impingement of the greater tuberosity on the acromion and resultant limited shoulder abduction and forward flexion
III. Unequal length of the humerus
IV. Staged operation for deformity correction followed by lengthening or simultaneous correction and lengthening

4 Treatment Strategy

I. Consider residual status of the proximal humerus physis to minimize the progression of varus deformity. Epiphysiodesis can be one of the treatment options.
II. Careful preoperative evaluation of three-dimensional articular incongruity and consideration of valgus correction and extension or flexion osteotomy according to specific deformity of the proximal humerus.
III. Consider lengthening of the humerus at mid-shaft level. This lengthening procedure may be performed simultaneously with deformity correction of the proximal humerus.
IV. Use hybrid monolateral fixator or dual monolateral fixator for one stage operation with correction and lengthening.

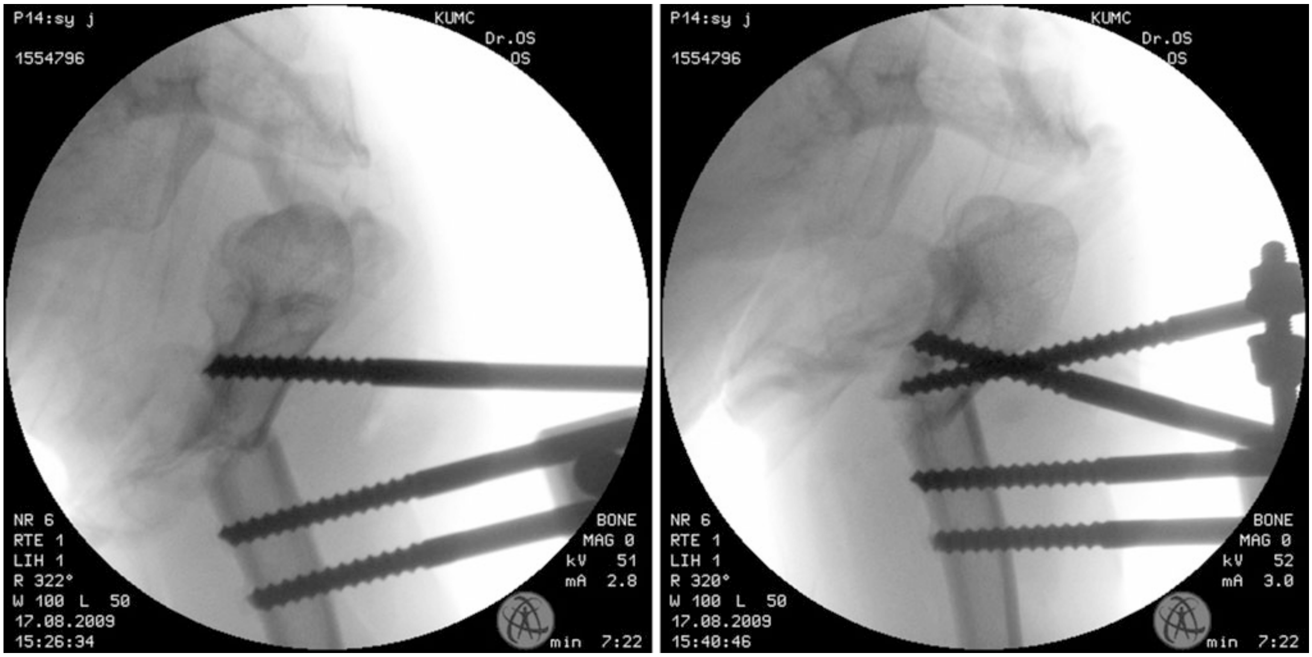
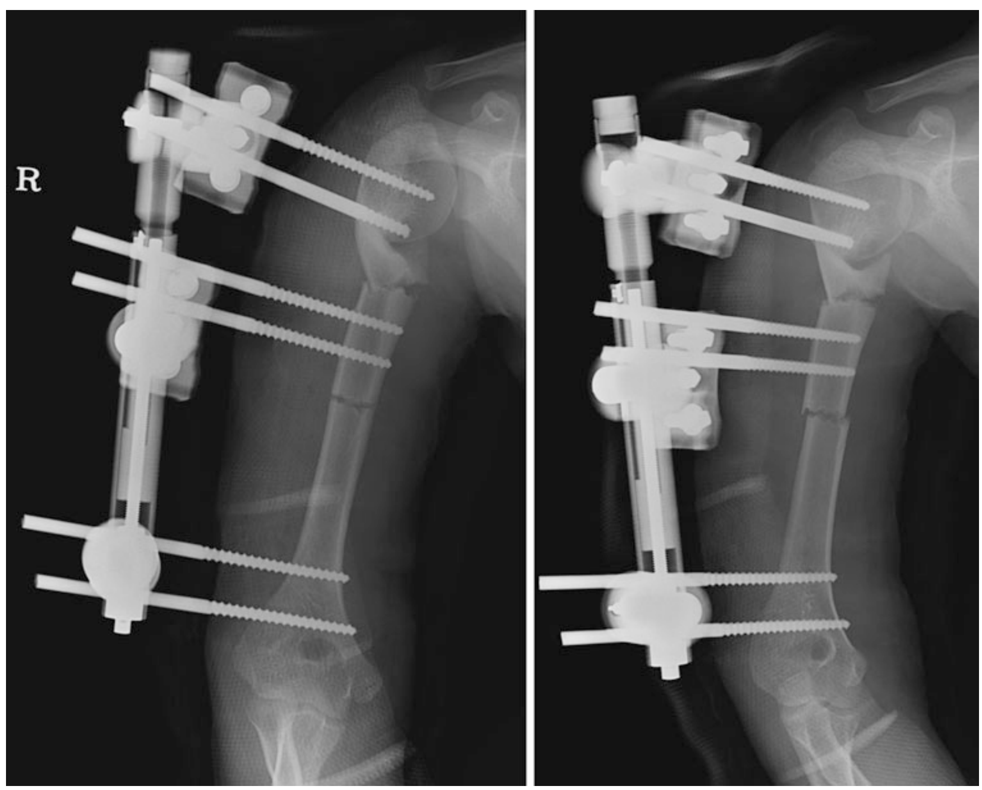


Fig. 5 One Schanz screw is not enough for acute correction during the operation. An additional Schanz screw should be inserted for more stability after acute correction

Fig. 6 After bifocal osteotomy with valgus correction of the proximal humerus and mid-shaft lengthening using dual monolateral fixator



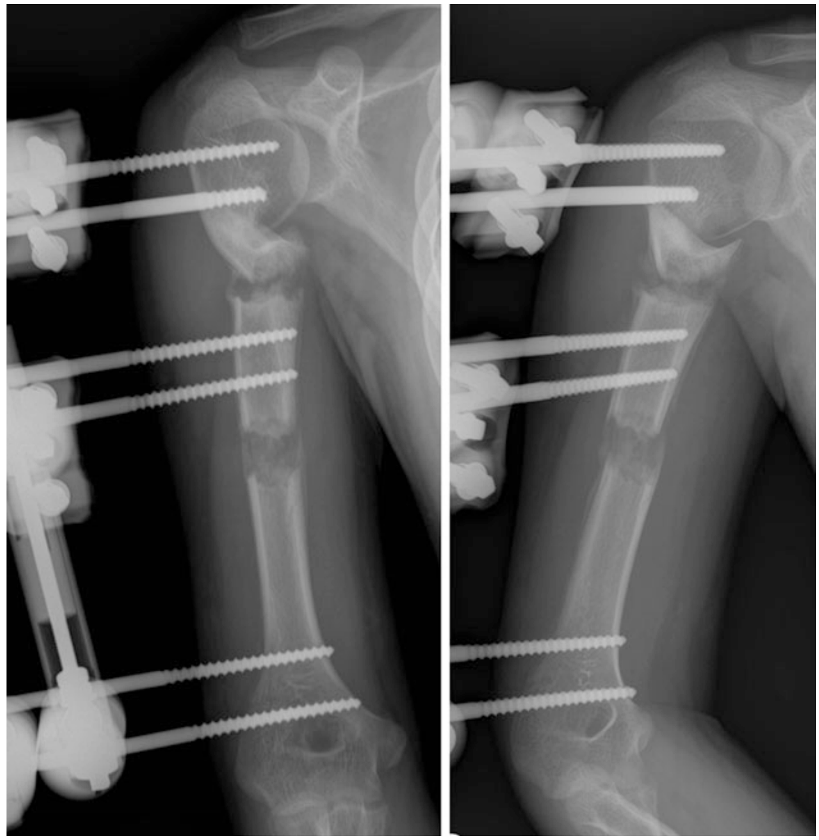


Fig. 7 Three weeks after operation. Gradual lengthening of the proximal osteotomy site was performed for abundant callus formation and correction

5 Basic Principles (Ugwonali et al. 2007; Ellefsen et al. 1994; Malot et al. 2013; Lucas and Gill 1947)

5.1 Timing of Surgery

Surgical treatment should be considered in the young growing patient with limited motion associated with functional limitations and pain.

5.2 Preserve Physis and Vascularity

(a) Make the osteotomy just distal to the physeal plate in the region of the metaphyseal deformity.
(b) Avoid iatrogenic injury to the ascending branch of the anterior humeral circumflex artery and thus minimize the risk of humeral head osteonecrosis.

5.3 Safe Zone and Stability of Construct

(a) Use two Schanz screws for the proximal bone segment to provide angular and rotational stability
(b) Insert two additional Schanz screws for the middle segment. This gives a possibility of adjustment of the magnitude of the correction postoperatively.
(c) Insert two cancellous Schanz screws at the supracondylar area.
(d) Lengthening osteotomy should be performed between the middle and distal pairs of half pins using the intermuscular plane between the brachialis and biceps.

5.4 Amount of Correction

The minimum amount of angular correction for functional restoration should be 45° wedge rather than the 90° change.

Fig. 9 POD 5 years after correction and lengthening

Fig. 8 Three months after 8.5 cm of lengthening. Epiphysiodesis of the proximal physis was performed

5.5 Sequence of Correction

(a) Sclerotic changes of the proximal humerus result in poor callus formation at the proximal osteotomy site. Small amount of lengthening of the osteotomy site first and then subsequent acute manipulation of varus deformity might minimize the risk of delayed bone formation, as well as may reduce the soft tissue resistance to acute correction.
(b) Once satisfactory deformity correction is achieved, compress the proximal osteotomy site for the solid consolidation using hybrid monolateral fixator or dual monolateral fixators. This system can provide rigid stability of the proximal segment during simultaneous lengthening at distal part.
(c) Convert the assembly from the hybrid monolateral fixator or dual monolateral fixator to simple monolateral fixator for gradual lengthening.

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, and 8.

7 Technical Pearls

Avoiding neurovascular injury

(a) Screw or pin insertion onto the humerus requires that one must always be aware of the safe zones to avoid neurovascular injury.
(b) On the proximal aspect it is best to insert pins laterally; however, one must not penetrate the medial cortex too deeply to avoid damage to the median nerve and brachial artery.
(c) At the mid-shaft level, pins should be inserted somewhat anteriorly. However, care should be taken not to pierce the far cortex too deeply, since the radial nerve runs across the back of the humerus in this area.

Fig. 10 Clinical photo at the time of last visit. Range of right shoulder joint motion: abduction 160° and forward flexion 150°

(d) Distally, half pins may be inserted in a lateral to medial direction. Beware of the radial nerve about 4–5 cm above the lateral epicondyle.
(e) As for the osteotomies themselves, the surgeon can use angle guides to determine the proper angle of osteotomy. Also, we recommend to perform these cuts under direct vision.

8 Outcome Clinical Photos and Radiographs

See Figs. 9 and 10.

9 Avoiding and Managing Problems

I. Perform a complete neurologic examination and document the status preoperatively. To avoid injury to the neurovascular structures, the guidelines above regarding pin insertion must be followed.
   (a) During dissection, ideally the incisions should be long enough to mobilize the soft tissues and prevent impaling the vessels and nerves.

II. The use of a monolateral fixator instead of a circular fixator system is preferred.
   (a) Lower incidence of pin tract infection and elbow flexion contracture.
   (b) The assembly is less cumbersome than with circular fixators, and patients can go about their daily activities without worrying about the bulkiness of the frame.

III. Treating surgeons should beware of refracture and angulation deformities after excessive lengthening. However, the incidence is less than with lengthening in lower limbs (Kim et al. 2012). The risk of refracture can be minimized by analyzing the regenerate during healing and adjusting the rate to make the best possible regenerate bone.

10 See Also in Vol. 1

Case 59: Intraoperative SSEP Monitoring of Circular External Fixation for Revision of Brown Rotationplasty

References and Suggested Reading

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Part XVI

Upper Extremity: Elbow and Forearm

Case 88: Arthrogryposis Elbow Extension Contracture

Dan A. Zlotolow

Contents

Abstract

Children with arthrogryposis commonly lack passive and active elbow flexion. Giving these children at least passive flexion can be life changing, with gains in self-feeding, grooming, and other activities of daily living. Often, it can make the difference between lifelong dependence on caretakers and independence. Posterior elbow release, triceps lengthening, and ulnar nerve transposition have become the standard of care for achieving passive elbow flexion. Previous attempts to reroute the entire triceps to provide active flexion yielded in fixed elbow flexion deformities and loss of perineal self-care. Active elbow flexion can most reliably be achieved via a bipolar latissimus dorsi muscle transfer at a later age, provided that the muscle is adequate for transfer.

1 Brief Clinical History

EM presented as a 2 year old left-hand-dominant boy with amyoplasia-type arthrogryposis. His lower extremities were minimally affected, and he was ambulating on his own without assistive devices. He had good hand function but was unable to feed himself because of bilateral elbow extension contractures. He had good triceps strength but no active elbow flexion. Passive elbow range of motion was from 5° to 50° bilaterally. His shoulder external rotation was to neutral. Forearm position was neutral as well. He was indicated for a left (dominant) elbow release to give him the ability to feed himself, while the right side was left alone to perform perineal care.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
DOI 10.1007/978-3-319-18020-5_330

Fig. 1 Intraoperative photograph of the child's elbow in maximal passive flexion

3 Preoperative Problem List

- Arthrogryposis (amyoplasia)
- Bilateral elbow extension contractures
- No active elbow flexion
- Inability to feed himself

4 Treatment Strategy

The goal of any global treatment plan for a child with arthrogryposis is to allow the child to reach independence with activities of daily living. At a minimum, self-feeding and perineal care should be obtainable for the majority of children. Treatment should seek to allow one hand to reach the mouth and one hand to reach the perineum, and that can be the same hand. For this child, his left upper limb had sufficient extension and his wrist sufficient flexion for him to be able to reach his perineum between the legs. His shoulder external rotation was insufficient to allow perineal access from behind. The right arm had a better hand and so was chosen for an elbow release to allow him to reach his mouth. Shoulder external rotation to neutral was sufficient to allow him to reach up to his face. Patients with maximal external rotation to less than 30° shy of neutral are still unable to self-feed after an elbow release because the hand flexes into the chest. For these children, a humeral rotational osteotomy is performed prior to or concurrent with a release.

5 Basic Principles

Care of the child with multiple joint contractures requires a global approach, incorporating expertise from therapists, orthotists, upper and lower extremity surgeons, and family members. The first goal of treatment should be ambulation. If the child requires elbow extension for ambulation, releases are contraindicated.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

Localizing the bony landmarks of the elbow can be difficult if the elbow has less than 30° of motion. It is easiest to find the subcutaneous border of the ulna in the forearm and trace it back to the olecranon. If still in doubt, fluoroscopic images are necessary. Incise full-thickness skin flaps posteriorly around the olecranon and down the brachium to expose the entire triceps tendon. The ulnar nerve can be found deep to a medial triceps fascial band that attaches to the medial epicondyle and is easiest to localize in the cubital tunnel. The nerve is very small inside a tight cubital tunnel and is prone to iatrogenic injury. Transpose the nerve into a subcutaneous pocket both to keep the nerve out of the way during the surgery and to prevent nerve injury during elbow flexion. For the triceps lengthening, make a distally based V-shaped flap along the entire length of the tendon, maintaining sufficient tendon proximally to affect a repair. Find and protect the radial nerve as it enters the spiral groove. Elevate the medial head of the triceps off of the humerus to increase its excursion, and release the posterior elbow capsule until the elbow can flex past 90°. Take care to preserve the collateral ligaments of the elbow during the release. Posterior fascial bands over the medial and lateral epicondyles and capsule in the gutters must be released in order to gain adequate flexion. Repair the triceps in a lengthened V to Y fashion with the elbow in maximal flexion. Cast or splint the elbow for 2 weeks in flexion. After 2 weeks, begin passive range of motion while wearing an Orthoplast static progressive flexion splint for a further 6 weeks. Wean the splint to nighttime use once motion has stabilized. An alternating flexion and extension splint schedule may be required in some patients to maintain extension.

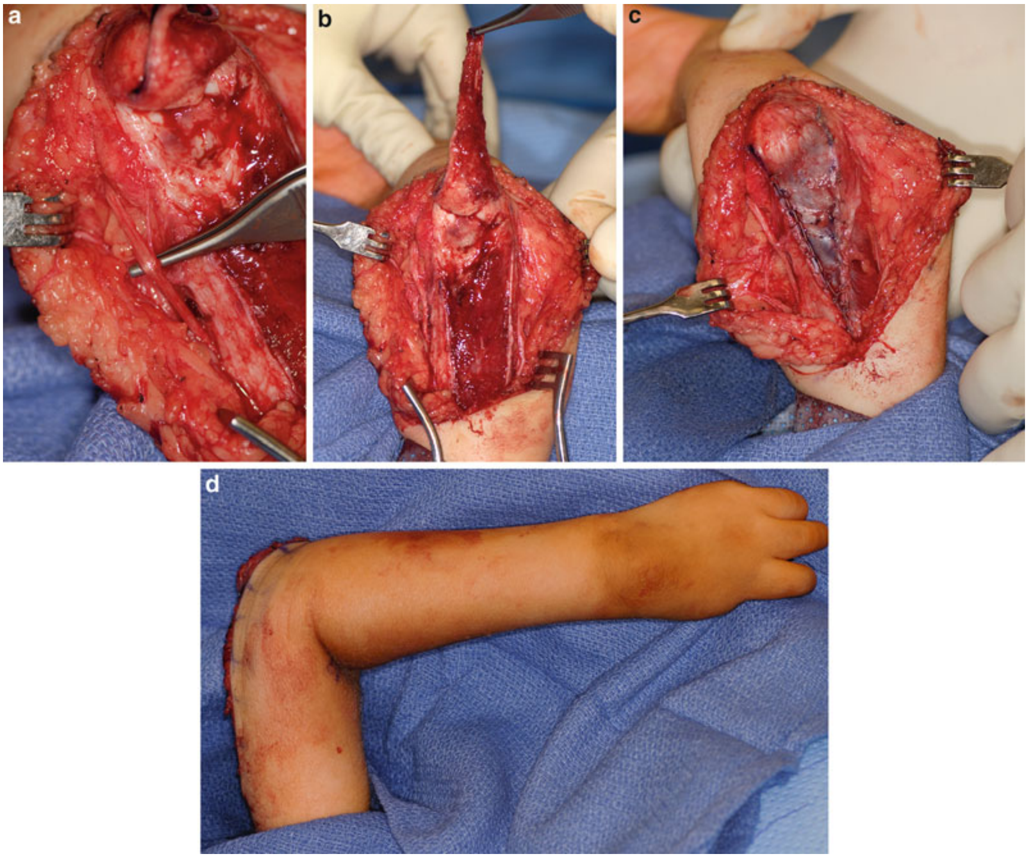

Fig. 2 (**a–d**): Intraoperative photographs demonstrating (**a**) the ulnar nerve after transposition. Note the small caliber of the nerve. The distally based V to Y flap can be seen both before (**b**) and after (**c**) repair. After the release (**d**), the elbow can reach 90° just with gravity assist

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

1. Make sure that the child has at least one elbow that can be used for perineal care before attempting to gain flexion in the other elbow.
2. Locate the olecranon confidently before marking the incision site.
3. Identify and transpose the ulnar nerve.
4. Identify and protect the radial nerve.
5. Make as long a triceps V flap as possible. If too short, an interposition graft will be required, and triceps strength will likely not recover.
6. Do not destabilize the collateral ligaments of the elbow. If these are compromised, repair or reconstruction is necessary.
7. Avoid contralateral procedures. Release one side, and then refer to rule 1 above.

Fig. 3 Postoperative clinical photograph demonstrates the child's newfound ability to feed himself

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Case 89: Radial Clubhand

Muayad Kadhim and Richard S. Davidson

Contents

Abstract

Radial clubhand deformity can present with a complex of problems including short forearm with ulnar deformity, limited wrist range of motion and wrist and elbow instability. The case presented here is of a 10.5 year old female with forearm deformity secondary to radial clubhand previously treated with wrist stabilization by ulnar centralization and pollicization of the index finger. The patient was complaining of ongoing disability due to forearm deformity.

1 Brief Clinical History

This 10.5 year old female presented with a short, deformed ulna (flexion), resulting in functional elbow motion of –45° of extension to 90° of flexion. Her primary complaint was difficulty using a keyboard due to short forearm and the need to tilt her spine to bring her deformed hand into functional keyboard position as well as problems with bimanual activities. She and her parents expressed interest in deformity correction and forearm lengthening.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Short ulna leading to difficulty using a keyboard and bimanual skills
2. Deformed ulna leading to limited functional range of motion
3. Radial deviation and flexion instability of the wrist

Disclosures: Dr. Davidson is a consultant for Biomet and receives royalties on the MAC external fixator of which he is a co-inventor.

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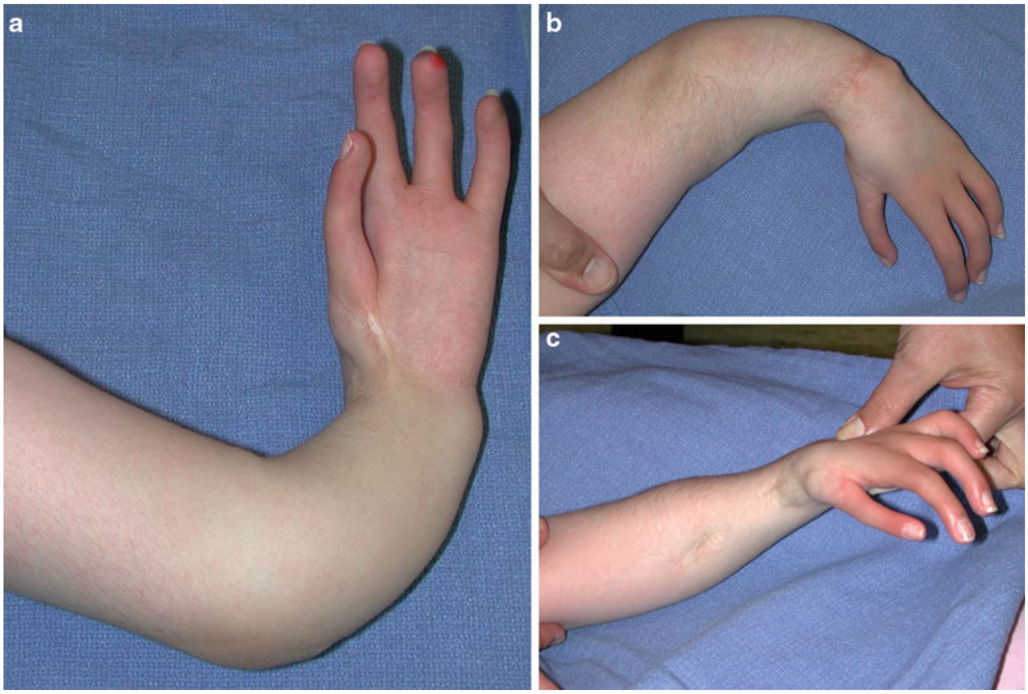

Fig. 1 Preoperative clinical photos demonstrate maximal flexion (**a**) and extension (**b**) of the elbow. Note previous pollicization of the index finger and wrist instability (**a**). (**c**) demonstrated the radial surface of the forearm with healed incision scars of previous surgeries (in another facility)

Fig. 2 Preoperative radiographs demonstrate that wrist alignment to the distal ulna is good, but there is instability to flexion and extension. While the elbow can flex to 90°, the ulnar deformity makes the flexion 130°. The elbow extends to −45°, but the ulnar deformity makes the functional extension −90°. Note elbow instability

4 Treatment Strategy

1. Deformity planning demonstrates the location of the CORA (Fig. 2).
2. External fixation for simultaneous angular and length correction can be accomplished using multiaxial monolateral fixation (MAC, Biomet) with the fixator hinge applied to the convex side of the CORA at the bisector line.
3. The wrist is stabilized using one fixation arc at the level of the distal ulna and another arc at the level of the metacarpals on the threaded rail (Fig. 4).

5 Basic Principles

1. The goal of treatment is to improve functional range of motion of the elbow for better performance of activities of daily life.
2. Simultaneous gradual correction of angulation and length can be accomplished using multiaxial monolateral external fixation device along the deformity bisector on the convex side. The MAC fixator can also correct deformity in two planes of angulation, two planes of translation, and length. If rotational deformity is present, a rotation arc can be added to the fixation construct. This fixation device can permit excellent ROM, function, and continued normal activities during the treatment while

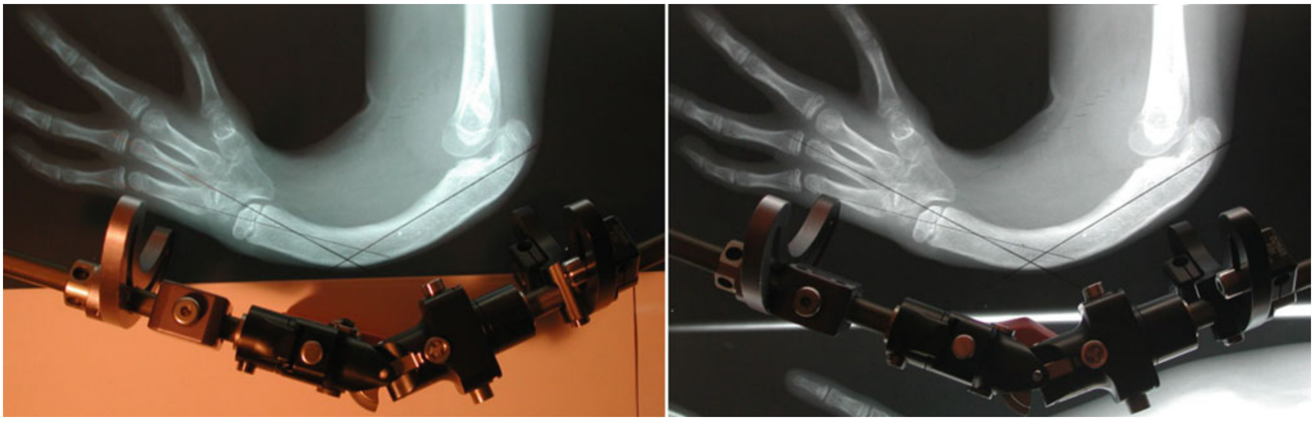

Fig. 3 Preconstruction of the external fixator based on preoperative radiographs

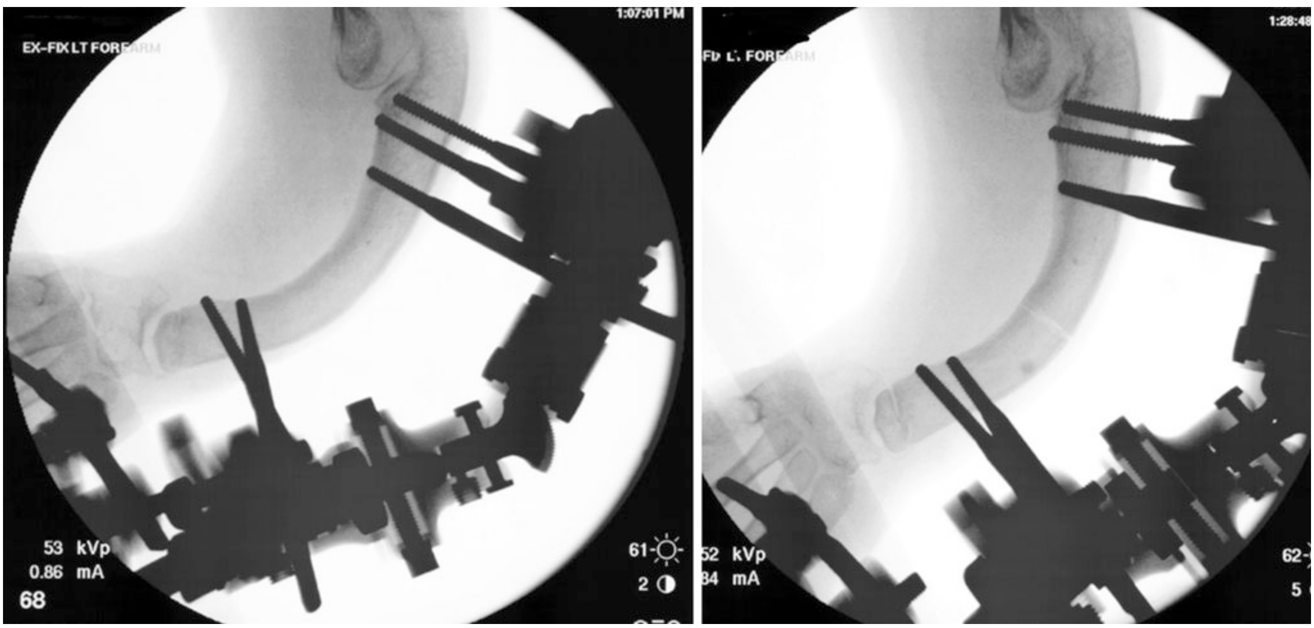

Fig. 4 Intraoperative radiographs showing placement of three pins into the proximal ulna, two into the distal ulna, and two into the metacarpals (stabilizing the wrist). Osteotomy is performed through a small incision at the CORA

providing easier treatment (turning one hinge at a time). No computer assessment or programs are needed, and there are no bulky rings. All the basic principles of external fixation apply.

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

7 Technical Pearls

The application of MAC external fixator on the upper extremity is less complicated than circular external fixators. The MAC external fixation can be extended across the joints as was done in the presented case to provide wrist stability. In this case, an additional arch was added to the fixator across the wrist to add stability to the hand.

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

Wrist instability and elbow instability are commonly associated with radial clubhand. Examination and manipulation under anesthesia demonstrated instability of

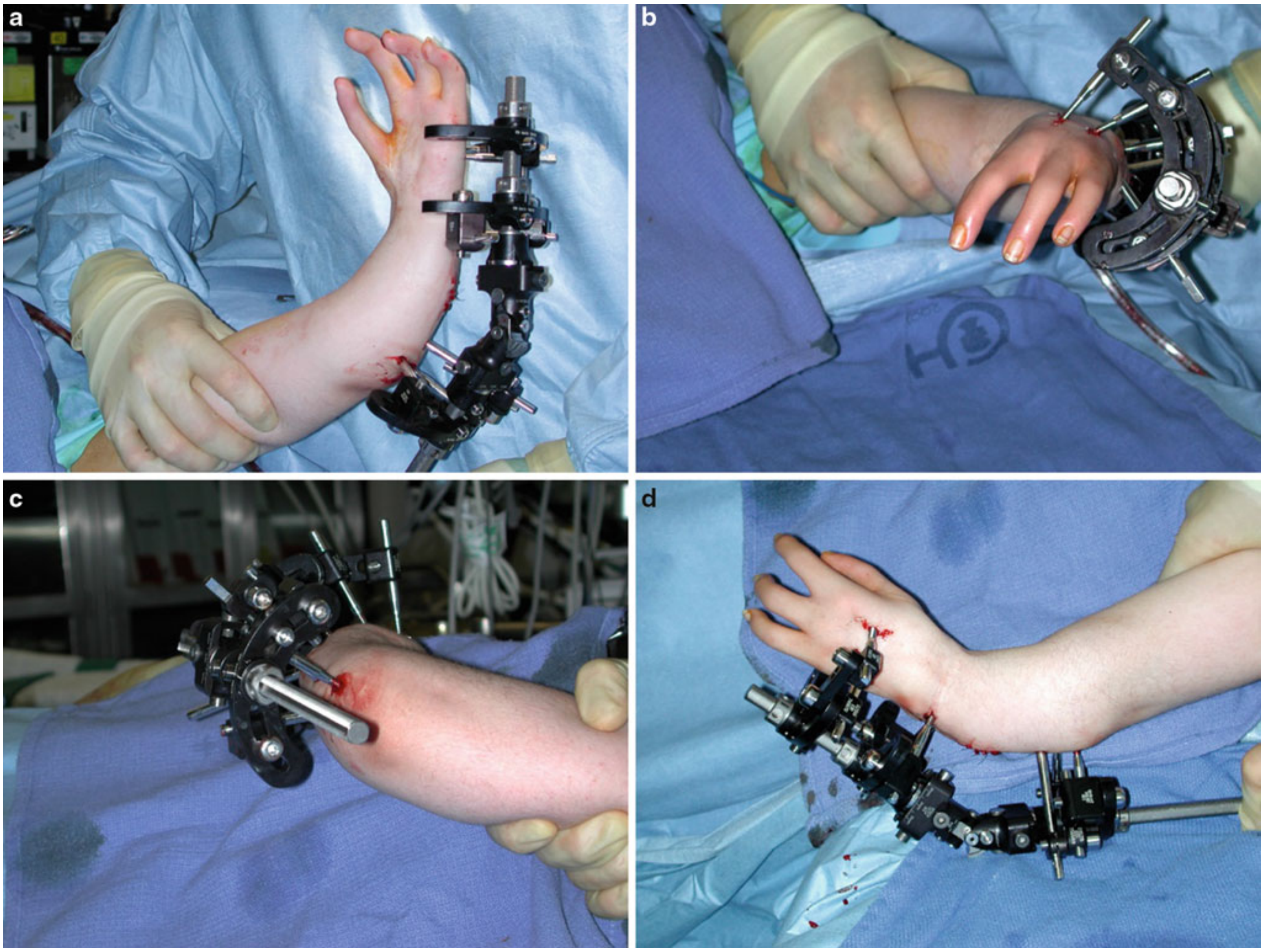

Fig. 5 Intraoperative clinical photos demonstrating the application of the MAC to the deformity of the ulna for simultaneous correction of the deformity and lengthening as well as wrist stabilization. (**a**) Volar surface of the forearm, (**b**) distal pins with rotation arc, (**c**) proximal pin of the fixator, (**d**) dorsal surface of the forearm

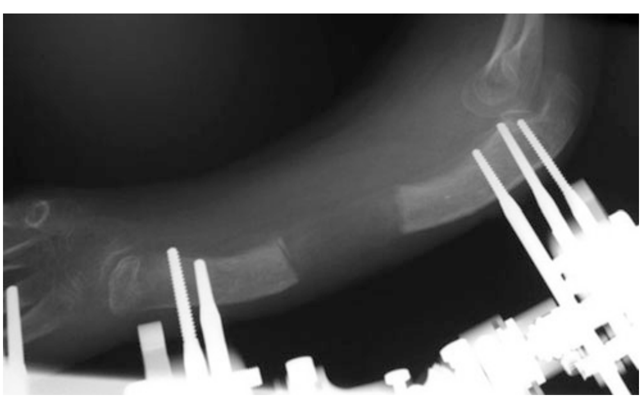

Fig. 6 Radiographs well into the treatment show correction of alignment and lengthening

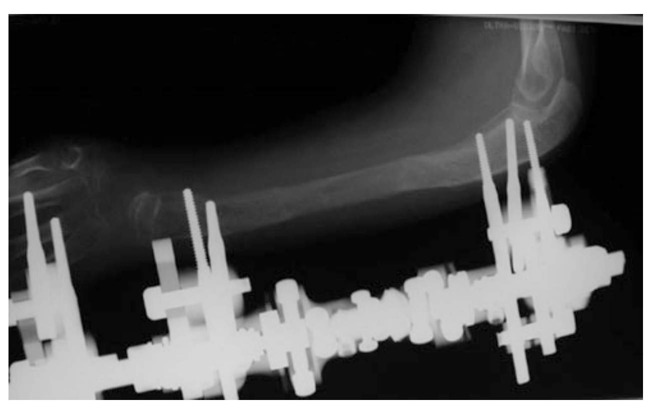

Fig. 7 Radiograph during consolidation phase

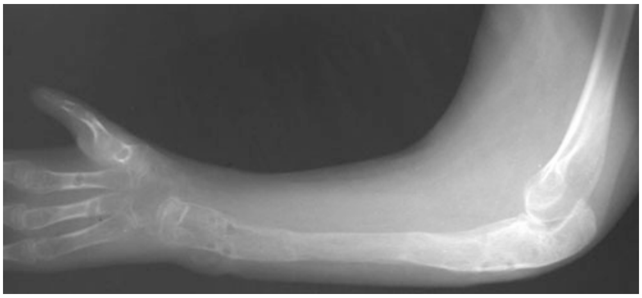

Fig. 8 Radiographs after removal of external fixator showing excellent bone formation, length, and maintenance of wrist alignment

Fig. 9 Clinical photo of resultant alignment of the forearm

the elbow in extension, but stability in flexion. Posterior splinting and physical therapy resulted in return to the preoperative level of stability.

10 Cross-References

▶ Case 90: Radial Clubhand Correction with Radius Lengthening Using the Ilizarov/TSF
▶ Case 91: Ulnarization as Treatment for Radial Clubhand (RCH)

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Case 90: Radial Clubhand Correction with Radius Lengthening Using the Ilizarov/TSF

S. Robert Rozbruch

Contents

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S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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Abstract
This is a case of radial clubhand correction. Lengthening of the relatively short radius and simultaneous correction of radial deviation wrist deformity were accomplished with a two-level Ilizarov/Taylor Spatial Frame (TSF).

1 Brief Clinical History

The patient is a 16 year old boy born with radial clubhand and absent thumb. As an infant he had a centralization procedure without an opponensplasty. He had recurrence of his wrist deformity and presented with functional deficit and displeasure with his appearance.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Radial clubhand
2. Short radius
3. Unstable wrist with radial deviation

4 Treatment Strategy

1. Lengthen the radius.
2. Gradually correct the radial deviation of the hand.
3. Avoid fusion of the wrist as the primary strategy.

This was to be done with a two-level frame. The proximal frame is used to lengthen the radius relative to the ulna. The distal frame is used to gradually correct the radial deviation

Fig. 1 (**a**, **b**) Clinical views showing short forearm/wrist with radial clubhand. Notice the extreme radial deviation of the hand

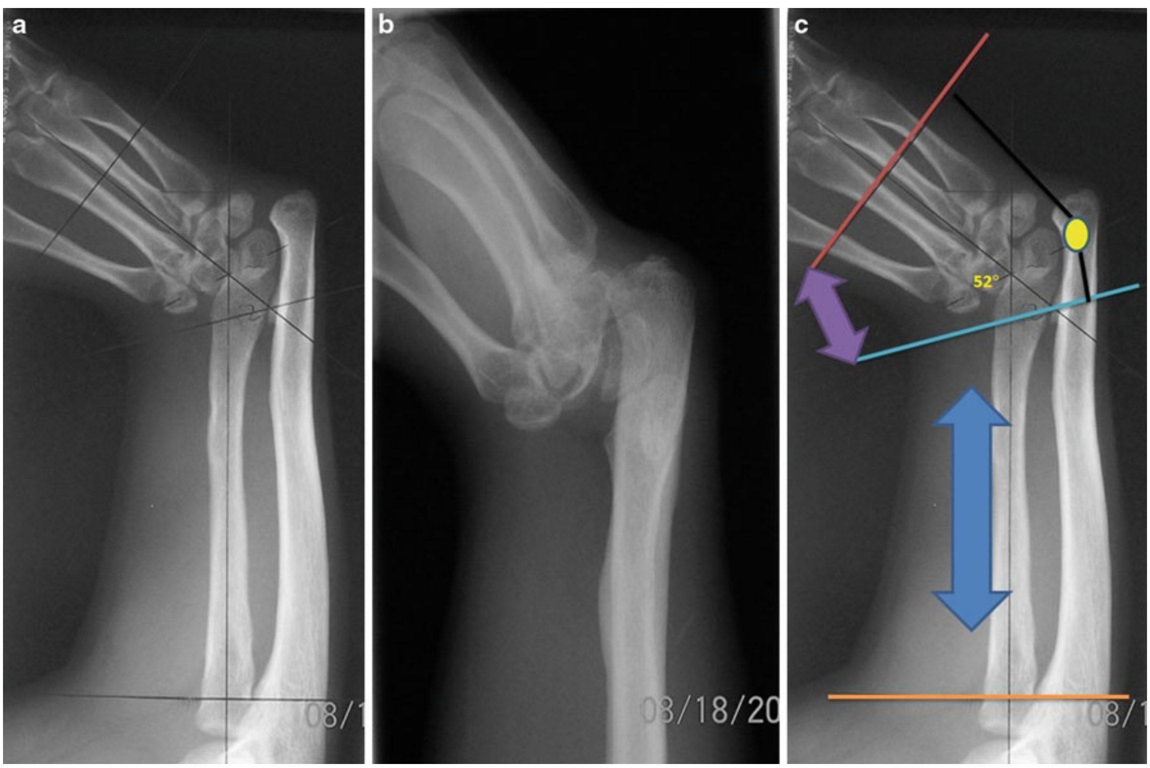

Fig. 2 Preoperative X-rays. (**a**) AP of the wrist showing 52° of radial deviation of the hand and short radius relative to the ulna. (**b**) Lateral X-ray showing palmar translation of the hand. (**c**) Surgical planning: proximal ring (*orange line*); distal radius ring (*blue line*); distraction and lengthening of the radius (*double-headed blue arrow*); hand ring (*red line*); hinges at the convexity of wrist deformity (*yellow circle*); distraction strut in the concavity of deformity (*double-headed purple arrow*)

(Fig. 2c). The rationale here was that once the wrist deformity was corrected and the radius was out to length, the wrist would be stable and not require fusion or tendon transfer. Wrist fusion could always be done in the future if necessary.

Editor's Comment: An alternative strategy for this case is to do a single-level correction through the distal radius, to lengthen the radius and simultaneously rotate the distal radius and the hand as a unit into a functional position. This is the so-called Ilizarov distal radius reconstruction. The potential advantage of this strategy is that the wrist joint is not distracted and thus may be more stable at the end of treatment, with less risk of relapse of the soft tissue deformity – JEH.

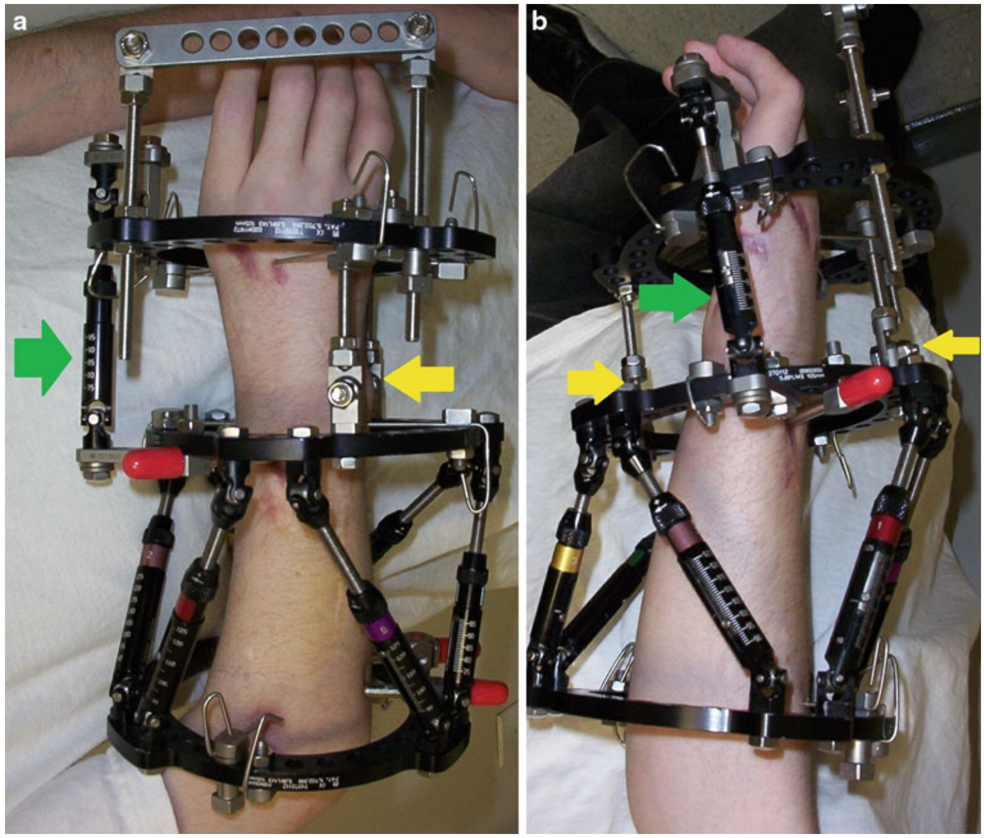

Fig. 3 Clinical photos in the frame at the end of distraction and deformity correction. (**a**) Front view of the two-level frame. The proximal frame for radius lengthening used TSF struts. The distal frame was very short and used hinges (*yellow arrow*) at the convexity of the deformity. A TSF strut (*green arrow*) was used to distract and motor the correction of the radial deviation. The plate attached to the distal hand ring was used to help the wrist rest in neutral by grabbing it with the fingers. (**b**) Side view showing the hinges (*yellow arrow*) and the distraction strut (*green arrow*)

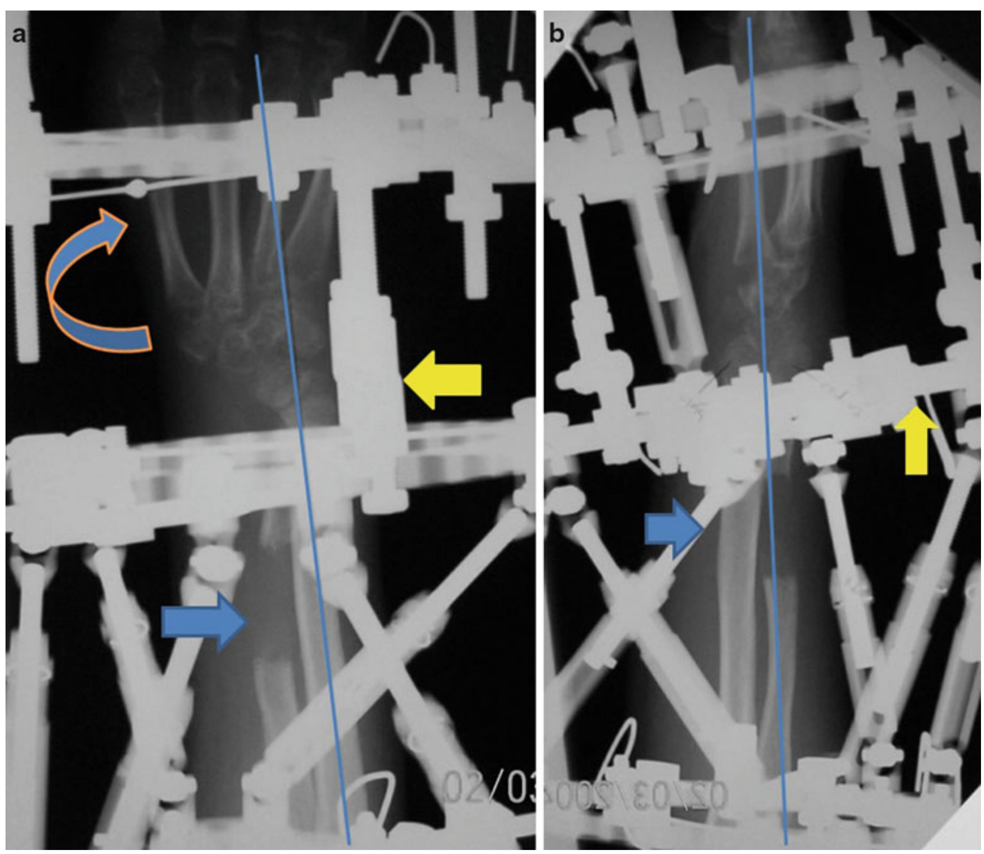

Fig. 4 Radiographs. **a** AP and **b** lateral views at the end of distraction. Note the two-level frame. The radius was lengthened by 4 cm (*blue arrow*). Note the hinges (*yellow arrows*) at the convexity of the deformity in the distal frame. The distal hand ring gradually moved the hand out of radial deviation (*curved arrow*). Note the neutral alignment of the forearm and hand on both views (*blue line*)

Fig. 5 (**a**–**c**) Clinical photos 6 months after frame removal showing correction of deformity and elbow ROM

5 Basic Principles

This is a combination of type 1 (short radius) and type 4 (radial hemimelia) by the Catagni classification. The approach requires correction of the radial deviation contracture and lengthening of the radius. This combination is expected to result in deformity correction and a stable wrist. Fusion can be done if there is persistent or recurrent instability.

6 Images During Treatment

See Figs. 3 and 4.

7 Technical Pearls

When lengthening the radius relative to the ulna, the distal ring placed at the distal radius should have wires fixating the radius only. In this way, the radius will be lengthened relative to the ulna. The proximal ring distal to the elbow should have fixation on both radius and ulna.

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6.

Fig. 6 Radiographs. (**a**) AP wrist and forearm in supination. (**b**) Lateral with forearm neutral. (**c**) AP with forearm neutral 9 months after frame removal showing well-healed radius lengthening and stable and well-aligned wrist/hand

9 Avoiding and Managing Problems

Attention to cross-sectional anatomy for wire placement is essential to avoid neurovascular injury. Avoidance of paralytic agents during anesthesia allows the surgeon to visualize motor nerve irritation with the placement of a wire too close to a motor nerve. Regional anesthesia does not impair this feedback.

Fixation of both the radius and ulna at the proximal ring is needed to avoid disruption of the ulna-radius relationship at the elbow.

10 Cross-References

► Case 89: Radial Clubhand
► Case 91: Ulnarization as Treatment for Radial Clubhand (RCH)
► Case 94: Correction of Forearm Deformities in Hereditary Multiple Exostosis (MHE)

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Case 91: Ulnarization as Treatment for Radial Clubhand (RCH)

Dror Paley and Craig A. Robbins

Contents

Abstract

Previous methods of treatment of radial clubhand (RCH) have resulted in recurrent deformity and growth arrest of the distal ulna in a very high percent of cases. Ulnarization (procedure developed by Paley in 1999) is the first treatment of RCH to demonstrate no recurrence or growth arrest. Through a volar approach, the entire carpus is acutely transferred to the ulnar side of the ulna.

Fig. 1 Clinical photograph of an 18-month-old boy with unilateral RCH and thumb aplasia. Copyright 2009, Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore

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DOI 10.1007/978-3-319-18020-5_250

Fig. 2 Radiograph showing the complete absence of the radius and thumb. Reprinted with permission from the Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore

Fig. 3 Z-shaped volar incision

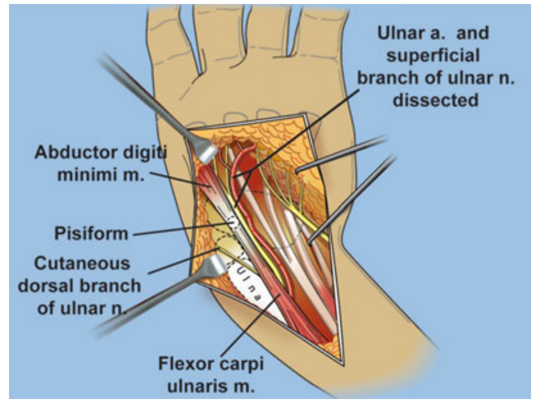

Fig. 4 Ulnar neuro-vascular structures exposed and decompressed

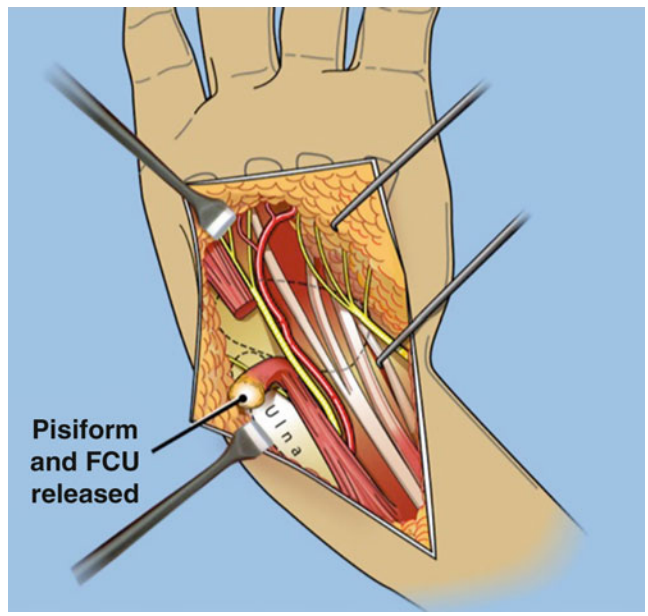

Fig. 5 FCU tendon reflected proximally with pisiform

1 Brief Clinical History

This case demonstrates the treatment of an otherwise healthy 18-month-old male child born with complete absence of the radius and thumb aplasia.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

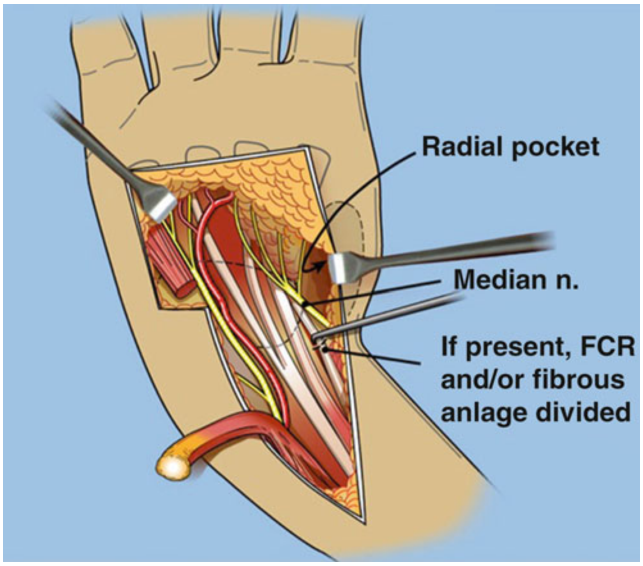

Fig. 6 Median nerve exposed; FCR released; radial pocket created

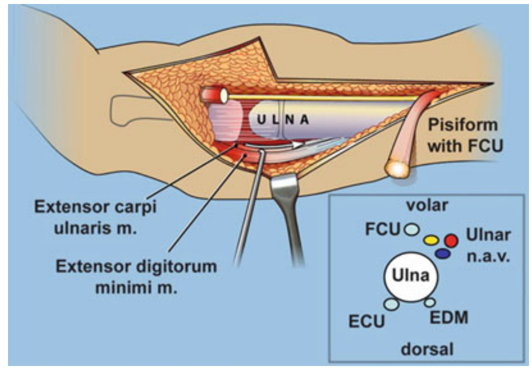

Fig. 8 Side view schematic with volar surface facing up. Begin by dissecting free the ECU and EDM tendons dorsally

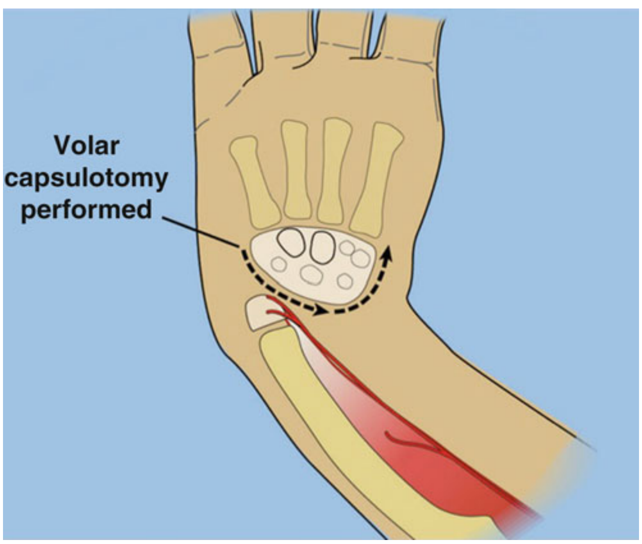

Fig. 7 Separate the carpus from the ulna; avoid the volar blood supply to distal ulna

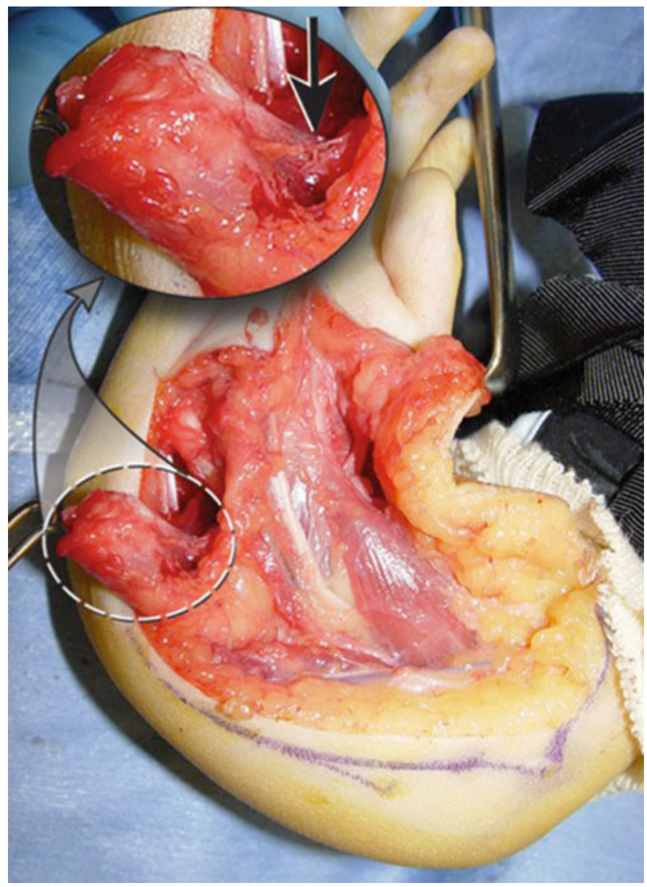

Fig. 9 Surgical volar surface view. The ulna can be dissected free of soft tissues on its distal, dorsal, and ulnar sides. The vascular pedicle of the epiphysis is located proximal, volar, and radial (as shown in this operative photo) and should not be disrupted

3 Preoperative Problem List

- Absent radius
- Radial clubhand deformity
- Absent thumb
- Need to evaluate for associated anomalies/syndromes (e.g.: Holt-Oram, TAR, VACTERYL, CHARGE, Fanconi anemia)

4 Treatment Strategy

RCH can be treated as early as 12 months of age. The extensile volar approach allows a comprehensive release of the carpus, acute transfer of the carpus to the ulnar side of the

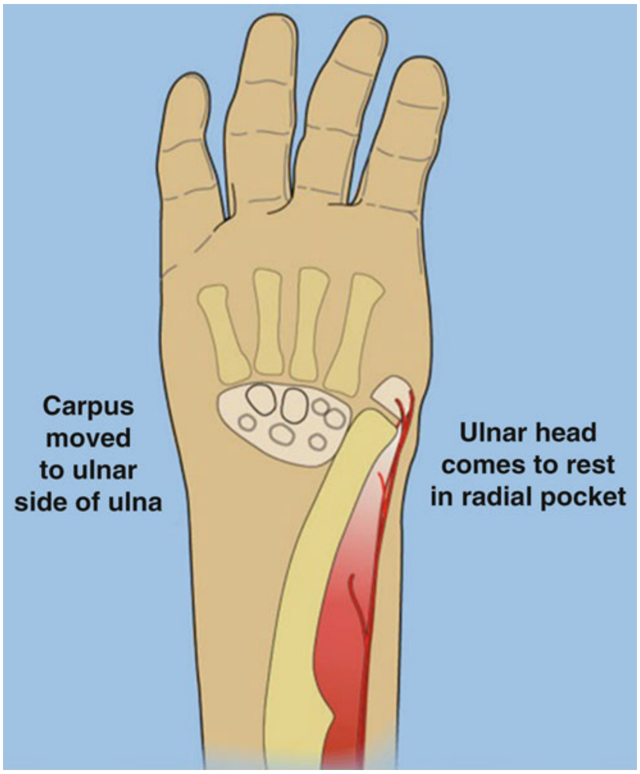

Fig. 10 The carpus is then moved ulnarly, "ulnarized" and the ulnar head is placed in the radial pocket

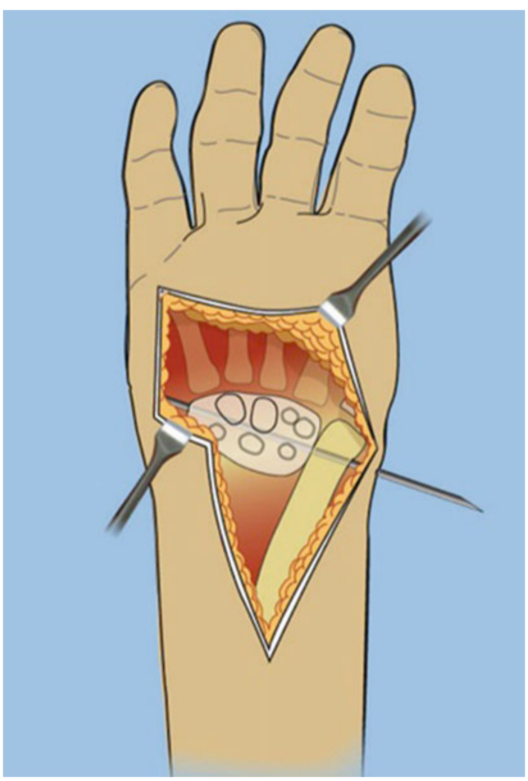

Fig. 11 The carpus is pinned to the ulna with a k-wire

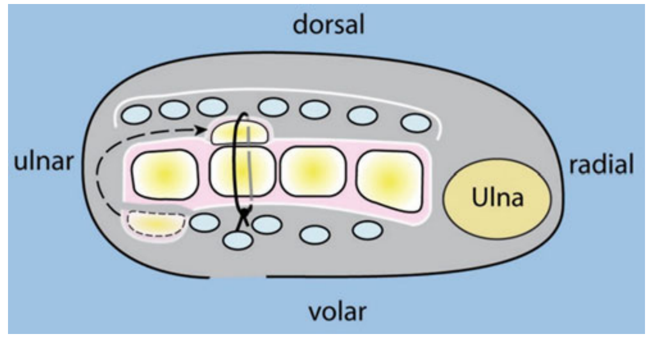

Fig. 12 After pinning the carpus, the FCU tendon is transferred to the dorsum of the wrist at the level of the base of the 4th (ring finger) metacarpal

wrist, and dorsal transfer of the flexor carpi ulnaris (FCU) with the attached pisiform. Ulnarization of the carpus converts the head of the ulna into a bone block to resist recurrence and as a fulcrum for muscle pull. Dorsal transfer of the FCU converts a deforming flexion force into a corrective extension force which improves wrist extension and thus finger flexion and strength. Pollicization of the index finger can be performed 6 months after ulnarization. Lengthening can be performed at ages 8 and 14.

5 Basic Principles

A zig-zag extensile volar approach is performed raising full thickness flaps to allow acute ulnarization of the carpus. The ulnar neurovascular bundle, including the dorsal branch of the nerve, is exposed and decompressed. The pisiform is released from its carpal attachments and reflected proximally along with the FCU tendon and muscle to allow later dorsal transfer. The median nerve is exposed, flexor carpi radialis (FCR) or its fibrous anglage is divided, and a radial pocket is created. The extensor carpi ulnaris (ECU) and the extensor digiti minimi (EDM) tendons are identified dorsally and released, and the carpus is separated from the distal ulna. Avoid volar dissection of the distal ulna to preserve its blood supply. Release the ulnar collateral and other capsular structures between the ulna and the carpus staying on the carpal side during dissection. The carpus is then moved ulnar to the ulnar head, "ulnarization," with the ulnar head lying in the radial pocket. The original procedure developed by Paley used an external fixator for fixation. More recently 3 k-wires (2 crossed and 1 axial) are used to pin the carpus to the distal ulna and left buried under the skin. The FCU tendon is then transferred to the dorsum of the wrist around at the base of the 4th (ring finger) metacarpal to improve active wrist dorsiflexion. The 3 k-wires are removed 3 months after surgery.

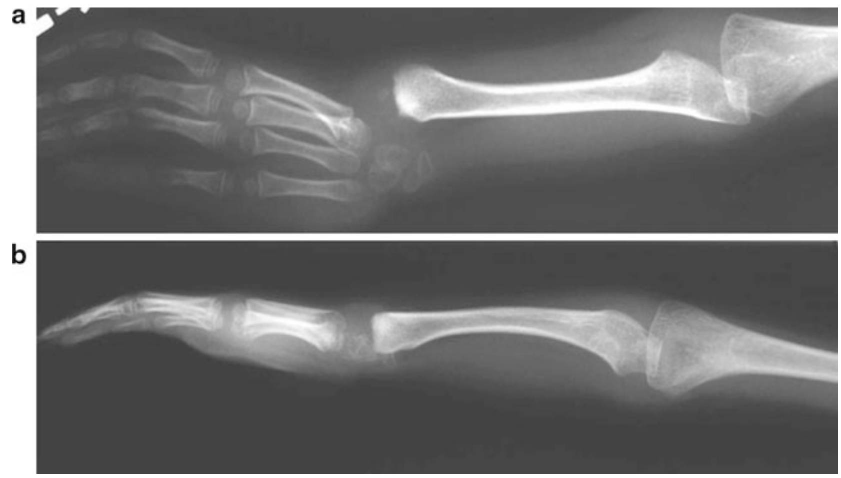

Fig. 13 (**a**, **b**) AP and lateral X-rays several months after index procedure and removal of buried k-wires

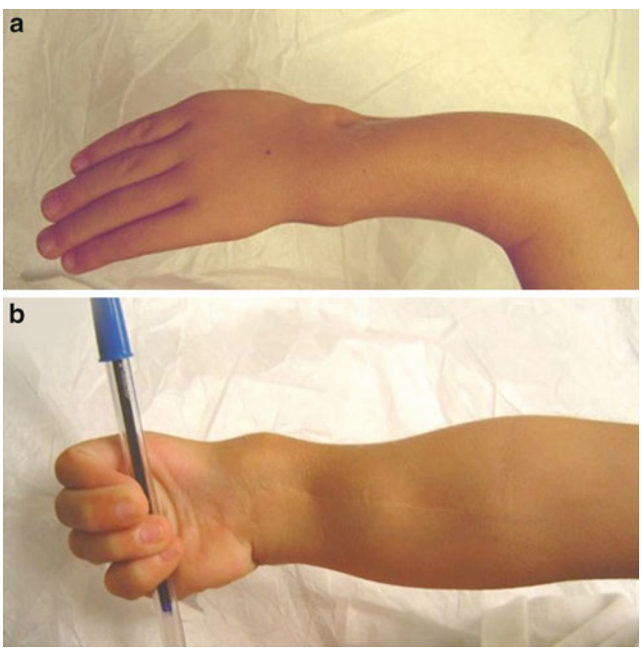

Fig. 14 (**a**, **b**) Dorsal and volar clinical pictures several months after surgery showing hand function

In some cases, where there is not too much overlap between the carpus and the distal ulna, a notch can be created in the radial aspect of the carpus to allow the ulnar head to lie in the recess. This makes the head less prominent under the skin and also places it under the carpus for better distal transport as the ulna grows. The downside of this is that wrist motion is not as good as without the notch. As well, the FCR tendon, if present, is transferred to the thumb in cases of TAR syndrome where the thumb is always present. This improves thumb extension.

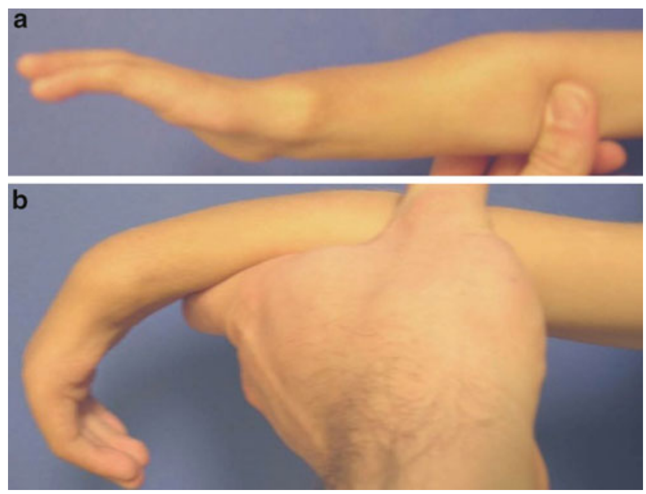

Fig. 15 (**a**, **b**) Side view clinical photographs showing active wrist extension and flexion

6 Images During Treatment

See Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.

7 Technical Pearls

- Volar incision and flaps are designed to allow acute translation to “ulnarize” the carpus
- Neurovascular structures and musculotendinous units are decompressed to allow tension-free mobilization
- Preserve the volar and radial blood supply to the ulnar head

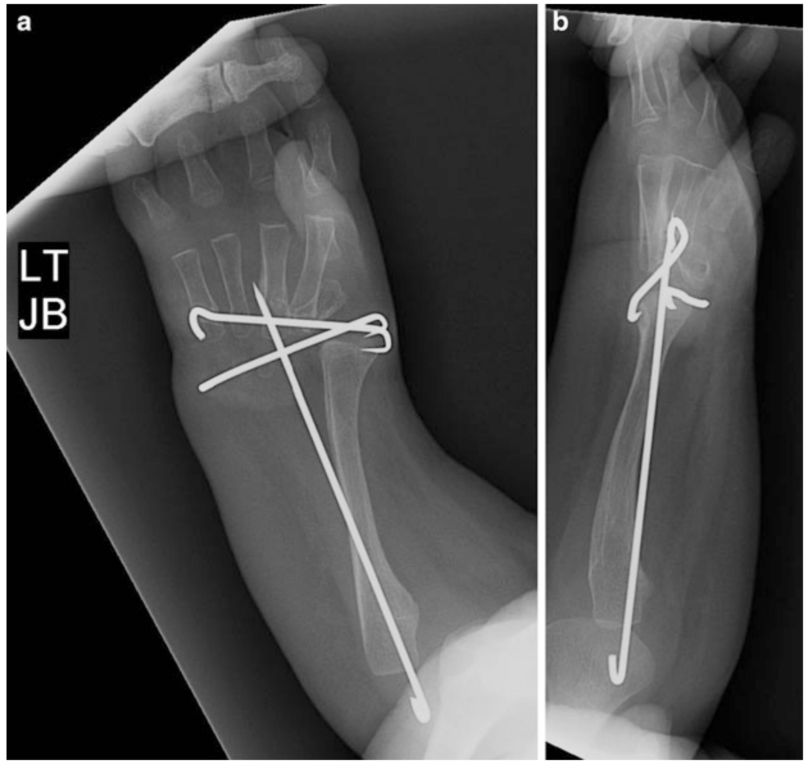

Fig. 16 (**a**, **b**) AP and lateral X-rays of a more recent patient (with hypoplastic thumb) showing three buried stabilizing k-wires

- Balance wrist forces with tendon transfer. By transferring the FCU, it is converted from a deforming flexion force into a corrective extension force
- Stabilize the carpus to the distal ulna with three buried k-wires
- Transfer the FCR, if present, to the thumb in TAR syndrome to improve extension

8 Outcome Clinical Photos and Radiographs

See Figs. 13, 14, and 15.

9 Avoiding and Managing Problems

Meticulous flap design, soft tissue handling, and loupe magnification are imperative. Dissection and exposure proceed sequentially to allow tension-free ulnarization of the carpus and transport of the ulnar head into a prepared radial pocket. Avoid the volar vascular pedicle to prevent a distal ulna growth disturbance. Balancing muscle forces (e.g., dorsal-FCU and possibly FCR-to-thumb transfer) help minimize deforming forces. Use of 3 k-wires allows for satisfactory bony stability, and burying them under the skin facilitates later removal, minimizes infection risk, and allows for easier postoperative bracing (see Fig. 16).

10 Cross-References

► Case 89: Radial Clubhand
► Case 90: Radial Clubhand Correction with Radius Lengthening Using the Ilizarov/TSF

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Case 92: Congenital Malformation of the Upper Limb (Ulnar Clubhand) in a 6 Year Old Child Treated by Lengthening Associated with Flexible Intramedullary Nailing

Dmitry A. Popkov, Arnold V. Popkov, and Pierre Lascombes

Contents

Abstract

Congenital ulnar clubhand (type 1, Bayne's classification) is shortening combined with ulnar deviation of the hand, dislocation of the radial head, and deformity of the radius. Forearm bone lengthening with restoration of correct proportions, deformity elimination, and reduction of the radial head can be successfully performed with the combined technique: circular external fixator and flexible intramedullary nailing. In this case we describe application of the combined technique which enabled correction of all the abovementioned defects as well as to shorten the period of external fixation significantly.

1 Brief Clinical History

The patient was originally seen at 5 years of age, when the parents applied to our hospital complaining of length discrepancy and deformation of the left upper limb. The child presented with an isolated ulnar clubhand of the left upper extremity. On physical examination, lower limbs and spine were unremarkable, as well as the right upper extremity. There was no evidence of proximal focal femoral deficiency or fibula deficiency. The decision about surgical lengthening and deformity correction was made at 6 years old. At that time, the overall length discrepancy of the left upper limb was 4 cm. There was also concomitant dislocation of the radial head, defect of distal ulna, and, as a result, ulnar deviation of the hand.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

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DOI 10.1007/978-3-319-18020-5_347

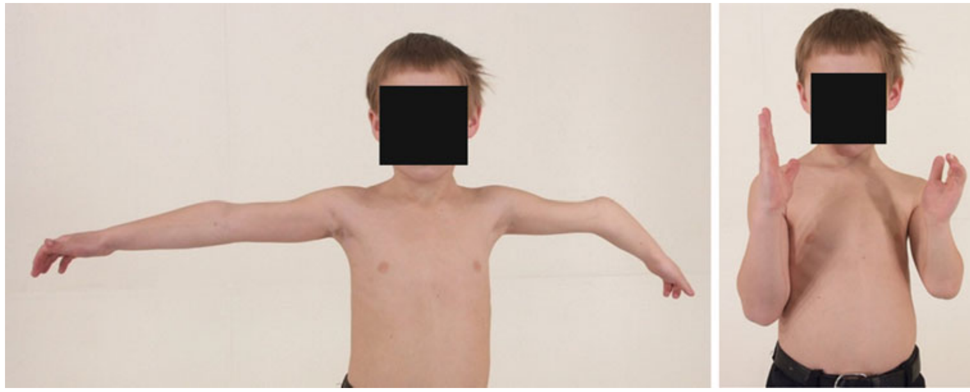

Fig. 1 Showing the affected and normal hands

Fig. 2 Showing X-ray of the forearm with defect of distal ulna and dislocation of the radial head

3 Preoperative Problem List

– Shortening of the left upper limb
– Dislocation of the radial head
– Ulnar deviation of the hand

4 Treatment Strategy

Reconstructive surgery in this case requires two stages. The first surgery was a single-event lengthening of the ulna and reduction of the radial head. The second surgery was osteotomy of the radius for lengthening and deformity correction as well as insertion of an additional wire in the upper third of the radius for traction and radial head reduction. After the second surgery, the lengthening was performed in both bones of the forearm. During the entire period of distraction, the elbow and wrist joints were stabilized by positioning the Ilizarov rings in the distal third of the forearm and at the level of hand and their connection with the frame on the forearm by hinges.

5 Basic Principles

– In progressive limb lengthening with any type of external fixator, the principles of the Ilizarov method should be respected (stable elastic osteosynthesis, percutaneous osteotomy aimed to preserve periosteal and intramedullary blood supply of the bone, distraction initiated on the fifth postoperative day, optimal rate and rhythm of distraction, early weight bearing and mobilization of adjacent joints).
– Flexible intramedullary nailing is performed according to the basic principles, but unlike with fractures, the diameter of the nails is 20–25 % of the medullary canal diameter. For the forearm, the nail size is usually 1.5–2 mm.
– Preserve radial and ulnar growth.

6 Images During Treatment

See Figs. 3, 4, and 5.

Fig. 3 First surgery: Osteotomy of the ulna, antegrade intramedullary osteosynthesis, fixation with the Ilizarov frame

7 Technical Pearls

- Intramedullary wires in forearm lengthening prevented lateral displacement of the fragments. This is important considering the small transverse size of the radius and ulna.
- First, just two wires or half-pins were inserted in the proximal and distal systems, then the external fixator was assembled, and the intramedullary nails were inserted after the osteotomy. All other wires and half-pins of the external fixator were added after the nails were in place.
- The osteosynthesis was retrograde in the ulnar and antegrade in the radius.
- Beginning of the distraction – on the 5th day.
- Rate and rhythm of distraction were defined according to radiographic markers of the reparative bone regeneration.
- Mobilization of the adjacent joints was obligatory during fixation.
- Disappearance of the "growth zone" and continuity of cortices at least on 3 out of 4 sides of the regenerate were indications for frame removal.
- Intramedullary nails were removed on average 6 months after frame removal, when at least 50 % of the range of motion of the adjacent joints was restored.

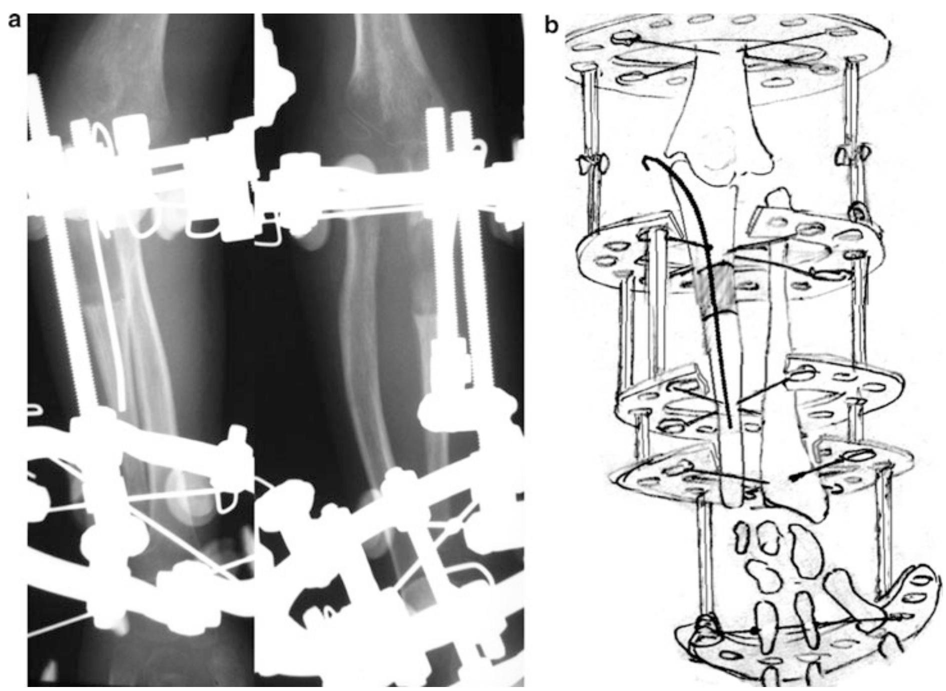

Fig. 4 On the 45th day of distraction: (**a**) Ulnar distraction regenerate is even and high density. The radial head is reduced. (**b**) Diagram of osteosynthesis Sch. at the moment

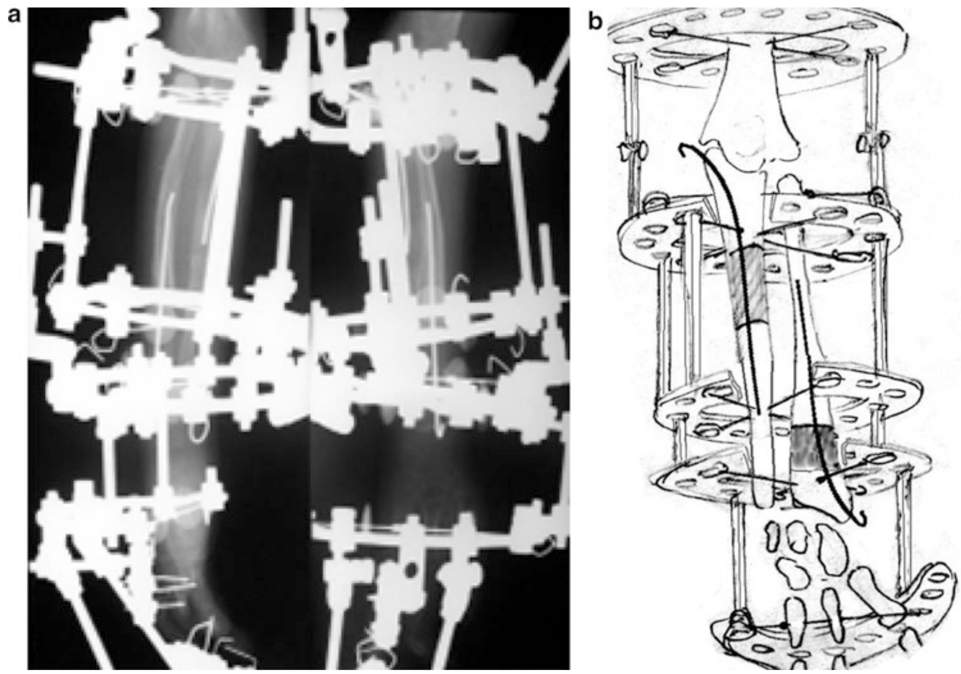

Fig. 5 On the 85th day of distraction: (**a**) Lengthening of the ulna and radius, deformity correction of the radius, radial head reduction. (**b**) Diagram of osteosynthesis Sch. at the moment

Fig. 6 X-ray of the forearm after Ilizarov frame removal: lengthening gain of the ulna – 7 cm, of the radius – 3.5 cm. Healing index: 17.1 days/cm

Fig. 7 X-ray of the forearm 6 months after frame removal and 2 days after removal of the intramedullary nails

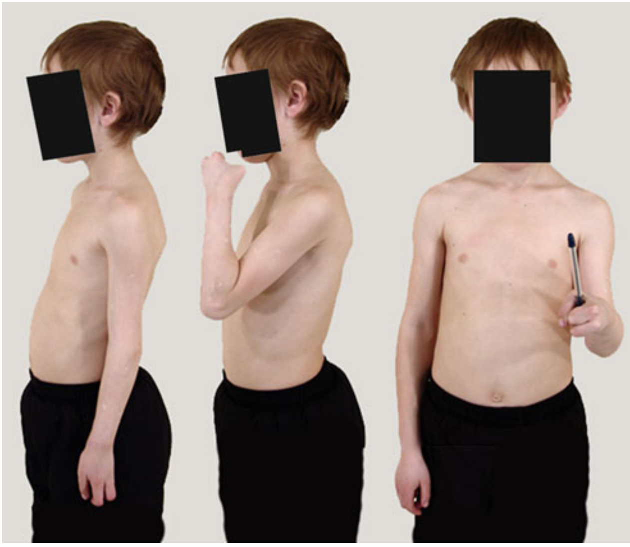

Fig. 8 Functional abilities 6 months after treatment

8 Outcome Clinical Photos and Radiographs

See Figs. 6, 7, and 8.

9 Avoiding and Managing Problems

– Visits to the surgeon for monitoring are held at least one time a week during distraction period, during fixation – at least one time every 2 weeks.
– The combined technique requires practice and experience of the surgeon with both the external fixation and flexible intramedullary nailing.

10 Cross-References

▶ Case 93: Correction of Forearm by Corrective Radial Osteotomy and Ulnar Lengthening by Distraction Osteogenesis Deformity in Hereditary Multiple Osteochondromatosis

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Case 93: Correction of Forearm by Corrective Radial Osteotomy and Ulnar Lengthening by Distraction Osteogenesis Deformity in Hereditary Multiple Osteochondromatosis

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Contents

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Abstract

Hereditary multiple osteochondromatosis is a skeletal dysplasia with an autosomal dominant pattern. It affects both lower and upper extremity long bones, causing short stature and deformities. These patients have a higher risk for malignant transformation compared to solitary osteochondromas. Forearm deformities are one of the most difficult deformities to handle due to complex anatomy and higher functional expectations. Asymmetric growth of the two bones in the forearm may lead to dislocation of the radiocapitellar joint. The case shown is a forearm deformity with severe ulnar shortening without radial head dislocation.

1 Brief Clinical History

A 14 year old male patient was referred to our clinic with forearm deformity, shortening. He was previously diagnosed with hereditary multiple osteochondromatosis and was operated several times due to lower and upper extremity osteochondromas. Patient had marked shortening with no forearm rotation loss in both supination and pronation.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Right arm, apex radial (lateral) radius angulation
2. Right arm, ulnar shortening
3. Right arm, mild carpal translation to ulnar direction

S.R. Rozbruch, R.C. Hamdy (eds.), *Adult Deformity/Tumor/Upper Extremity*,
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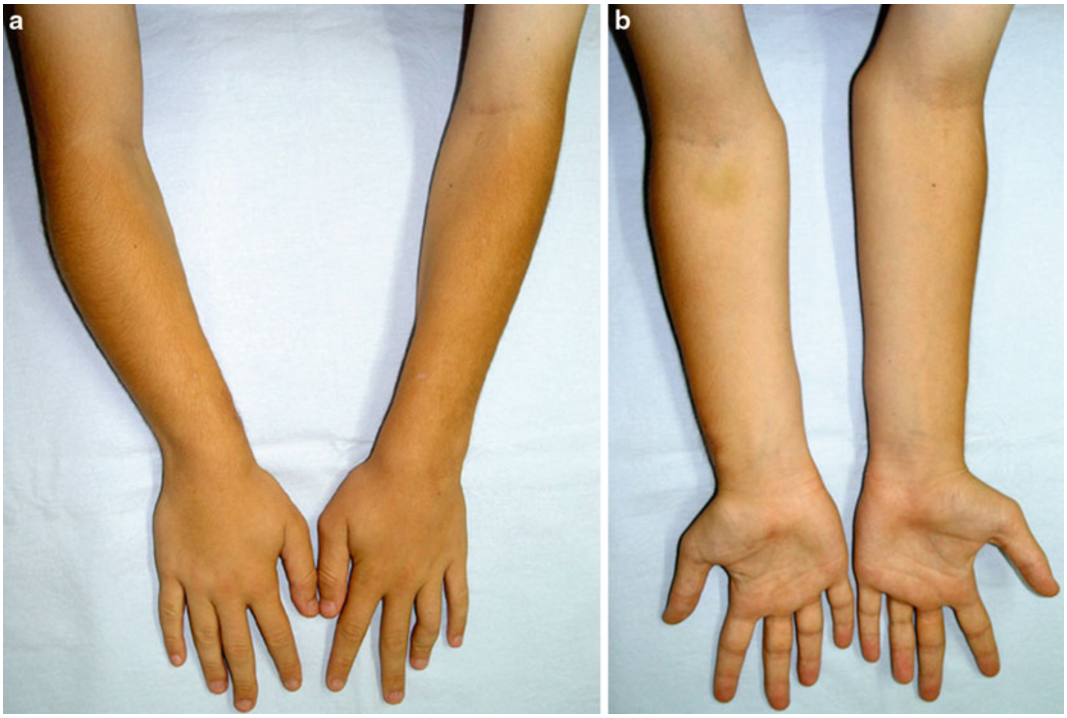

Fig. 1 Clinical photos of the patient before treatment

Fig. 2 Anteroposterior and lateral radiographs of the patient before surgery. Both radius and ulna are angulated, and there is marked shortening of the ulna

4 Treatment Strategy

1. Acute correction of radial angulation with plate osteosynthesis.
2. Acute correction of ulnar angulation with external fixation.
3. Lengthening of ulna through the angular correction osteotomy.

5 Basic Principles

During planning, it is important to define problems and individualize treatment. We use Masada and Ono classification (Table 1). The presented case is an example of Type 1; the lesion is located at distal ulna, inhibiting growth of the distal ulna, causing ulnar shortening. In this case, there is no radial head subluxation or dislocation.

Anteroposterior (AP) and lateral radiographs of both forearms are obtained for planning. Ulnar shortening, radial articular angle (RAA), and carpal slip (CS) are measured and recorded. RAA is measured between two lines on AP X-ray: one along the articular surface of the distal radius and the other perpendicular to a line from the center of the radial head to the radial edge of the distal radial epiphysis (Fig. 3).

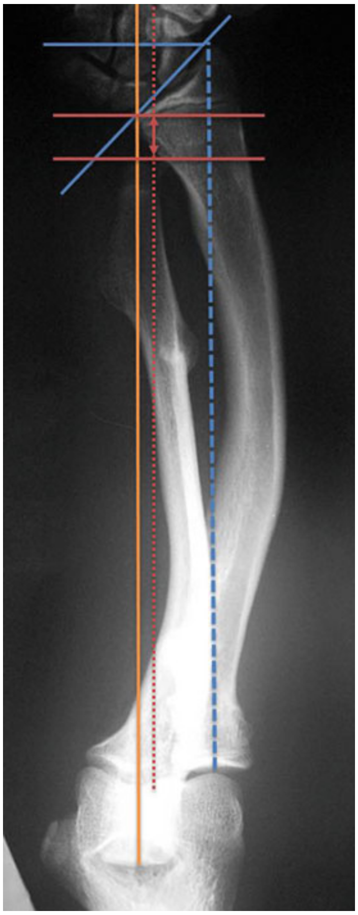

Fig. 3 Measurement of radial articular angle (RAA, *blue lines*), carpal slip (CS, *orange line*), and shortening (*red lines*)

Table 1 Masada and Ono Classification for forearm deformities in hereditary multiple osteochondromatosis

Type I: Ulna is short, osteochondroma formation at the distal ulna
Type IIa: Ulna is short, osteochondroma formation at both proximal radius and distal ulna, radial head dislocated
Type IIb: Ulna is short, osteochondroma formation at the distal ulna, radial head dislocated
Type III: Radius is relatively short to the ulna, osteochondroma formation at the distal radius

Normal value of RAA is 15–30°. It is 46° in the presented case. Planning the osteotomy level is analogous to lower extremity planning.

CS is measured as the percentage of the lunate proximal surface in contact with the radius, as limited by a line drawn from the center of the olecranon through the ulnar edge of the radial epiphysis (Fig. 3). This line normally bisects the lunate, and the CS is abnormal when ulnar displacement of the lunate is more than 50 %. In this case, amount of slippage of lunate is at 50 %.

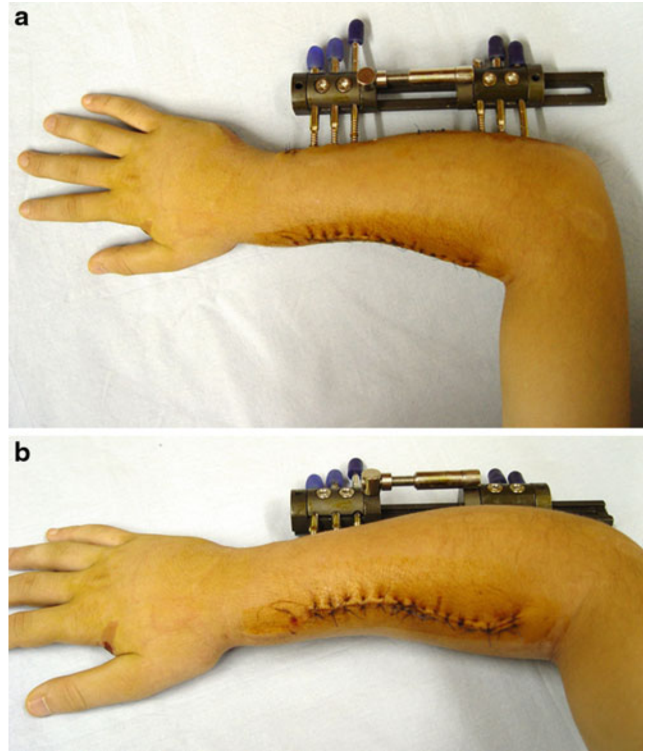

Fig. 4 Postoperative clinical photos of the patient

Shortening is measured between two lines at the level of distal ulnar epiphysis and ulnar edge of the radial epiphysis, which are perpendicular to the axis of the forearm (Fig. 3).

Although it is possible to correct radial deformity and osteotomize ulna through one incision, we prefer using two different approaches. Both dorsolateral or volar approaches can be used, depending on the radial deformity. Ulnar osteotomy is performed with a small incision, using multiple drill holes and an osteotome.

Place two half-pins proximally and distally, with great care so that half-pins are perpendicular to the related segment and on the same plane to the other segment. These pins serve as a guide following osteotomy. After osteotomy is performed, place fixator and check alignment of ulna and revise pins if necessary. If the realignment of the bone is as planned, place the remaining half-pins for secure fixation. Two or three pins per segment are recommended.

The radius of this patient has lost its physiologic bow during growth because of the tethering effect of the short ulna. We planned the correction more on the mid-diaphysis due to two reasons: staying close to the apex of the mid-diaphyseal deformity and achieving a more stable osteosynthesis (compared to a more distal osteotomy) which can keep rigid during lengthening.

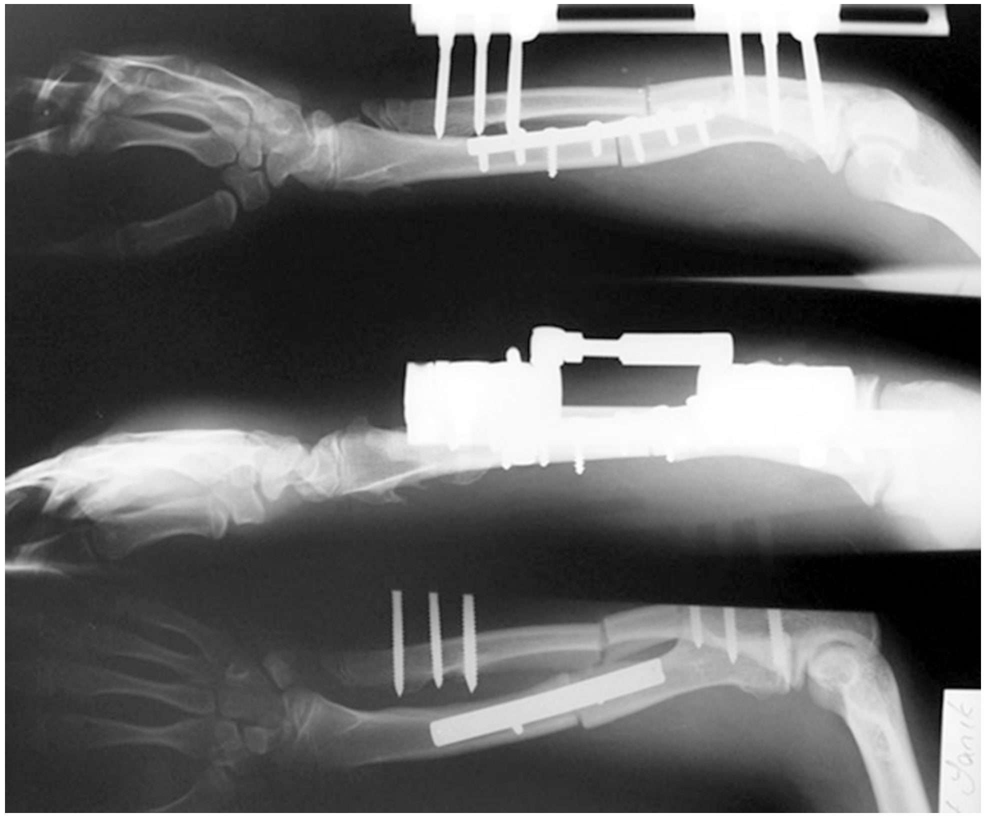

Fig. 5 Postoperative radiographs at the latent period

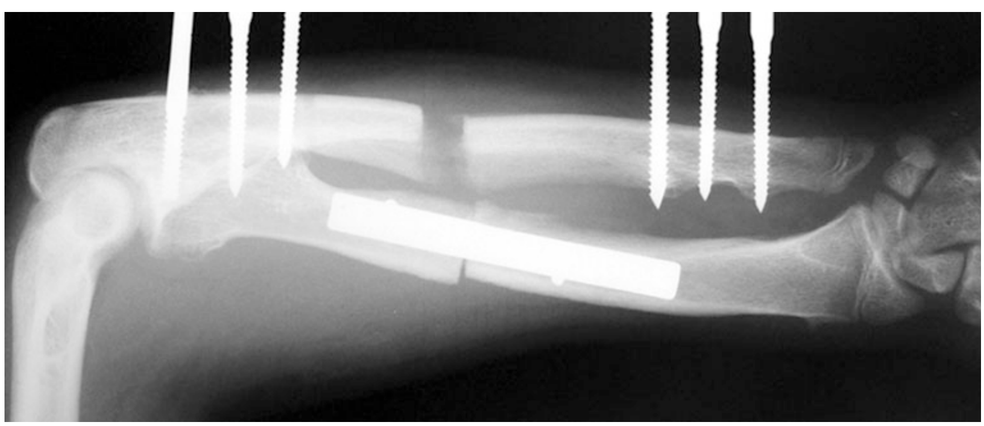

Fig. 6 First month postoperatively. Good callus formation observed in the ulna, and radius is well aligned

Lengthening is initiated after a seven-day latency period and proceeds with a speed of 0.5 mm/day in divided doses. It is very important to monitor callus formation during lengthening and manage distraction speed according to its quality. In this particular patient, we slowed down the distraction to 0.25 mm/day for short periods.

6 Images During Treatment

See Figs. 4, 5, 6, 7, and 8.

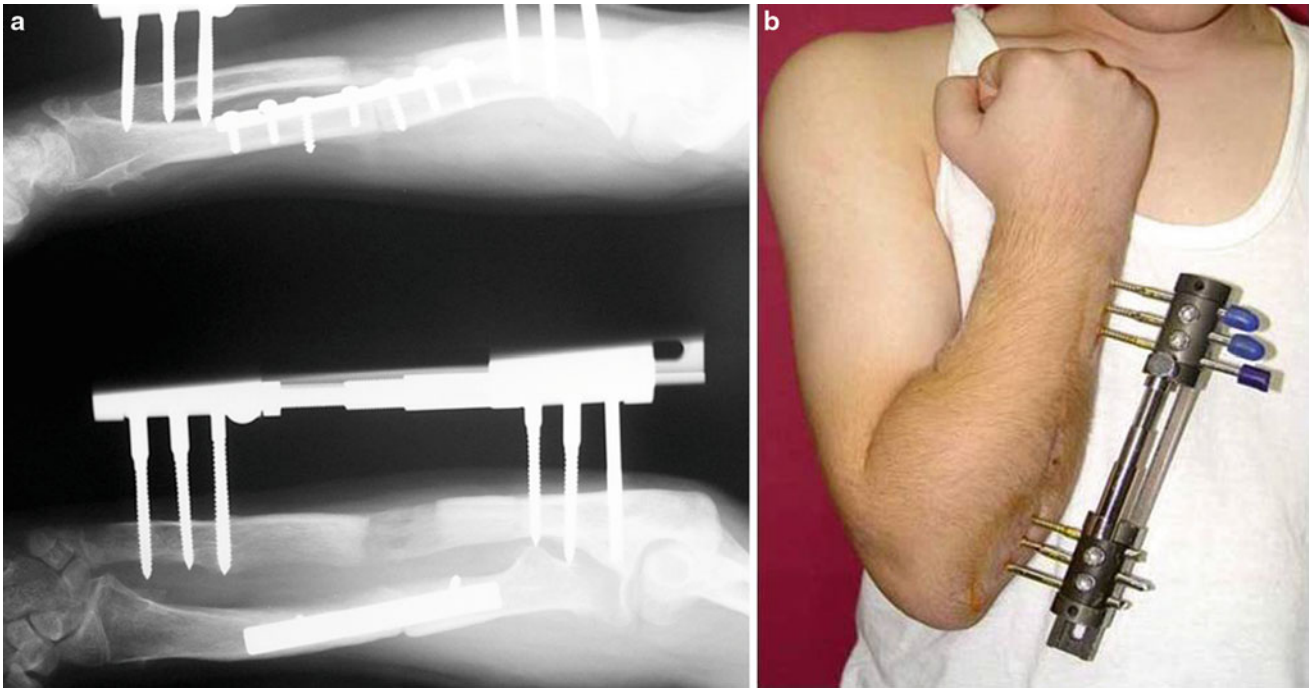

Fig. 7 (**a**) X-ray at third month, during consolidation of the regenerate bone of the ulna. The radius osteotomy is also showing signs of bridging. (**b**) Clinical photo of the patient with full elbow flexion

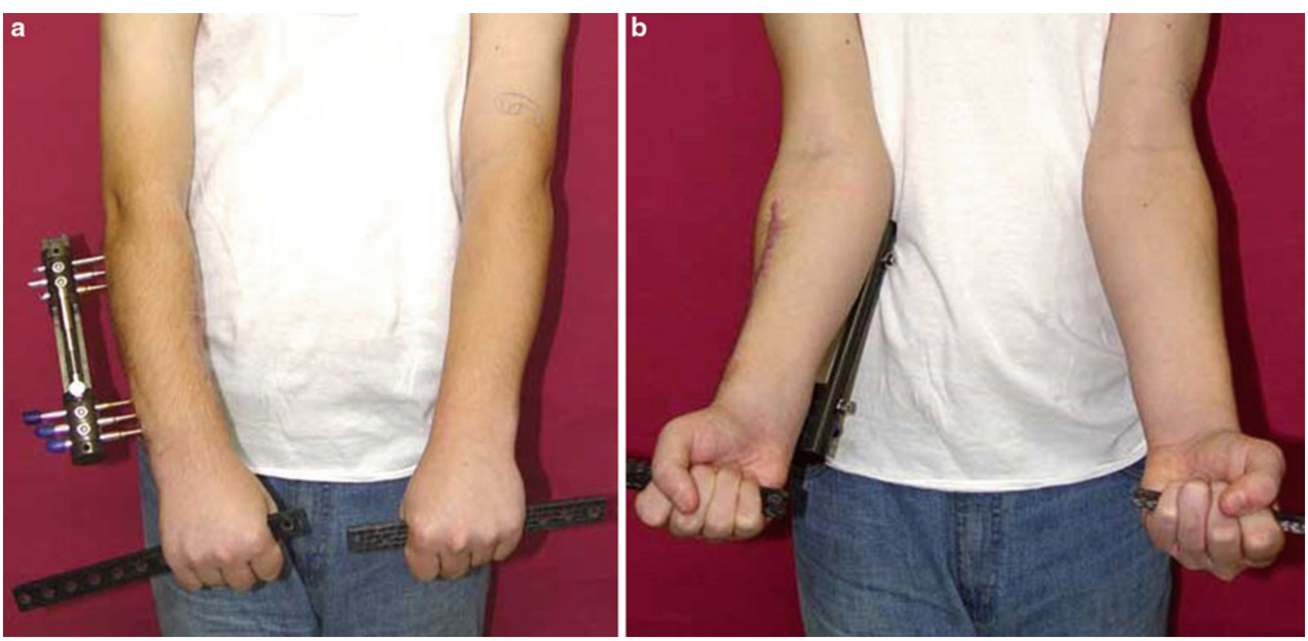

Fig. 8 Clinical photos of the patient during consolidation. At this period, patient achieved full pronation and supination with 10° loss

Fig. 9 Postoperative seventh month. Solid union achieved

7 Technical Pearls

It is possible to use circular external fixator instead of monolateral fixator for the ulna. For the acute radial osteotomy correction, plates work well.

Masada and Ono type 2 cases require radial head reduction. For those cases, radius and ulna are transfixed distally; therefore, ulnar lengthening also reduces radial head. Once radial head is reduced, radioulnar transfixation is removed for further ulnar lengthening. The distal radioulnar joint is mostly fixed with a single, threaded, 1.5 mm K-wire under fluoroscopic guidance.

An intramedullary wire can serve as a guide for lengthening and helps avoid secondary deformities during lengthening. If we choose to lengthen the ulna over an intramedullary implant, we use a Rush pin; the diameter should be about one third to one half the diameter of the ulnar medulla at the narrowest point. It is inserted through the olecranon. The medulla is prepared with a cannulated drill. Osteotomy drill holes are prepared prior to this reaming for internal grafting purposes.

8 Outcome Clinical Photos and Radiographs

See Figs. 9, 10, and 11.

Fig. 10 Wrist range of motion of both arms on seventh month postoperatively

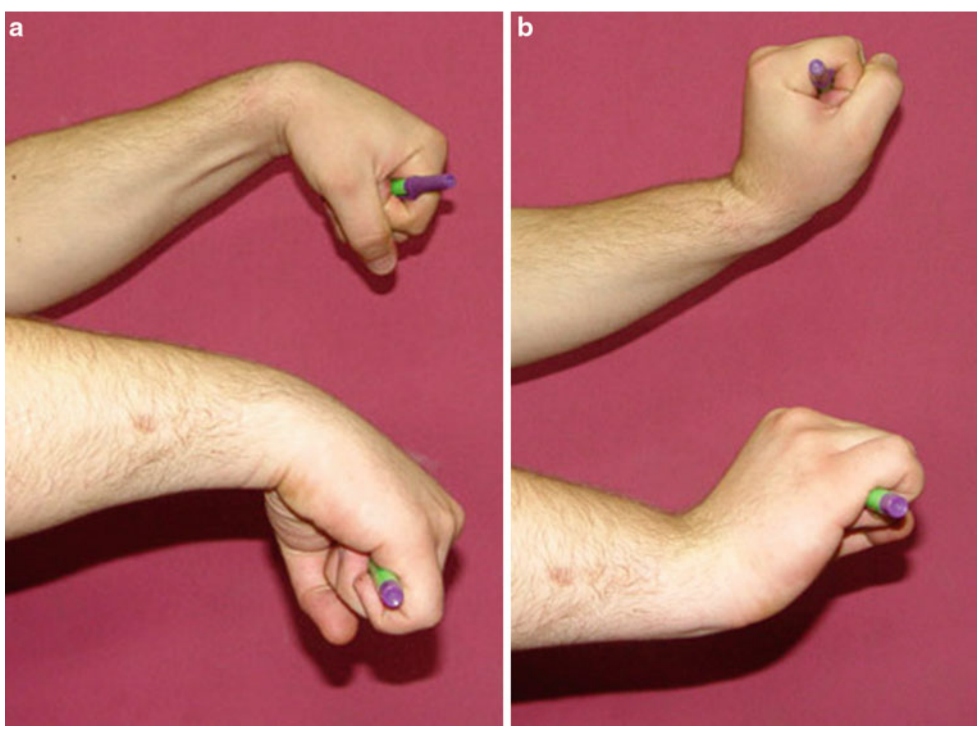

Fig. 11 Radiographs of the patient after removal of the plate. Full range of motion was achieved

9 Avoiding and Managing Problems

Lengthening and deformity correction of the forearm require close monitoring of neurovascular and functional status, due to complex anatomy of the upper extremity, especially distal to the elbow.

10 Cross-References

► Case 94: Correction of Forearm Deformities in Hereditary Multiple Exostosis (MHE)

References and Suggested Readings

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Case 94: Correction of Forearm Deformities in Hereditary Multiple Exostosis (MHE)

Mark Eidelman

Contents

Abstract

Hereditary multiple exostoses (HME) may cause significant upper limb deformities and disabilities. Forearm deformities are the most common manifestation of this syndrome in the upper limb. The underlying cause is disturbance of growth of the distal ulna, leading to shortening of the ulna, and

Fig. 1 Anterior (**a**), oblique (**b**), and lateral (**c**) view of the left forearm

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Fig. 2 Clinical picture of the forearm showed forearm bowing and wrist deviation

Fig. 3 Wire insertion demonstrated angle of correction and guides the osteotomy of the distal radius

subsequent tethering of the radius with resultant ulnar deviation of the distal radius. In this case presentation, acute correction of the radial deformity with acute Z-lengthening of the ulna fixed both deformities simultaneously and without the need for external fixation.

Fig. 4 Closing wedge of the radius with fixation using two Kirschner wires

1 Brief Clinical History

An 11 year old girl with HME presented with severe bowing of the radius, shortening of the ulna (Masada type 1), and limitation of forearm rotation.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1 and 2.

3 Preoperative Problem List

1. Increased radial intra-articular inclination
2. Shortening of the ulna
3. Ulnar wrist deviation
4. Limitation of forearm rotation

Fig. 5 Z-osteotomy of the ulna and distraction using a lamina spreader

Fig. 6 Clinical picture before plating; bone graft (from radius closing wedge osteotomy) inserted at the proximal part of the osteotomy

4 Treatment Strategy

1. Radial closing wedge osteotomy
2. Z-lengthening of the ulna
3. Plating of the ulna and wire fixation of the radius

5 Basic Principles

Closing wedge osteotomy not only reorients the radial surface to normal position but also corrects the length of the radius relatively to the ulna. Ulnar lengthening might be performed gradually using external fixation or in a single stage with acute Z-lengthening of the ulna. While gradual distraction osteogenesis for lengthening of the ulna is potentially easier surgically and more adjustable postoperatively, it is much more comfortable for the patient to undergo acute correction with internal fixation.

6 Images During Treatment

See Figs. 3, 4, 5, 6, and 7.

7 Technical Pearls

Always start with the radial osteotomy first and use the resected closing wedge from the radius to fill the Z-lengthening gap of the ulna. Perform prophylactic volar forearm compartment fasciotomy to minimize risk of compartment syndrome.

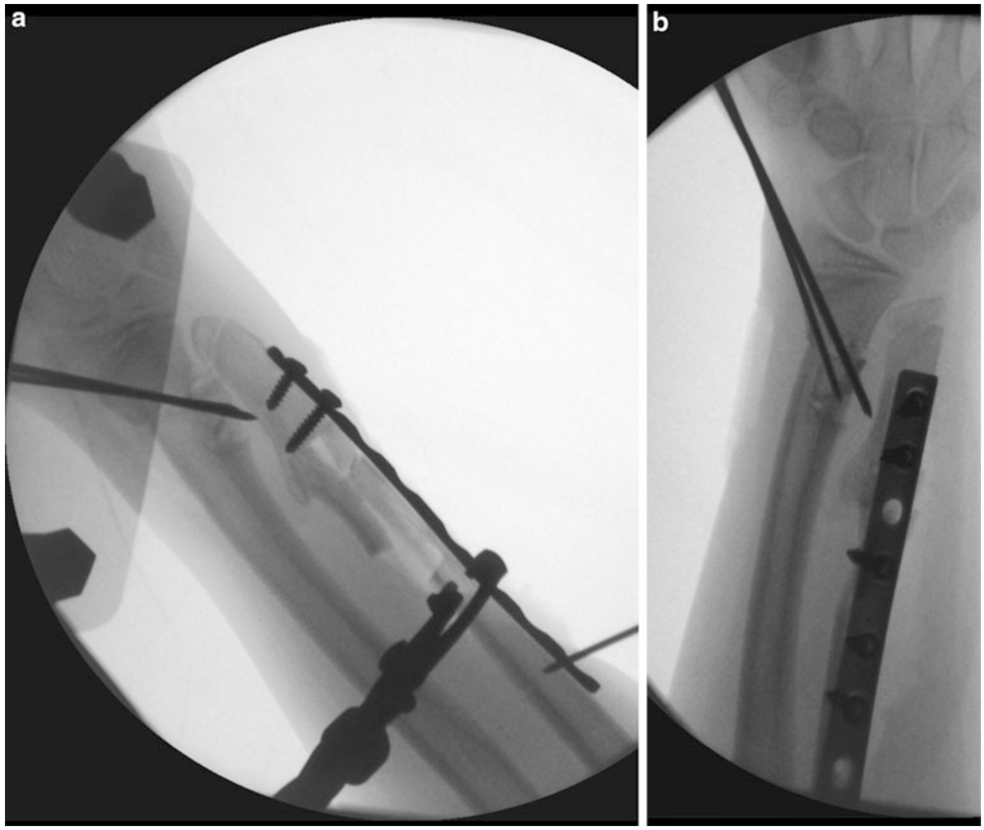

Fig. 7 (**a**, **b**) Fixation of the ulna using 1/3 tubular plate

Fig. 8 Anterior (**a**) and lateral (**b**) radiographs a year after operation

8 Outcome Clinical Photos and Radiographs

See Figs. 8 and 9.

9 Avoiding and Managing Problems

To avoid compartment syndrome, carefully monitor neurovascular status. Use splint or split circular cast. Avoid tendon entrapment after Kirschner wire fixation.

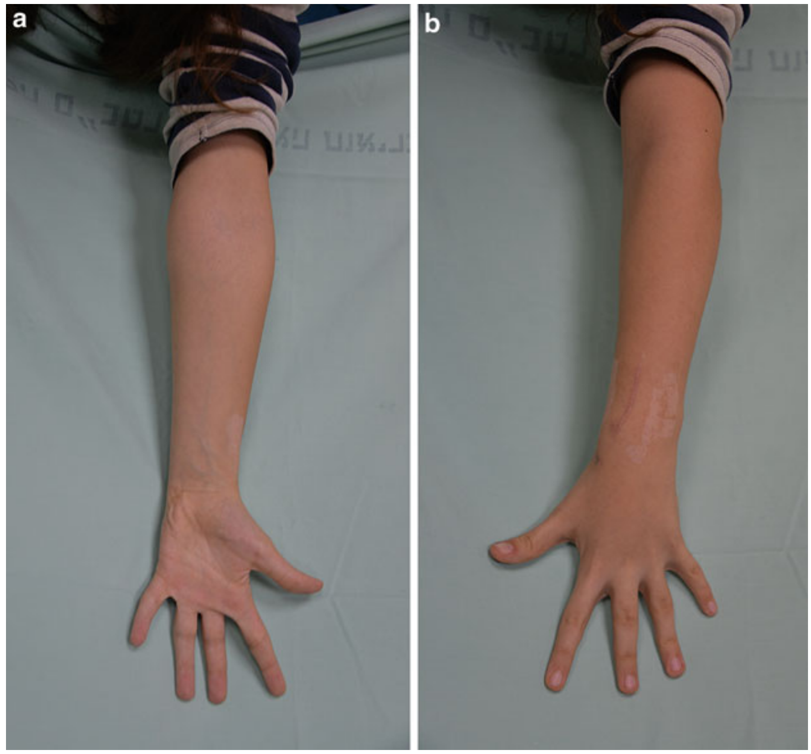

Fig. 9 (**a**, **b**) Clinical picture 1 year after surgery

10 Cross-References

▶ Case 93: Correction of Forearm by Corrective Radial Osteotomy and Ulnar Lengthening by Distraction Osteogenesis Deformity in Hereditary Multiple Osteochondromatosis

References and Suggested Reading

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Case 95: Cubitus Varus Deformity due to Multiple Hereditary Exostosis Treated with Ulnar Lengthening and Closed Radio-Capitulum Reduction

Aik Saw and Rukmanikanthan Shanmugam

Contents

Abstract

A 7 year old boy with multiple hereditary exostoses presented with progressive swelling of the left elbow and reduced range of elbow motion. Radiographs showed a distal ulnar exostosis, ulnar negative wrist, and subluxation of the radiocapitellar joint. On follow-up, the elbow deformity became worse. Repeated radiograph showed lateral dislocation of the radiocapitellar joint (Masada type IIB). He was treated with gradual lengthening of the ulnar and distal distraction of radius using an Ilizarov external fixator. The radiocapitellar joint was gradually reduced during the ulnar lengthening. Following the removal of the Ilizarov external fixator, the radial variant was also corrected with proximal migration of the radius. General appearance of the elbow improved with a slight increase in elbow flexion. On the last follow-up, a similar deformity was noted to be developing in the opposite elbow.

1 Brief Clinical History

A 7 year old boy presented with progressive left elbow deformity. He had been diagnosed with multiple hereditary exostoses (MHE) with multiple bone swellings around the wrists, shoulders, and knees since he was 5 years old. At age 6, his parents also noted reduced elbow and forearm mobility, but the boy was pain-free with no problems with

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Fig. 1 Radiograph of the left forearm at age 6 showing lateral subluxation of left radial head

activities of daily living. Plain radiographs taken showed subluxation of the left radiocapitellar joint (Fig. 1). About 1 year later, the deformity became more obvious and the family returned for further consultation.

2 Preoperative Clinical Photos and Radiographs

On physical examination, both elbows appeared straight with reversal of the normal carrying angle. Bony swelling over the lateral aspect of left elbow gave an impression of varus forearm deviation/cubitus varus deformity (Fig. 2a). Flexion and extension of the left elbow were 10–100°, while on the right side they were 10° and 135° (Fig. 2b). The right elbow had 30° pronation and 90° supination, while the left elbow has 30° pronation and 70° supination (Fig. 2c, d). Bony swellings were palpable over the wrist, but there was no localized tenderness or significant limitation of wrist motion. Plain radiographs showed left distal ulnar exostosis with anterior-lateral dislocation of the radial head (Fig. 3) corresponding to Masada type IIB deformity (Masada et al. 1989). Surgical treatment was eventually performed about 10 months later to coincide with his school holidays.

3 Preoperative Problem List

- Distal ulnar exostosis with shortening of the ulnar bone
- Radiocapitellar joint dislocation with proximal migration of the radial head
- Ulnar minus left wrist, with ulnar deviation of the wrist joint
- Slight bowing of both the radius and ulnar bones
- Limited flexion and pronation of both elbows

4 Treatment Strategy

Lengthening of the left ulnar with distraction osteogenesis was performed using an Ilizarov external fixator. The proximal ulnar was fixed with two 3 mm diameter half pins and one tensioned smooth wire, and the distal ulnar was fixed with two tensioned smooth wires and one 3 mm half pin. One of the distal wires also fixed the distal radius metaphysis (Fig. 4a). Postoperative radiograph showed radial deviation to be about 15°, and proximal migration of the radial head of about 25 mm before gradual lengthening was initiated (Fig. 4b). Distraction across the mid-shaft corticotomy was started about 7 days after surgery and continued for about one and a half month until 40 mm of lengthening was achieved (Fig. 4c). At this stage, the proximal radioulnar relationship remained the same, and the radiocapitellar dislocation has been reduced with radial head migrating distal to the capitellum. The Ilizarov external fixator was removed 8 weeks later when the new ulnar bone

Fig. 2 (**a**) Preoperative picture in full elbow extension showing swelling over the lateral aspect of left elbow. (**b**) Preoperative picture showing limited flexion of the left elbow (range of motion 10–100°). (**c**) Significant limitation in the pronation of both elbows (30° for the right and left sides, respectively). (**d**) Near-normal supination of both elbows (90° and 80° for the right and left sides, respectively)

appeared to be strong. A radiograph taken 2 weeks following the removal showed proximal migration of radius where the ulnar minus deformity of the left wrist has improved and the radiocapitellar dislocation was reduced (Fig. 5).

5 Basic Principles

- Linear lengthening of the short ulnar with Ilizarov external fixator.
- Debulking of the distal ulnar exostosis if it causes pain or significant restriction of forearm motion.
- Fixation across the distal radioulnar joint with one tensioned wire.
- Distal distraction of radius to achieve closed reduction of the radiocapitellar joint dislocation.
- Overcorrection of the radiocapitellar joint to compensate for the radius plus deformity at the wrist.
- Proximal migration of radius after the removal of the external fixator frame to achieve normal radiocapitellar joint and distal radioulnar relationship.

Fig. 3 Plain radiograph of radius and ulnar with ulnar minus deformity of the wrist and radiocapitellar dislocation

- More lengthening of the ulnar can be considered in younger children where future growth discrepancy is anticipated.

6 Images During Treatment

See Fig. 4a–c.

7 Technical Pearls

- Ilizarov external fixator allows fixation with wires and half pins in multiple planes. It can provide more stable fixation of the ulnar bone.
- Amount of lengthening depended on the proximal migration of radius after radiocapitellar dislocation and distal migration of radius following distal radioulnar dislocation. The minimal amount of lengthening required should be equal to the sum of these measurements.
- Stretching exercise of the wrist and fingers throughout the treatment is important to avoid stiffness.
- Acute reduction of the radial head (Yong and Jung 2014) may not be necessary. By over-lengthening of the ulnar, we were able to achieve closed reduction without open manipulation of the joint.
- A mild degree of elbow deformity can be improved without radius osteotomy (Song et al. 2013) because the general appearance of the forearm would improve by reducing the radiocapitellar joint dislocation.

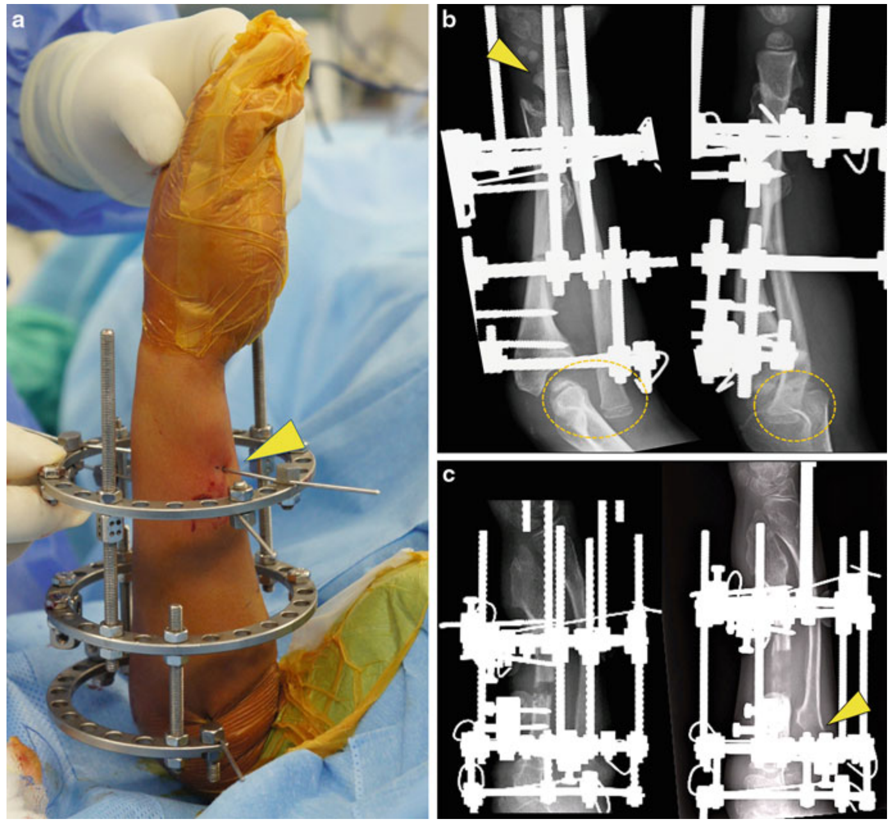

Fig. 4 (**a**) Fixation of the left forearm. *Yellow arrow* indicates tensioned wire that was fixed across both the proximal ulnar and radius. (**b**) Anterior-posterior and lateral radiographs of radial variant left wrist (*yellow arrow*) and dislocated radiocapitellar joint dislocation with proximal migration of radial head (*orange circles*). (**c**) Early stage of ulnar distraction and final stage of ulnar distraction. *Yellow arrow* showing distal migration of the radial head

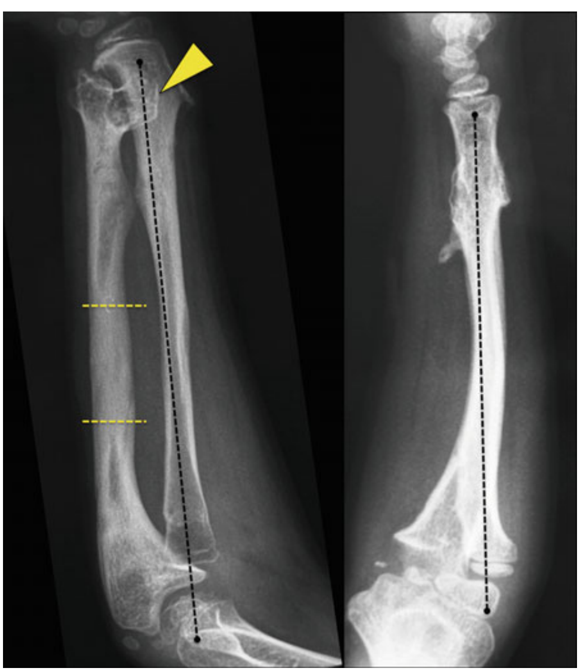

Fig. 5 Radiograph following the removal of the Ilizarov external fixator showing reduced radiocapitellar joint and improved distal radioulnar joint alignment. Distal ulnar exostosis has enlarged over the period of treatment and may have contributed toward reduced pronation at the end of treatment

8 Outcome Clinical Photos and Radiographs

See Figs. 5 and 6a–d.

9 Avoiding and Managing Problems

- Stiffness of the wrist and fingers: Aggressive physical therapy of the wrist and fingers is very important to avoid stiffness during ulnar lengthening.
- Corticotomy of the ulnar bone should be performed in the shaft to allow adequate bone for good quality fixation of the proximal and distal ulnar.
- The rate of gradual lengthening can be adjusted according to the rate of new bone formation, especially in children. This is to avoid premature consolidation or delayed healing.
- For severe deformities, changes in forearm pronation and supination are not predictable. Loss of motion maybe due to either change size of exostosis (Fig. 5) or change in the relationship between the radius and ulnar (following reduction of radiocapitellar dislocation).

Fig. 6 (**a**) Picture of both elbows in full extension. Left elbow swelling has resolved, and the right elbow has started to develop similar swelling on the lateral aspect. (**b**) Picture showing deterioration of right elbow flexion to 100° (from 135°), while the left elbow can be flexed to 120° (from 110°). (**c**) Picture showing a slight increase in right elbow pronation (30–45°) and decrease in elbow pronation (30–10°) probably due to the growth of distal ulnar exostosis. (**d**) Pictures of an elbow showing similar range of supination compared to before surgery (90° and 80° for the right and left sides, respectively)

10 Cross-References

- ▶ Case 93: Correction of Forearm by Corrective Radial Osteotomy and Ulnar Lengthening by Distraction Osteogenesis Deformity in Hereditary Multiple Osteochondromatosis
- ▶ Case 94: Correction of Forearm Deformities in Hereditary Multiple Exostosis (MHE)
- ▶ Case 96: Multiple Hereditary Exostoses: Forearm Deformities

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Case 96: Multiple Hereditary Exostoses: Forearm Deformities

Dror Paley and Craig A. Robbins

Contents

Abstract

Multiple hereditary exostoses (MHE) produces characteristic deformities of the forearm leading to problems at the wrist and elbow. Understanding the patho-anatomy allows one to correct all these deformities in a single or staged fashion. Two complementary cases, both in skeletally immature patients, are presented side by side to illustrate the scope of deformity and treatment.

1 Brief Clinical History

Case 1 is a 5 year old boy with osteochondromas affecting his right forearm. Though he has no pain, he had progressive bowing and limitation of his pronation. His radial head is located.

Case 2 is a 3 year old girl with osteochondromas affecting her right forearm. She has always had elbow deformity and limited motion. Though she has no pain, she had progressive bowing and loss of motion of the forearm. Her radial head is dislocated.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, and 5.

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Fig. 1 Case 1. Preoperative AP and lateral radiographs of right forearm. There is a solitary sessile large osteochondroma of the distal ulna. The ulna is shortened and bowed toward the concavity of the radial bow. The interossesous space is narrowed. The distal radial articular angle is increased. There is increased carpal slip with the lunate ulnar to the ulnar side of the radius. The radial head is starting to sublux. This is a Massuda I and Paley 2a: ulna short, radial head located

3 Preoperative Problem List

Case 1:

- Osteochondroma of the distal ulna
- Ulnar shortening
- Diaphyseal ulnar bow with loss of interosseous space
- Increased distal radial tilt
- Carpal slip
- Loss of pronation

Case 2:

- Osteochondromas of the distal ulna
- Ulnar shortening
- Diaphyseal ulnar bow with loss of interosseous space
- Radial head dislocation
- Valgus deformity of the radial neck

4 Treatment Strategy

Case 1:

- Resect distal ulnar osteochondroma
- Acutely correct radial tilt and carpal slip with distal radial osteotomy and internal fixation.
- Place proximal and distal ulnar fixator pin clusters perpendicular to their bone segment and acutely correct diaphyseal ulnar bow to increase interosseous space

Fig. 2 Case 1. Clinical photos in maximal supination and pronation; note the lack of pronation past neutral of the right arm

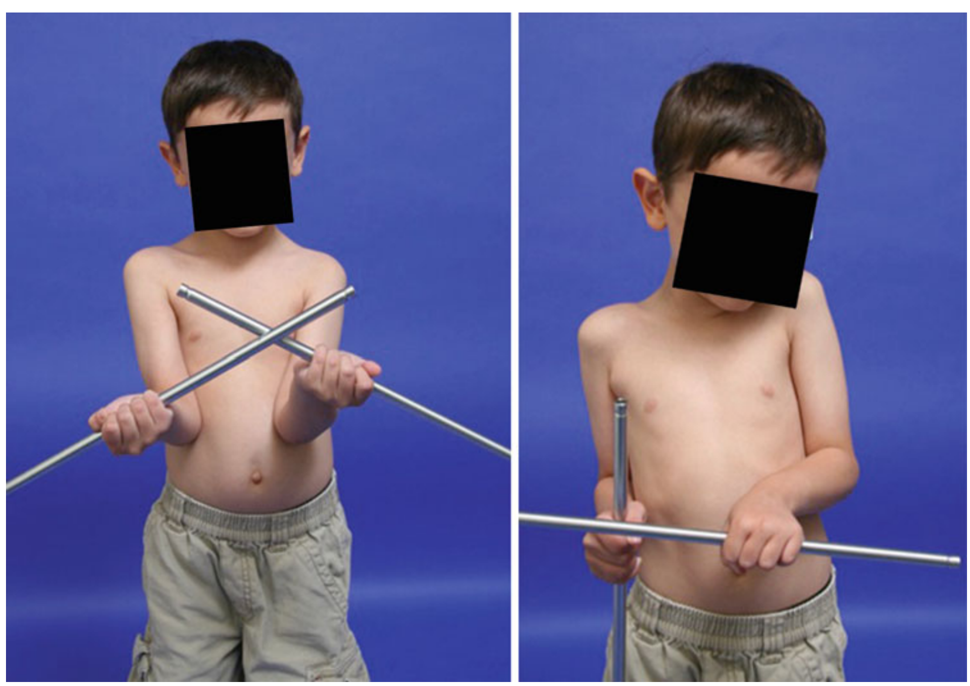


Fig. 3 Case 1. Clinical photo with elbows fully extended; note the supinated position of the right forearm; right radial head is located

Fig. 4 Case 2. Preoperative AP and lateral radiographs of right forearm. There is a large osteochondroma involving the distal ulna. The ulna is shortened and bowed. The radial neck is in valgus and the radial head is dislocated. This is a Masuda IIa and Paley 2b: ulna short, radial head dislocated

- Gradually lengthen ulna through osteotomy to transport ulnar head distally

Case 2:

Stage 1:

- Resect distal ulna osteochondroma
- Place proximal and distal ulnar fixator pin clusters perpendicular to their bone segment and acutely correct diaphyseal ulnar bow to increase interosseous space
- Gradually lengthen ulna through osteotomy to transport ulnar head distally
- Distally transport the entire radius through its interosseous membrane connection to the ulna as it lengthens or by adding a half pin distally between the radius and ulna

Stage 2:

- If the radial head does not spontaneously reduce after ulnar lengthening and radial transport, then plan for a staged reconstruction at the time of fixator removal. The radio-capitellar joint is opened to reduce the radial head

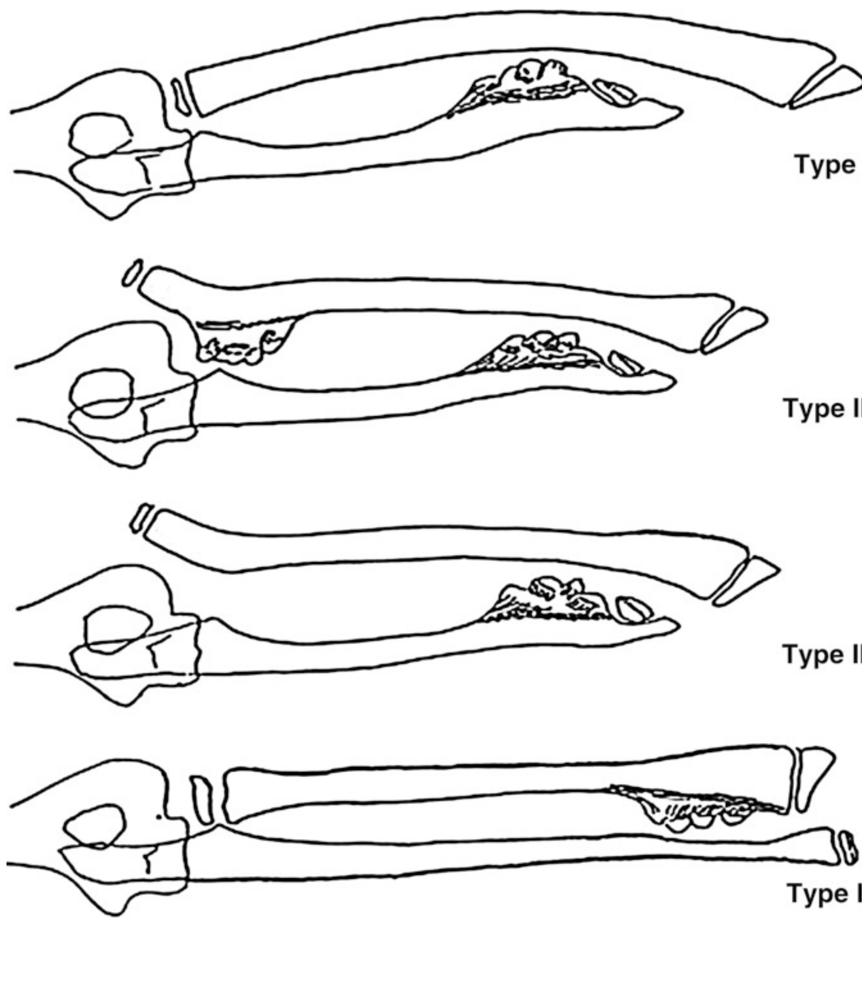
Fig. 5 Case 2. Clinical picture showing a marked forearm-elbow deformity due to the dislocation with proximal migration of the radial head

and reconstruct the ulnar collateral ligament complex and proximal radio-ulnar ligament. The radial nerve is always decompressed. Perform a varus osteotomy of radial neck if needed. Resect proximal radial and ulnar osteochondromas if present.

5 Basic Principles

Forearm osteochondromas can produce characteristic deformities of the forearm leading to problems at the wrist and elbow. Often there are multiple deformities and careful assessment of the proximal and distal radio-ulnar joints is imperative. An extensile approach is required to allow adequate tumor resection, neurovascular exposure, and acute deformity correction when needed. A consideration for a

Fig. 6 Masuda classification of MHE forearm deformity. Masuda I corresponds to a Paley 2a (short ulna, located radial head); Masuda IIa/b to a Paley 2b (short ulna, dislocated radial head); Masuda III to a Paley 1 (short radius). The Massuda classification is more specific to MHE



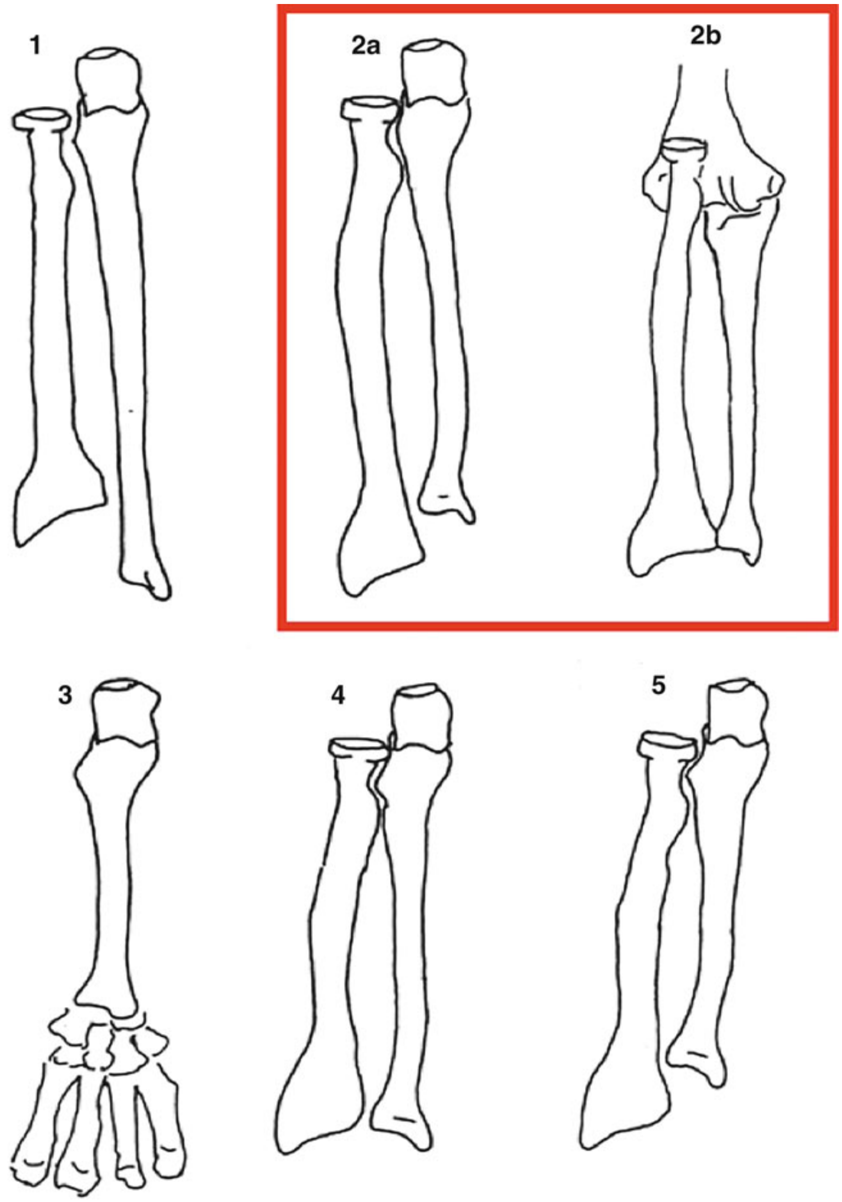


Fig. 7 Paley classification of forearm shortening. MHE most commonly leads to shortening of the ulna with and without dislocation of the radial head (Paley 2a and 2b)

bowed, shortened ulna is acute angular correction to restore the interosseous space then gradual lengthening with an external fixator. In some cases, the dislocated radial head will spontaneously reduce after the radius is transported distally. If not, consider a second staged procedure to reconstruct the elbow after the radial head has been transported distal to the capitellum. Place drains postoperatively at sites of tumor resection. Follow children closely through skeletal maturity.

The Masuda classification (Fig. 6) of forearm deformities in MHE overlaps with the Paley classification of forearm shortening (Fig. 7).

See Figs. 6, 7, and 8.

Fig. 8 Distal radial articular angle (*left*) (normal 15–30) and carpal slip (*right*) are measured to quantitate the distal deformity (Fogel et al. 1984)

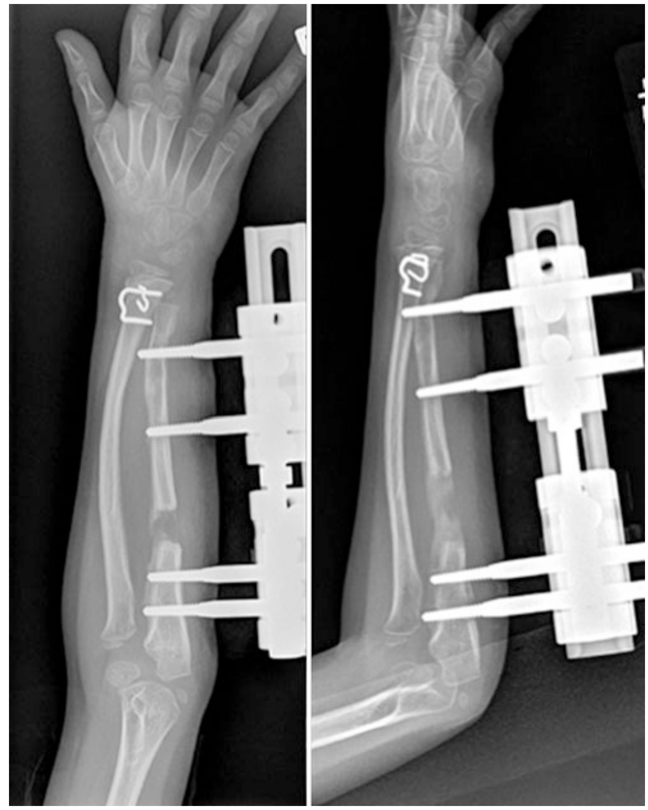


Fig. 9 Case 1. Postoperative X-rays at 3 weeks (*left*) and 6 weeks (*right*): a distal radial closing wedge osteotomy to correct the increased tilt was fixed with two staples. The ulnar bowing was corrected acutely. The ulna was lengthened through this osteotomy. The ulnar head was transported distally

6 Images During Treatment

See Figs. 9, 10, 11, and 12.

7 Technical Pearls

- Careful identification of preoperative deformities
- Formulate a reconstruction plan including possible staged surgeries
- Extensile approach
- Plan incisions and flaps to accommodate acute corrections
- Resection of osteochondromas
- Adequate nerve and fascial decompression
- Restore interosseous space
- Restore radial tilt and carpal slip
- Transport a dislocated radial head distally by either capturing the radius to the ulna with external fixator pins or by tethering to the ulna via the interosseous membrane
- Place drains at sites of tumor resection

8 Outcome Clinical Photos and Radiographs

See Figs. 13, 14, 15, 16, and 17.

9 Avoiding and Managing Problems

As with any deformity correction adequate preoperative planning and analysis are imperative. Extensile approaches allow for adequate tumor resection, exposure, and soft tissue decompression. Plan the incisions to accommodate for any acute corrections. Consider staged surgeries – for example to reduce the radial head after gradual transport of the radius. Place drains at sites of tumor resection to prevent hematoma. Anticipate postoperative swelling and decompress fascia and nerves as needed.

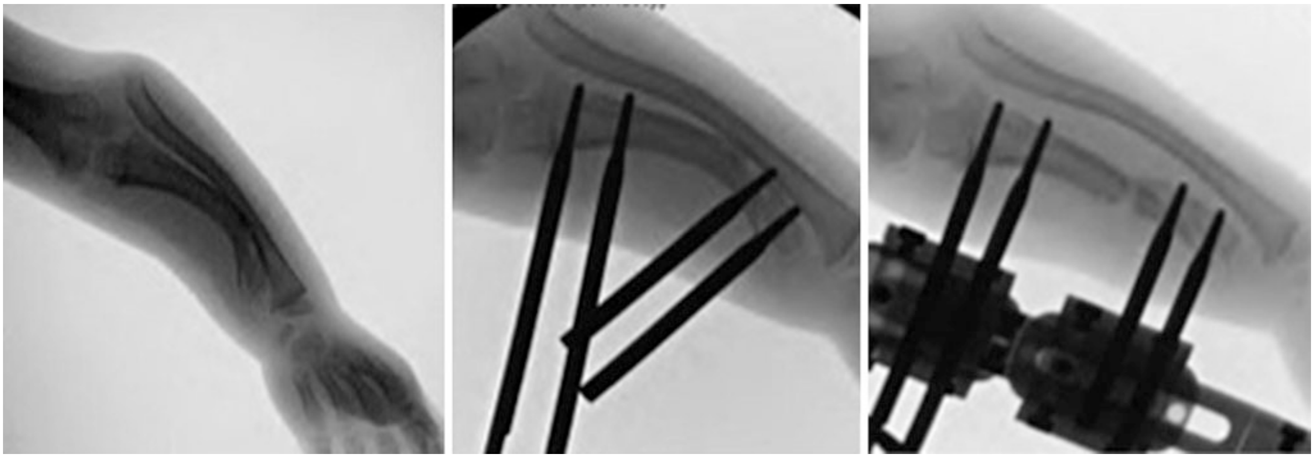


Fig. 10 Case 2. Intraoperative radiographs: Note the narrowing of the interosseous space due to the ulnar bowing (*left*). Placement of external fixation pins perpendicular to the proximal and distal segments of the ulna (*middle*). An osteotomy is made at the apex of the angulation and the deformity corrected acutely (*right*). Note the increase in interosseous space

Fig. 11 Case 2. X-ray 8 weeks after stage one surgery. As the ulna was lengthened, the entire radius was transported distally through the interosseous membrane. Note, however, the radial head remains dislocated

Fig. 12 Case 2. Postoperative X-ray after stage 2 surgery. The radio-capitellar joint was opened and the radial head reduced. Reconstruction of the ulnar collateral complex and the proximal radio-ulnar ligament was performed. The radial nerve was decompressed

Fig. 13 Case 1. AP and lateral X-rays several months after fixator removal

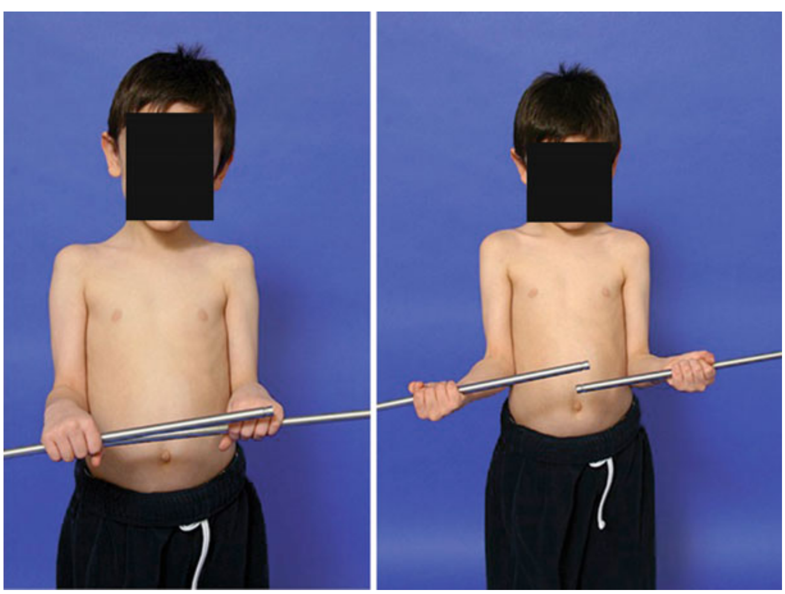


Fig. 14 Case 1. Clinical view in maximal pronation and supination after surgery; pronation of right forearm has increased to 80°

Fig. 15 Case 1. Clinical view in maximal wrist extension and flexion

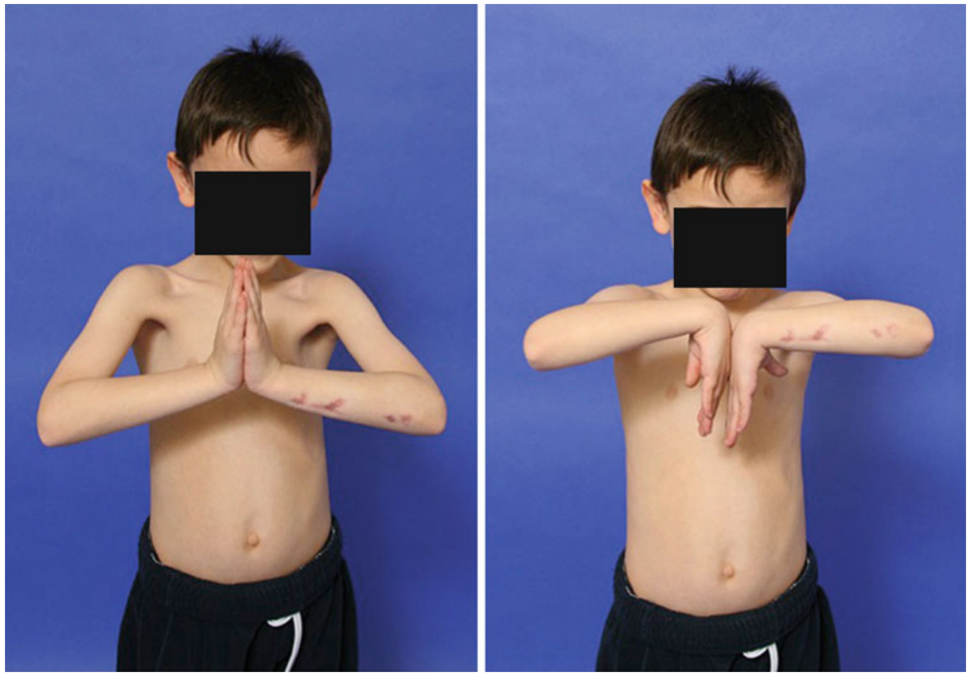


Fig. 16 Case 1. Five-year followup radiographs showing that some of the distal radial tilt has recurred. The ulna remains at the correct length relative to the radius. The radial head remains located

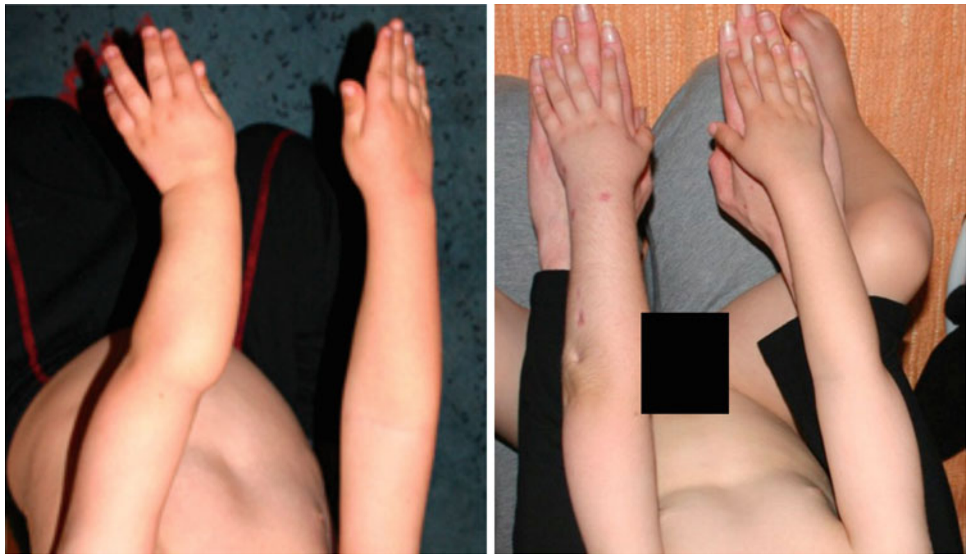


Fig. 17 Case 2. Clinical before (*left*) and after (*right*) photos of another child with a similar deformity and treatment

10 Cross-References

- ▶ Case 93: Correction of Forearm by Corrective Radial Osteotomy and Ulnar Lengthening by Distraction Osteogenesis Deformity in Hereditary Multiple Osteochondromatosis
- ▶ Case 94: Correction of Forearm Deformities in Hereditary Multiple Exostosis (MHE)

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Case 97: Forearm Deformity in a Fourteen-Year-Old Boy with Osteogenesis Imperfecta

Elizabeth Ashby, Reggie C. Hamdy, and François Fassier

Contents

Abstract

This is a case of severe deformity in the right forearm of a 14 year old boy with osteogenesis imperfecta type VI. Osteotomies of the radius and ulna were performed and stabilized with K-wires.

1 Brief Clinical History

A 14 year old wheelchair-bound boy with osteogenesis imperfect type VI presented with difficulty self-propelling his chair. Medical treatment with intravenous bisphosphonates had not been beneficial. Treatment was changed to subcutaneous denosumab which leads to an improvement in pain and bone density.

A left humeral deformity had been surgically corrected at the age of 10 years. The right forearm remained bowed with an angular deformity of over 60°. It is known that such a deformity leads to significant impairment in functional activities of daily living (Amako et al. 2004). It was therefore decided to proceed with surgical correction. This involved multiple osteotomies and insertion of K-wires into both the ulna and radius. The K-wire in the ulna migrated causing skin irritation and was removed 10 months later. One year after surgery the boy was self-propelling his wheelchair with relative ease.

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

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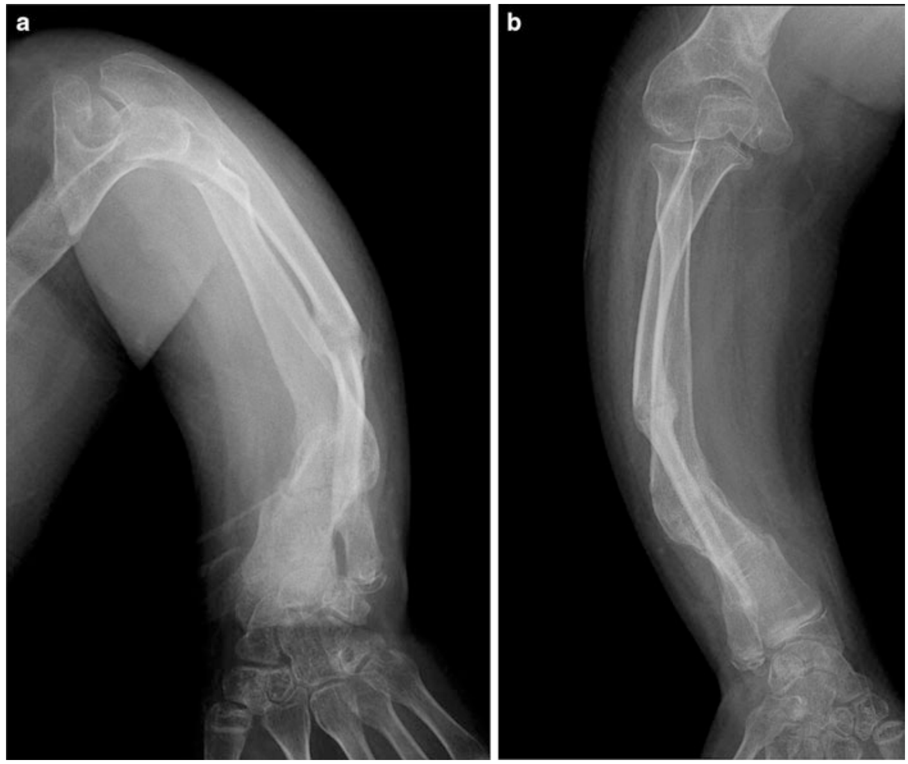

Fig. 1 (**a** and **b**) Anteroposterior and lateral radiographs of the deformed *right* forearm

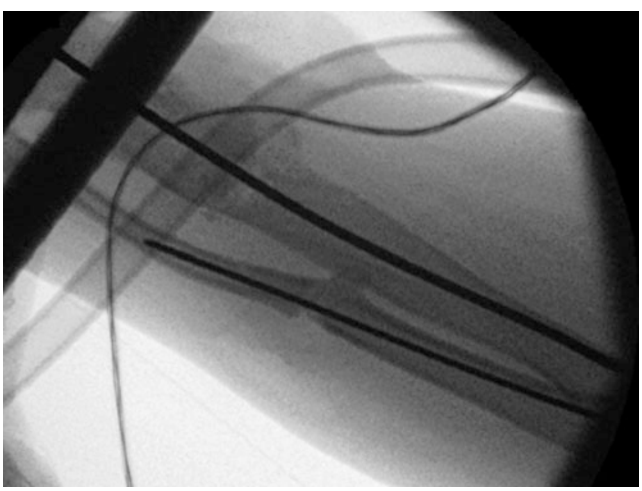

Fig. 2 The ulnar wire being inserted during surgery

3 Preoperative Problem List

1. There is severe deformity of the right radius and ulna. The deformity in both bones must be addressed simultaneously.
2. The bones are small and osteopenic.

4 Treatment Strategy

1. To stop medical treatment a minimum of 48 h before surgery and restart a minimum of 4 months after surgery.
2. To perform appropriate osteotomies and stabilize with K-wires. The bones are too narrow to insert the smallest telescopic Fassier-Duval rod (3.2 mm).
3. To maintain reasonable movement in the elbow and wrist by minimizing surgery involving the joints.

Fig. 3 (**a** and **b**) Immediate postoperative anteroposterior and lateral radiographs of the forearm with K-wires in situ

5 Basic Principles

The basic principles of this case are to correct deformity, maintain joint movement, and prevent further fracture in the future. This is achieved in the following ways:

1. Perform all manipulations gently.
2. Perform as many osteotomies as necessary to ensure the forearm is straight.
3. The elbow and wrist joints are not breeched during surgery. This prevents iatrogenic joint damage and helps maintain movement postoperatively.
4. Minimize postoperative immobilization (4 weeks in this case). Intensive physiotherapy follows.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

1. Do not use an Esmarch. It could cause fractures.
2. Use a tourniquet to reduce blood loss and facilitate surgery.
3. Use bone clamps judiciously. They can create further fractures.
4. Insert the K-wire into the distal radius through the styloid process. Advance the wire until deformity prevents further progression. Perform an osteotomy of the radius at this level. An ulna osteotomy will be necessary to allow manipulation of the radius and advancement of the K-wire across the radial osteotomy site. Advance the K-wire until deformity prevents further progression. Perform an osteotomy at this site. Continue in this fashion until the K-wire reaches the proximal radial physis. Once a K-wire is present along the entire length of the radius, insert another into the ulna either through the posterior aspect of olecranon or through the proximal metaphysis. Advance the K-wire and perform further osteotomies as needed until the wire reaches the distal ulnar physis.

8 Outcome Clinical Photos and Radiographs

See Figs. 3 and 4.

Fig. 4 (**a** and **b**) Radiographs 1 year following surgery after removal of the ulnar K-wire. All osteotomy sites are fully healed

9 Avoiding and Managing Problems

1. Avoid giving bisphosphonate treatment until osteotomy sites have healed. We usually allow bisphosphonate treatment 4 months following surgery providing radiographic evidence of bone healing is satisfactory.
2. Perform open osteotomies (not percutaneous) to ensure nerves are not injured.

10 See Also in Vol. 1

Case 85: Eleven Year Old Child with Osteogenesis Imperfecta Type III and Multiple Severe Deformities, Treated with Telescoping Fassier-Duval Rods
Case 87: Revision of Bilateral Tibial Fassier-Duval Rods in an Eleven Year Old Girl with Osteogenesis Imperfecta

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Part XVII

Upper Extremity: Hand

Case 98: Bilateral Metacarpal Lengthening for Congenital Brachymetcarpia

S. Robert Rozbruch

Contents

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Abstract

This is a case illustrating bilateral congenital shortening of the 4th metacarpal. Lengthening was successfully accomplished using a mini-rail fixator.

1 Brief Clinical History

The patient is a 30 year old female who has congenital bilateral 4th brachymetacarpia. She had normal ROM of her wrist and fingers. She was embarrassed by the appearance of her hands.

Fig. 1 Front view of the left hand showing shortening of the 4th finger

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2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

Fig. 2 When in a fist position, the absence of the knuckle (*arrow*) and the metacarpal shortening is apparent

3 Preoperative Problem List

1. Congenital shortening of bilateral 4th metacarpals.
2. Starting bone length is short.
3. Lengthening need is approximately 50 % of starting bone length.
4. Concerns for abnormal joint loading, function, grip strength, discomfort, and aesthetics of the hand.

4 Treatment Strategy

1. Approach left side first. Avoid bilateral hand surgery.
2. Application of mini-rail fixator (Orthofix) with small diameter threaded half-pins.
3. Staged treatment of the right hand.

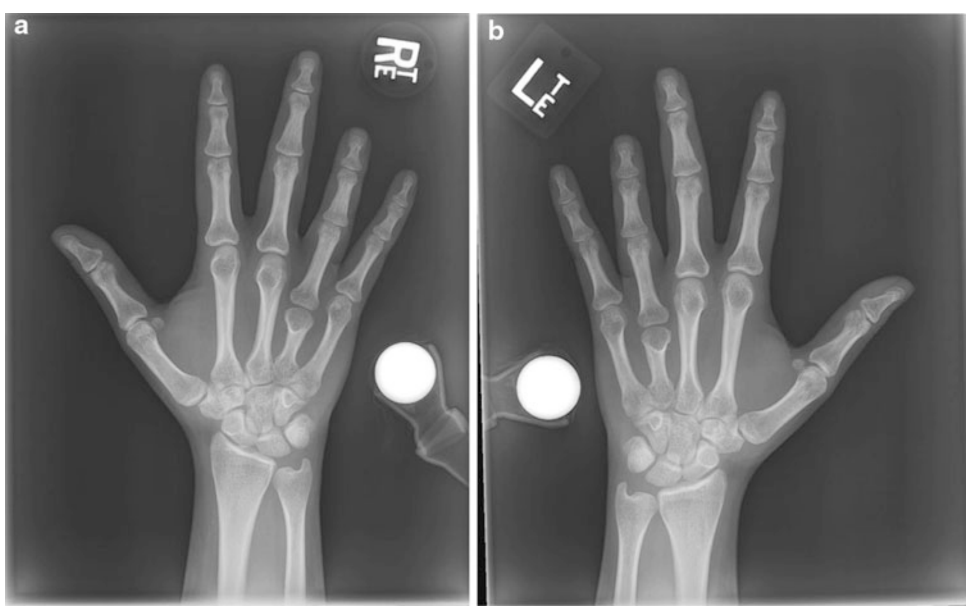
5 Basic Principles

1. The monolateral fixator must be aligned parallel to the bone that will be lengthened.
2. Small diameter half-pins are needed
3. With lengthening of the metacarpal, the expected stiffness is a decrease in MCP flexion.

6 Images During Treatment

See Figs. 4, 5, 6, 7, and 8.

Fig. 3 (**a**, **b**) AP X-rays of both hands showing bilateral 4th metacarpal shortening of about 13 mm (magnification marker is 25.4 mm or 1 in.)



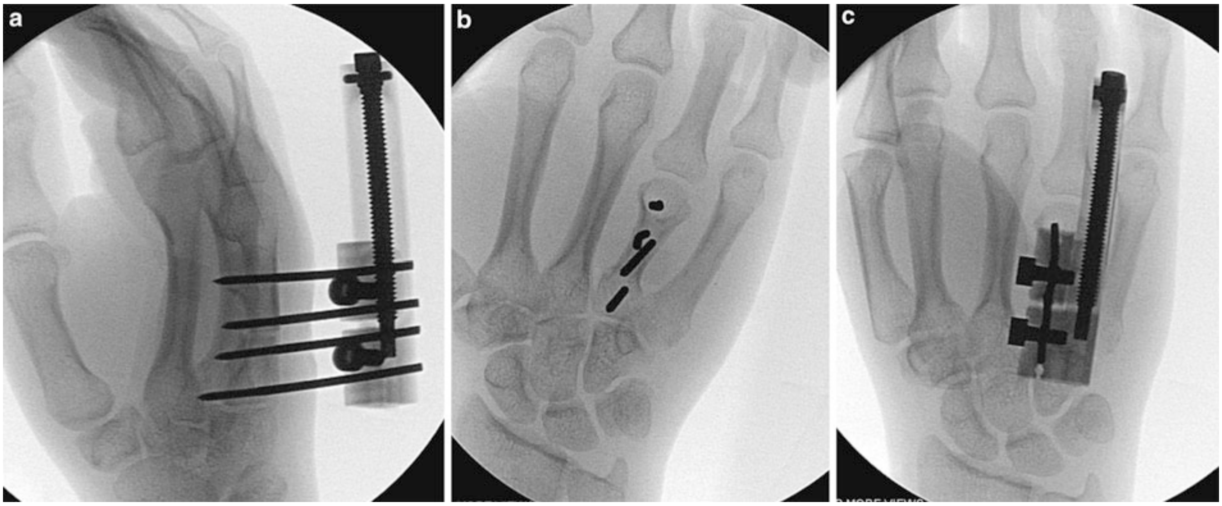


Fig. 4 Intraoperative fluoroscopy images (**a**) lateral of the metacarpal showing the rail parallel to the bone; (**b**) AP view showing 4 pins, 1.8 mm in diameter, in the metacarpal; (**c**) AP view showing the rail parallel to the bone. Note that the rail is set at its minimum length and the space between the proximal and distal pin clusters is very small

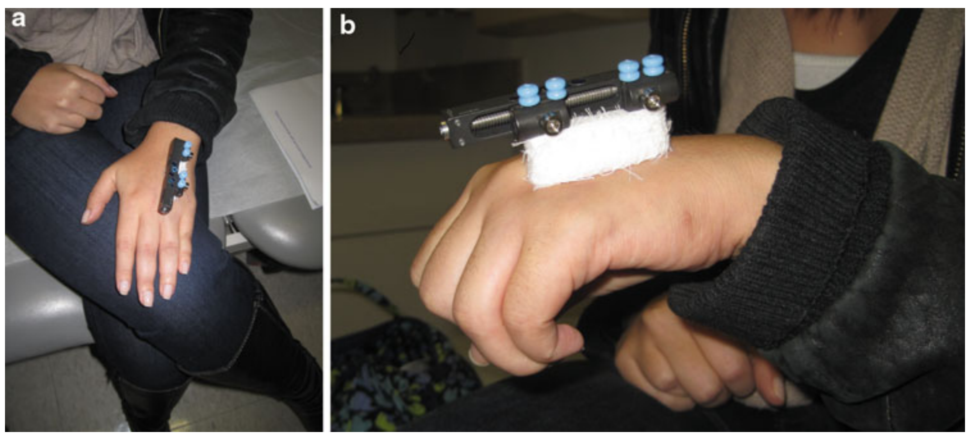


Fig. 5 During the consolidation phase after left fourth metacarpal lengthening, (**a**) optimal length has been achieved; (**b**) side view showing temporary maximum flexion of the fourth metacarpophalangeal (MCP) joint

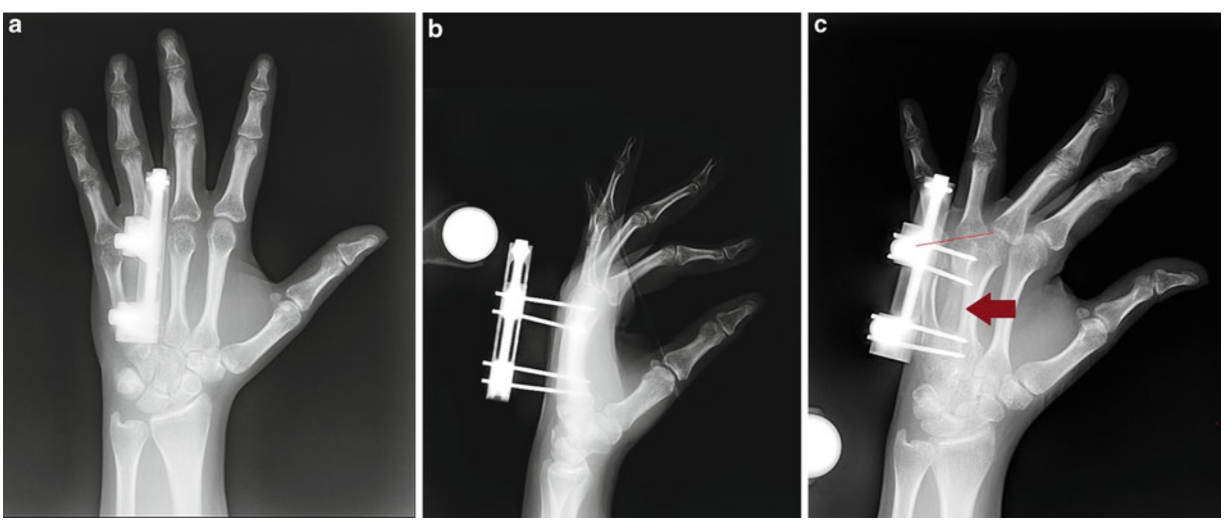


Fig. 6 (**a**–**c**) AP, lateral, and oblique X-rays of the left hand during the consolidation phase. Note that the bone is best visualized on the oblique (**c**) view (*arrow*). The line shows the restoration of the metacarpal length in relation to the 3rd and 5th metacarpal heads

Fig. 7 Front view during the consolidation phase after right metacarpal lengthening. The left side is complete

Fig. 8 Oblique view of the right hand during the consolidation phase showing the restoration of metacarpal length and the progression of bone healing. Fifty percent bone lengthening has been accomplished

7 Technical Pearls

1. Use small diameter half-pins. In this case, 1.8 mm self-drilling half-pins were used.
2. Since the bone that will be lengthened is short, preoperative templating is needed to see if the shortest setting on the rail will fit the bone.
3. First pin placed is the most proximal pin. The pin is centered on the bone and directed from dorsal to palmar, perpendicular to the bone axis.
4. The second pin is the most distal pin. The frame is applied to the proximal pin and the frame is used as a guide to insert the distal pin. These two pins are parallel to each other.
5. These two pins establish the orientation of the frame. The frame should be parallel to the bone.
6. The frame is used as a guide to insert a second pin in the proximal clamp and in the distal clamp.
7. The osteotomy is performed after the pins have been inserted and the frame has been removed. A 1 cm incision is made along the dorsolateral aspect of the 4th metacarpal. A multiple drill-hole osteotomy is performed using a 1.6 mm wire to drill holes and a 3 mm osteotome. The frame is applied stabilizing the osteotomy in the non-displaced position.

8 Outcome Clinical Photos and Radiographs

See Figs. 9 and 10.

9 Avoiding and Managing Problems

1. Avoid impaling the extensor tendon. Make sure the MCP joint can be flexed after each pin insertion.
2. The osteotomy is performed between the second and third pins in a very small space. It is important to avoid propagation of the osteotomy into an adjacent pin site. The osteotomy is done under direct visualization.
3. MCP stiffness is avoided by prescribing an aggressive and regular exercise regimen focused in MCP flexion.
4. A resting splint may be made to flex the proximal phalanx.
5. Distraction is performed slowly on small bones to avoid poor bone formation. The rate was 1/8 mm four times per day for a total of ½ mm per day of distraction.

Fig. 9 (**a**–**d**) Two months after removal of the right hand frame, the patient demonstrates excellent function and ROM of hand

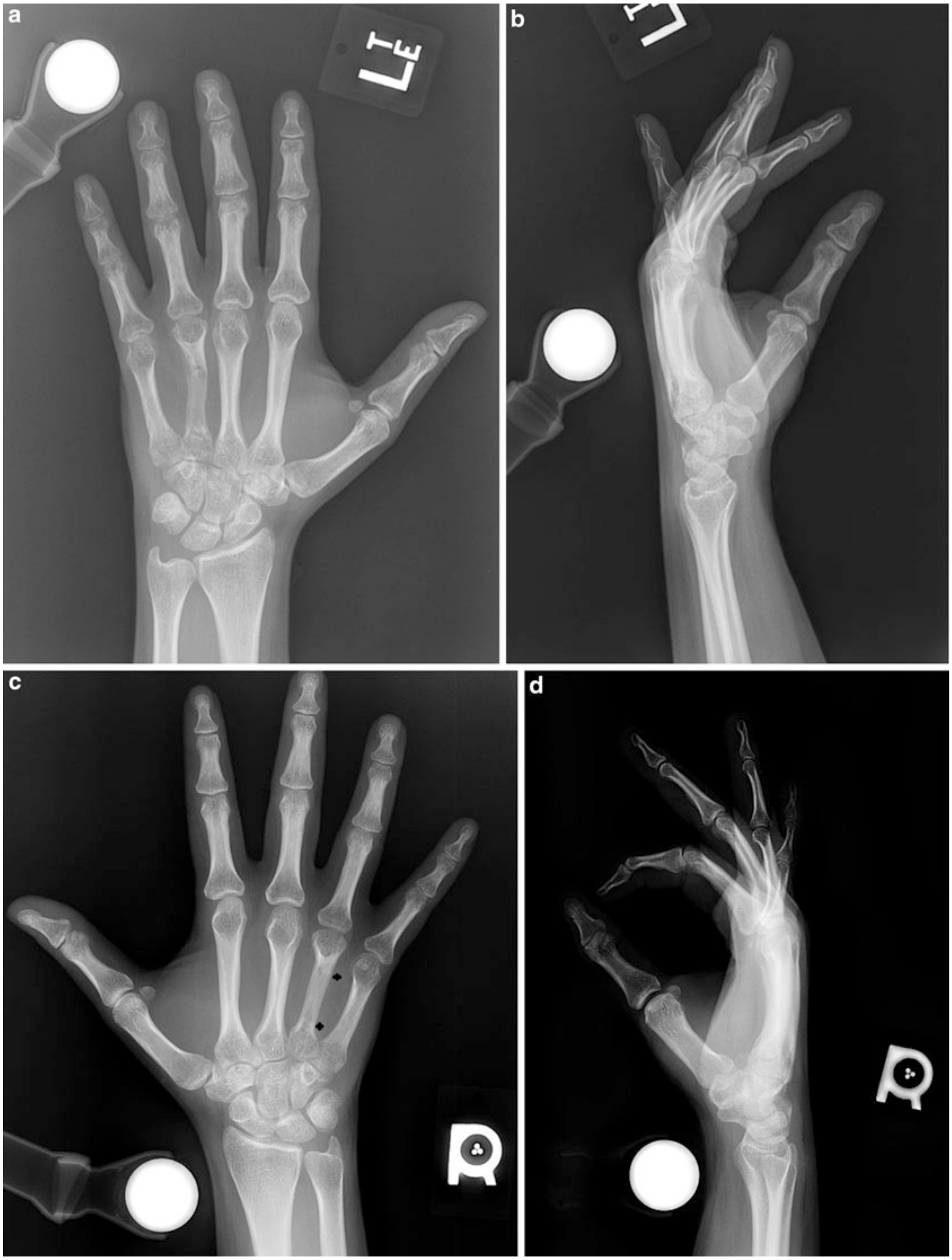


Fig. 10 (**a–d**) AP and lateral X-rays of both hands showing bone union, restoration of 4th metacarpal lengths, and satisfactory alignment. Note the healed regenerate bone is bordered by two *black stars* in (**c**)

10 See Also in Vol. 2

Case 79: Brachymetatarsia: Distraction Osteogenesis
Case 80: Metatarsal Lengthening

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Part XVIII

Upper Extremity: Upper Extremity Trauma

Case 99: Mangled Upper Extremity Salvaged with Spatial Frame, Skin Grafts, Radial Lengthening, and Wrist Fusion

Daniel Schlatterer

Contents

Abstract

A 24 year old male sustained a mangled right upper extremity after ejection from his motor vehicle. He was found unconscious in a ravine 8 h after a short drive to a friend's house. He presented with a grossly contaminated (bugs reportedly in the wound) both bone forearm fracture. The distal 6 cm of his ulna was missing as was the ulnar artery and nerve at this level. Four debridements were completed in the first 8 days of admission. All extensor tendons except to the thumb were irreparable, and a nonviable 6 cm segment of the distal radial shaft required removal. The articular distal radius was intact. Limb reconstruction began with spatial frame application, an acute shortening of the forearm bony and soft tissues, and an osteotomy of the proximal radius. The radius was lengthened 3.5 cm to fill the distal segmental defect. The spatial frame gradually lengthened the forearm. Six months later a dorsal wrist fusion plate replaced the spatial frame. At this operative setting, the extensor carpi radialis longus (ECRL) and brevis (ECRB) tendons were wrapped around the distal ulna to limit its translation. The patient has made various adaptive devices to continue activities such as playing the drums. At all stages of treatment a below the elbow amputation was discussed. The patient is very satisfied that during his weeks of intubation and sedation, limb salvage was pursued. He has no plans for an amputation. The initial aggressive debridements and negative pressure wound therapy enabled progression to the limb reconstruction phase.

1 Brief Clinical History

This is a healthy 24 year old male who sustained a mangled upper extremity after a motor vehicle accident. He sustained extensive soft tissue and bone loss. Upon presentation it

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Fig. 1 (**a**) Forearm radiograph on day of injury. (**b**) Intraoperative photograph demonstrating extensive soft tissue and bone involvement. (**c**) Intraoperative photograph corresponding to (**b**), volar view

appeared as if a below the elbow amputation was his only option (Fig. 1a–c). He underwent an emergent debridement and irrigation (Fig. 2a, b). The goals were to treat his contaminated and compromised arm and to further assess limb salvage capability. His initial 2 weeks in the hospital were complicated by being intubated and sedated. Family members had to make decisions regarding limb salvage and numerous further surgeries. His wrist was acutely shortened to facilitate soft tissue closure (Fig. 3a, b). Split thickness skin grafting was required in areas of full thickness dermal loss. Limb reconstruction continued over the next 6 months. The extensor carpi radialis longus (ECRL) and brevis (ECRB) tendons were wrapped around the distal ulna to limit its translation, and the carpus was stabilized with a wrist fusion. The patient has made various adaptive devices to continue activities such as playing the drums (Fig. 6c). He enjoys driving his car with this arm (Fig. 6d) among other activities and has no plans for an amputation.

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

1. Mangled forearm and wrist.
2. Grossly contaminated open forearm fractures.
3. Ulnar artery and nerve disruption at wrist level.
   A. Single vessel to hand limits flap coverage options if needed.
4. Segmental loss of distal radius and entire distal ulna after debridements.
   A. Long-term stability of wrist is a concern with distal ulna missing.
5. Loss of all extensor tendons except to thumb.

4 Treatment Strategy

Treatment of mangled extremities can be divided into two broad categories. First is limb salvage. This requires an emergent debridement but also an aggressive debridement to minimize infection risk (Fig. 2a, b). Vascular status requires assessment and intervention as needed. Serial debridements and negative pressure wound therapy facilitate progression into the limb reconstruction phase. Our strategy

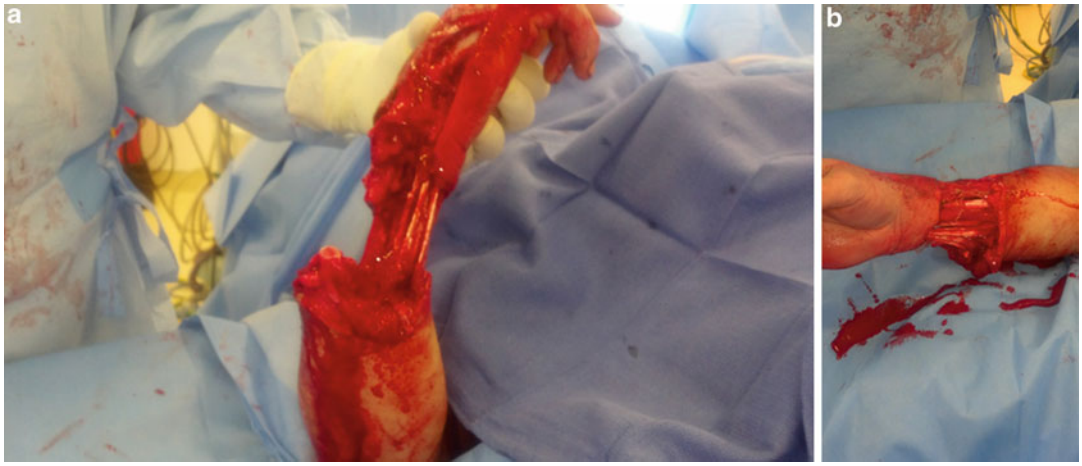

Fig. 2 (**a**) Intraoperative photograph after first debridement (same day of injury). (**b**) Intraoperative photograph corresponding to (**a**)

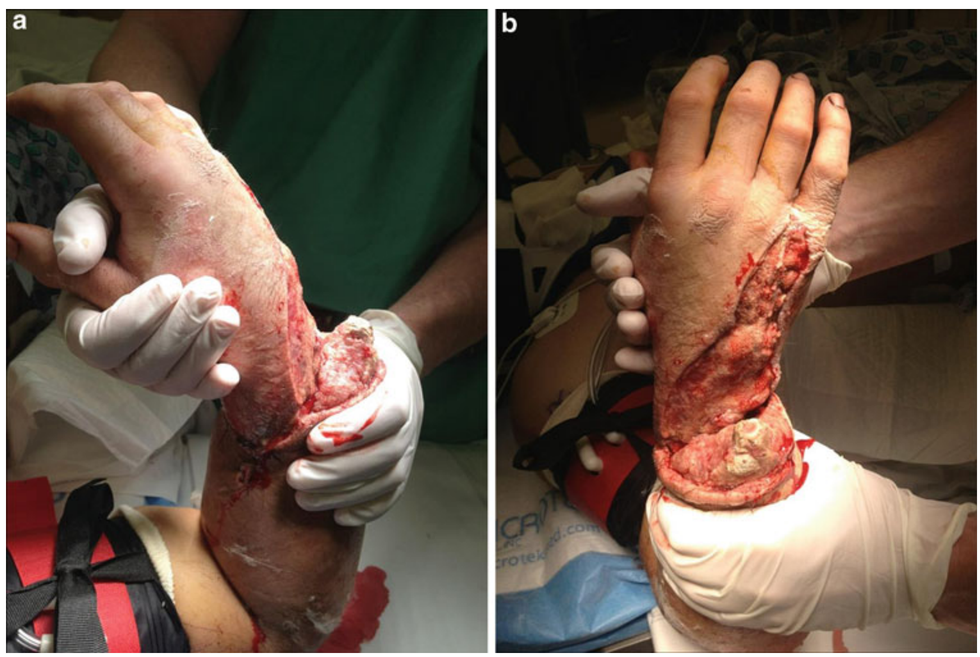

Fig. 3 (**a**) Intraoperative photograph 3 days after injury. Volar wrist skin sutured closed 2 days prior, negative pressure wound therapy to dorsal wrist for 3 days. (**b**) Intraoperative photograph corresponding to (**a**)

was to get through the first phase without infection. Then all other issues including bone loss and tendon issues and so forth would be dealt with going forward. The spatial frame was selected to treat the complex bone injuries because it allowed lengthening of the radius and correction of the forearm without internal fixation.

5 Basic Principles

Closure and coverage of the bone was the first priority after the debridements. The limb was shortened acutely and skin grafted to facilitate wound closure (Fig. 3a, b). The radial osteotomy (Fig. 4b) followed standard principles of waiting 7–10 days before initiating distraction. The lengthening progressed at 1 mm per day. The distracted radial segment was easily controlled with two half pins in the radius and attached to a single threaded rod. The threaded rod was attached to the proximal ring only (Fig. 5a, b).

6 Images During Treatment

See Figs. 4 and 5.

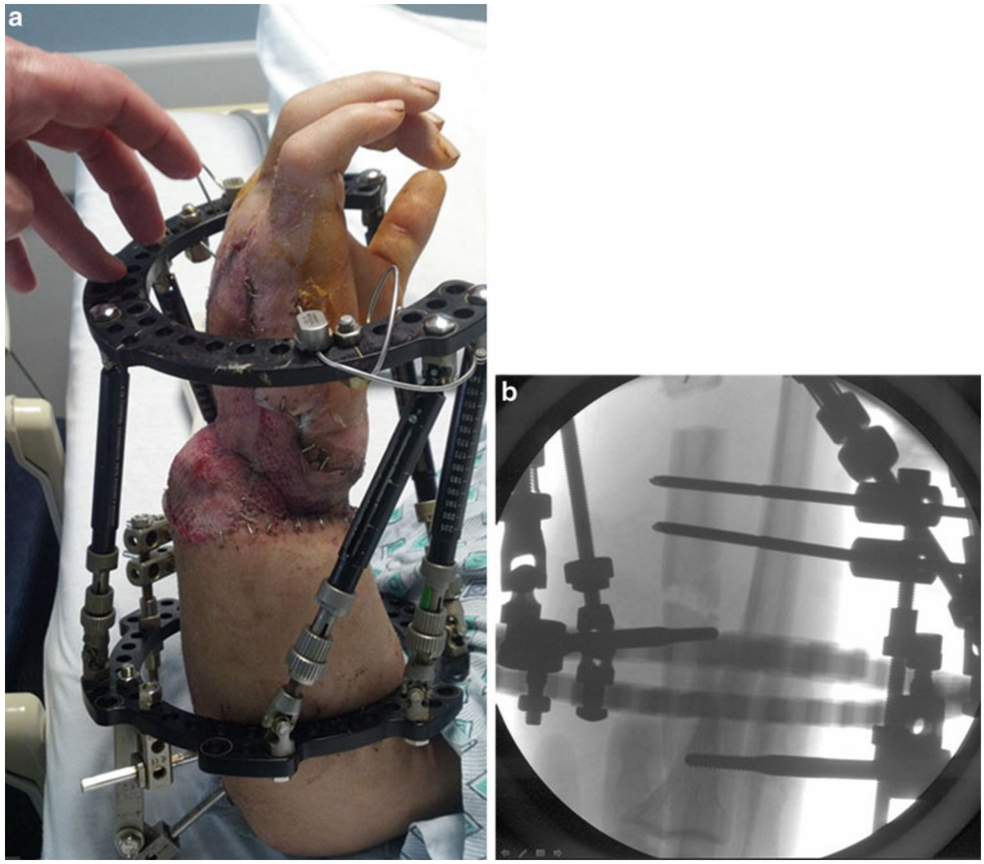

Fig. 4 (**a**) Clinical photograph after spatial framed application on post-injury day #12. (**b**) Intraoperative fluoroscopy image demonstrating proximal radius osteotomy. Two half pins in the radius were attached to a threaded rod. The rod was distracted by 4-point D/C counters (See clinical pictures in Fig. 5a, b. The radial osteotomy was performed on post-injury day #15)

Fig. 5 (**a**) Clinical photograph after distraction of forearm. Note the threaded rod attached to the proximal ring and attached to the radius with two half pins. Two 4-point D/C counters drive the threaded rod and the radial lengthening. (**b**) Clinical photograph corresponding to (**a**) (See Fig. 4b for radiographic appearance of radial osteotomy)

Fig. 6 (**a**) Final radiograph after wrist fusion with 18-hole plate. Ulna has been secured with tendon sling. (**b**) Final radiograph corresponding to (**a**). (**c**) Clinical photograph of patient using adaptive equipment to play the drums. (**d**) Clinical photograph of patient driving a car with a manual transmission (stick shift)

7 Technical Pearls

The spatial frame in this case had struts which are easily adjusted by the patient. A software program generates a prescription for the patient to follow at home. One of the most challenging aspects of this case was accurately inputting the mounting parameters of the spatial frame. Weekly office visits were necessary early on and frequent prescription changes were required. Early on the frame was not correcting as planned. Several times the mounting parameters were changed but with little benefit. Finally the mounting parameters were left as is, and if the correction was not in the direction planned, for example, correction of an ulnar apex deformity, then the “deformity” was changed on the computer to apex radial. With this strategy and some trial and error, the correction progressed as planned. During the course of treatment, the ulna remained prominent due to the disruption distally of the distal radial ulnar joint and other structures. The wrist fusion procedure was indicated to stabilize the wrist and prevent carpal subluxation. This permitted harvesting of the ECRL and ECRB tendons to limit ulnar translation. In Fig. 6b a tunnel in the ulna can be seen. The tendons were passed through the ulna at this level.

8 Outcome Clinical Photos and Radiographs

See Fig. 6.

9 Avoiding and Managing Problems

An infection was the biggest problem that could have occurred. Infection was avoided with repeated and aggressive debridements. It was also avoided by using external fixation. The wrist fusion procedure 6 months after injury was successful in part because the soft tissues had recovered. This patient did however require a short course of antibiotics early on for pin site erythema. Further pin care consisted of soaking the entire arm in a kitchen garbage can filled with warm water and two capfuls each of Clorox bleach and Epson salt. Soakings lasted 20 min 2–3 times per week. Daily showering was encouraged. A final problem worth mentioning is follow-up radiographs. Making measurements on radiographs in the office can be difficult due to fixator parts overlapping the deformity. This can be circumvented by adding a temporary method of fixation with a strut or threaded rod and removing a strut or two for imaging purposes. In addition, removing a single strut without temporary fixation for imaging purposes did not result in loss of limb position in this case. Record the strut settings and return them to those same positions after the radiograph. These methods will improve the correction process.

10 Cross-References

- ▶ Case 101: Mangled Upper Extremity Salvaged with Spatial Frame, Skin Grafts, Wrist Fusion and Transfer of FCR to EDC

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Case 100: Reconstruction of the Elbow After Gunshot Injury with Dynamic Articulated Frame

León Gonzalo Mora Herrera

Contents

Abstract

War injuries by high velocity weapons in the upper limb can cause major functional damage and permanent loss of mobility, especially in the elbow and forearm. Immediate and appropriate management of soft tissues and stabilization of tissues and joints can prevent comprehensive loss of function. Current techniques using articulated external fixators in the elbow associated with immediate mobility and skin coverage, combined with acute shortening techniques, avoid undesirable complications and permanent sequelae. More than just the management of open fractures, the application of techniques for early mobility and joint stability are also required, along with judicious use of external fixation and immediate coverage of soft tissues.

1 Brief Clinical History

A 26 year old soldier, with high velocity gunshot wounds, from an AK47 rifle, presented to the emergency room 12 h post-injury with segmental loss of bone and soft tissue in the forearm, a completely unstable elbow bone injury, and soft tissue defect.

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Fig. 1 Bone loss – open, contaminated, comminuted elbow fracture

Fig. 2 Comminuted compound fracture in the distal third of the ulna and radius

Fig. 3 Bone and soft tissues loss in the elbow, with exposed articular surface

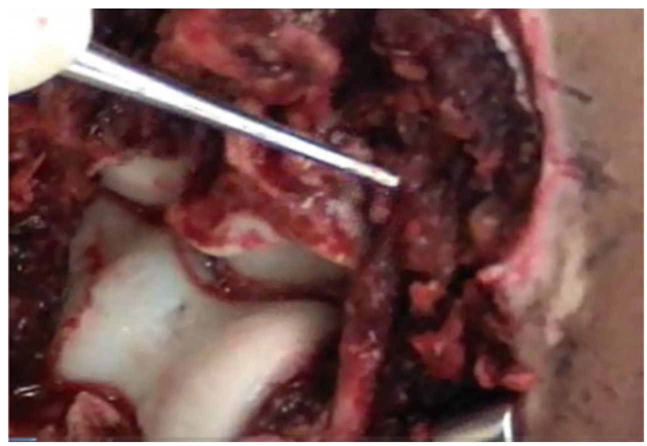

Fig. 4 Ulnar nerve edema and hematoma

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, 4, 5, 6, and 7.

3 Preoperative Problem List

– Severe trauma to soft tissues of the forearm with bone loss; elbow articular surface involved
– Massive contamination of wounds and delayed arrival at the hospital
– Segmental fracture with short, comminuted bone fragments and elbow instability

Fig. 5 Complex upper limb injury, with high risk of infection and amputation

Fig. 6 Multiple tendon and muscle trauma, and transection of the radial artery

Fig. 7 Forehand and elbow fracture instability

4 Treatment Strategy

- Immediate damage control
- Tertiary level multidisciplinary trauma team
- Combination of internal and external fixation techniques

5 Basic Principles

- Stabilization of bone and soft tissues
- IV antibiotics
- Use of articulated external fixator to control elbow stability while maintaining motion

Fig. 8 Soft tissues stability – Monofilament sutures without tension

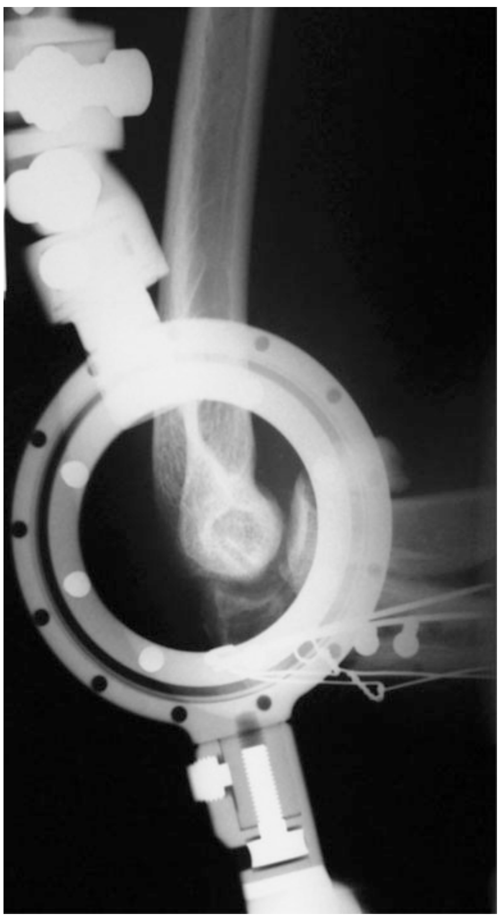

Fig. 9 Elbow hinged external fixator positioned over the center of rotation of the joint

Fig. 10 Minimally invasive external fixation and dynamic stability. Low profile internal fixation

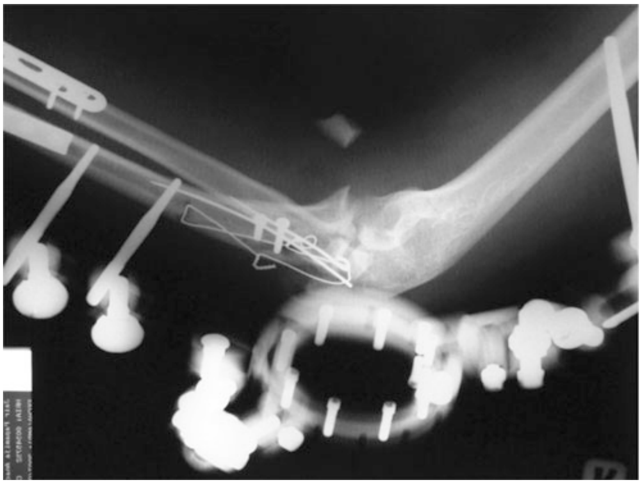

Fig. 11 Elbow stability maintained by external fixator. Minimally invasive osteosynthesis

Fig. 12 Combination of external and internal fixation

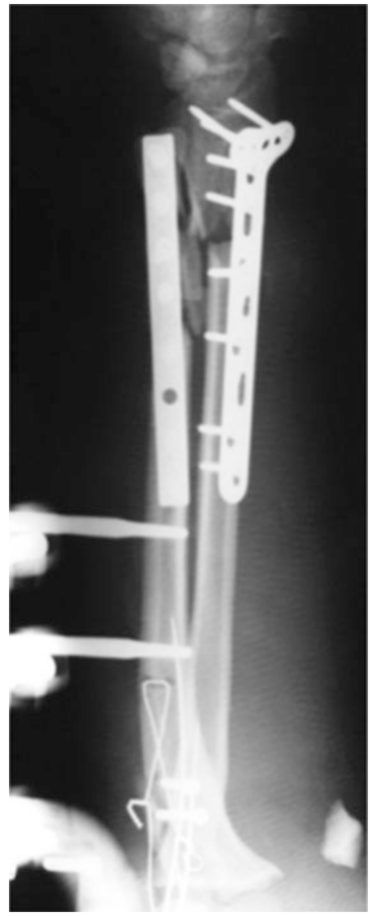

Fig. 13 Forearm plate osteosynthesis and acute shortening

Fig. 14 Immediate physiotherapy and dynamic stability. Passive flexion

Fig. 15 Passive extension

Fig. 17 Functional rehabilitation of soft tissue while maintaining limb alignment

Fig. 16 Comprehensive rehabilitation of shoulder, elbow, and wrist

6 Images During Treatment

See Figs. 8, 9, 10, and 11.

7 Technical Pearls

- Prompt articular surface reconstruction
- Early skin coverage plan – Acute shortening in the forehand and regional fasciocutaneous rotational flap in the elbow (Fig. 8)
- Early MIO (minimally invasive osteosynthesis) combined with articulated external fixation

8 Outcome Clinical Photos and Radiographs (postoperative)

See Figs. 12, 13, 14, 15, 16, 17, 18, and 19.

9 Avoiding and Managing Problems

- Immediate elbow stability and movement of articular surfaces
- Articulated external fixator aligned to the elbow center of rotation
- Early total bone and soft tissues stability with movement

10 Cross-References

▶ Case 99: Mangled Upper Extremity Salvaged with Spatial Frame, Skin Grafts, Radial Lengthening, and Wrist Fusion
▶ Case 101: Mangled Upper Extremity Salvaged with Spatial Frame, Skin Grafts, Wrist Fusion and Transfer of FCR to EDC

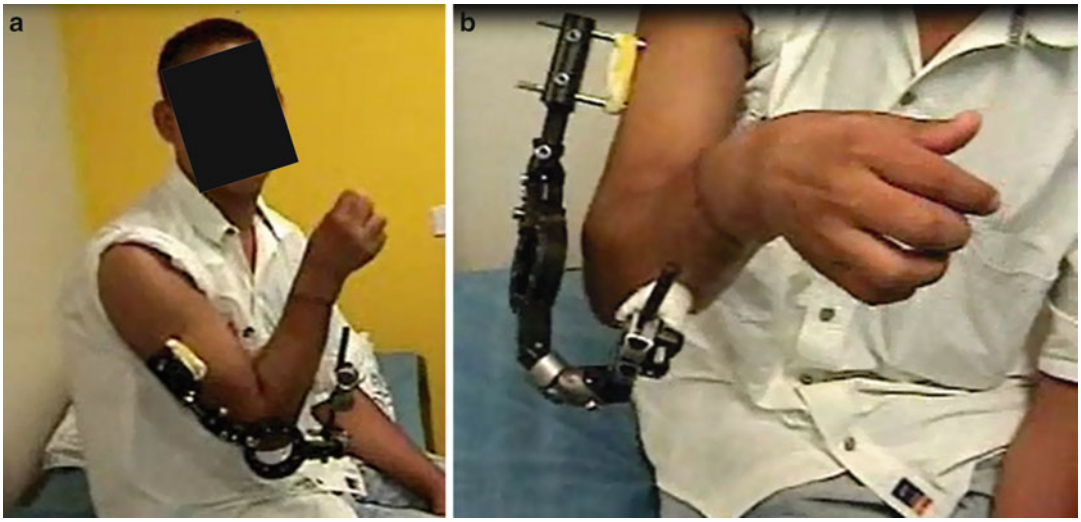

Fig. 18 (**a**, **b**) External fixator alignment

Fig. 19 (**a**, **b**) Final soft tissues recover and functional movement 60–170°

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Case 101: Mangled Upper Extremity Salvaged with Spatial Frame, Skin Grafts, Wrist Fusion and Transfer of FCR to EDC

Daniel Schlatterer

Contents

Abstract

An 18 year old male sustained a mangled upper extremity after a motor vehicle collision. The injuries to his forearm included open fractures with bone loss to the radius and ulna, two areas of full-thickness dermal loss, and irreparable damage to all extensor tendons except to the thumb. A large area of skin degloving was present circumferentially. All arterial flow through the forearm and into the hand was intact on an angiographic study. The ulnar nerve had a segmental defect in the mid-forearm of 4 centimeters (cm). Treatment consisted of three debridements in the first 5 days followed by wound closure and skin grafting. For 6 weeks, no attempt was made to stabilize the fractures with either internal or external fixation. Infection risk was deemed to be too high. A Taylor spatial frame (TSF) corrected the forearm alignment over a course of 8 weeks. Open reduction and internal fixation of the radius and wrist fusion was performed with a long 18-hole plate. Transfer of flexor carpi radialis to the finger extensors was the final part of the procedure at the time of fixation. The patient has returned to school, and he has regained functional use of his hand.

1 Brief Clinical History

This is a healthy 18 year old male who sustained complex injuries to his dominant forearm. He had an emergent debridement at an outside facility and then transferred to our institution a day later. Serial debridements were required as the wound continued to declare itself over the next several days. Wound closure and skin grafting were the focus of the next stage of treatment. The soft tissues improved over the next 6 weeks at which time the fractures and deformity were addressed with a spatial frame. The final procedure was internal fixation of the radius and a wrist fusion procedure. A flexor tendon transfer procedure restored finger extension.

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Fig. 1 (**a**) Anteroposterior (AP) forearm radiograph. Patient was referred to our institution 1 day after a debridement elsewhere. (**b**) Lateral radiograph corresponding to figure (**a**)

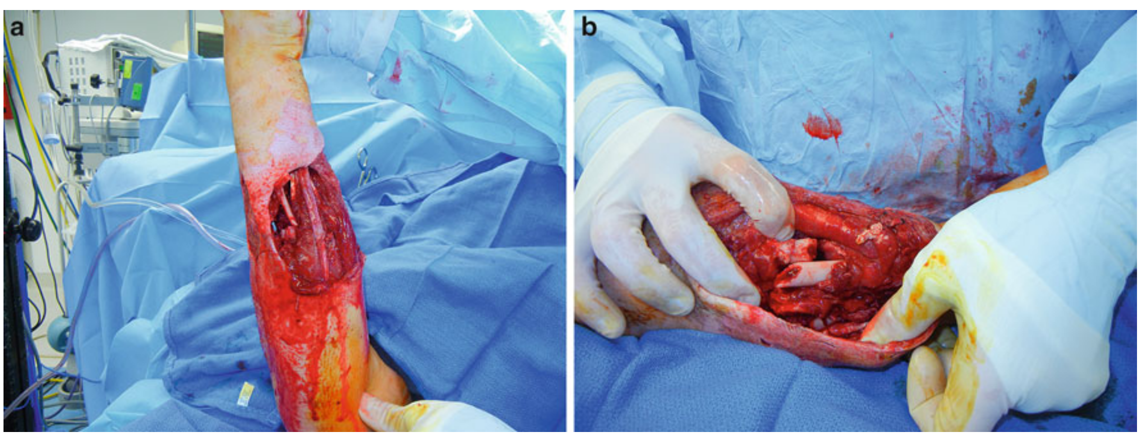

Fig. 2 (**a**) Intraoperative photograph of the forearm. Note the *blue* drape can be seen through the forearm. (**b**) Intraoperative photograph demonstrating extensive damage to the bone and soft tissues

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, 3, and 4.

3 Preoperative Problem List

1. Mangled forearm of dominant extremity in an 18 year old male
2. Grossly contaminated open forearm fractures
3. Segmental loss of ulnar nerve
4. Loss of all extensor tendons except to thumb
   (A) Ability to restore wrist extension limited. Flexor tendon transfer to finger extensors was feasible.
5. Forearm with shortening and deformity 6 weeks after injury

4 Treatment Strategy

Treatment of mangled extremities can be divided into two broad stages. First is limb salvage. This requires an emergent and aggressive debridement to minimize infection risk. Vascular status requires assessment and intervention as needed. Serial debridements and negative pressure wound

Fig. 3 Intraoperative photograph 6 days after injury demonstrating technique of securing degloved dermis. Foley catheters are cut into strips, and suture is passed through the dermis, through underlying fascia or muscle and back out the dermis. The suture is then knotted through the rubber tubing to increase force distribution. The central bare area was skin grafted at a later date

therapy facilitate progression into the limb reconstruction phase. Our strategy was to get through the first phase without infection. Then all other issues including bony loss and tendon issues and so forth would be dealt with going forward. The soft tissue damage and zone of injury were quite extensive (see Fig. 3). While application of a fixator to maintain the length of the forearm is a typical strategy, in this case, the risk of pin track infections was predicted to be 100 % if a fixator were applied at the outset. With the goal of not compromising the radius and/or ulna, with osteomyelitis, I wanted clean surgical planes for definitive fixation later on. In the 6-week interim prior to TSF application, the radius/ulna shortened and overlapped. This shortening further helped the soft tissues heal while the forearm was adequately stabilized in a splint. The TSF then allowed gradual correction of the deformity and shortening while the Integra and skin grafting continued to heal and remodel. Having the TSF for stage 2 of this limb salvage allowed me to focus on the soft tissues without reservation during stage 1 of limb salvage. The spatial frame was selected to treat the complex bony injuries because it allowed correction of the forearm without the incisions and dissection required of internal fixation. The frame corrected the deformity while the soft tissues continued to heal. Once out to length and straight, internal fixation was used for definitive fixation of the radius and the wrist fusion.

5 Basic Principles

Closure and coverage of the bone was the first priority after the debridements. The limb was shortened acutely and the skin grafted to facilitate wound closure.

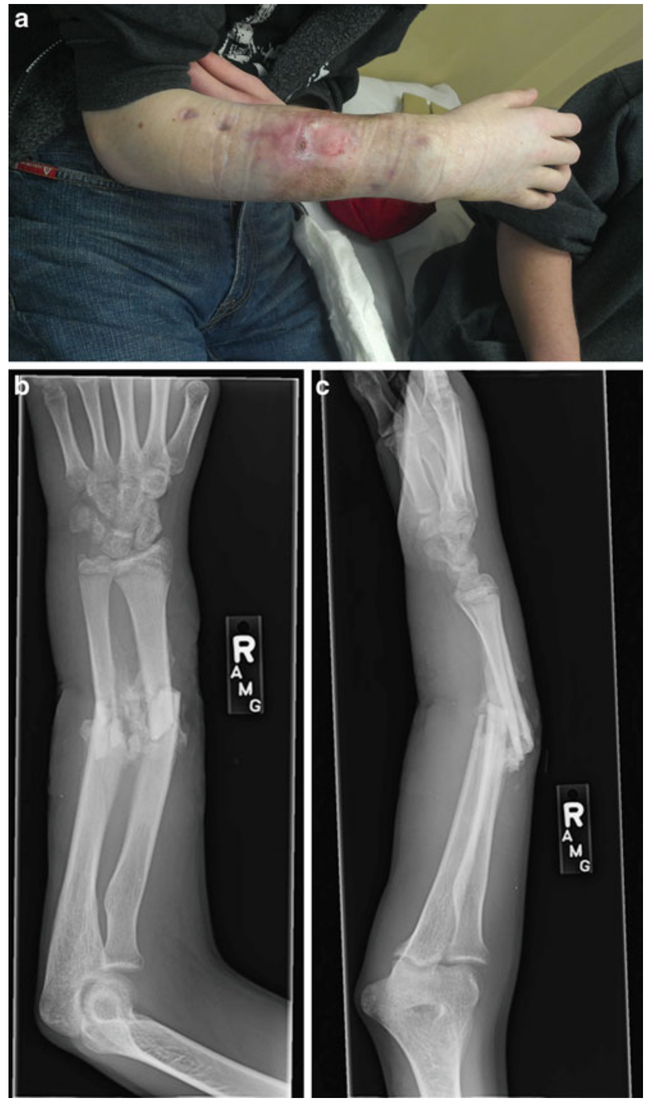

Fig. 4 (**a**) Clinical photograph at 6 weeks postinjury. Soft tissue healing is much improved. (**b**) AP forearm radiograph at 6 weeks postinjury. The fractures are headed toward a malunion. (**c**) Lateral radiograph corresponding to figure (**b**)

For 6 weeks, nothing further was done while the soft tissues improved. Spatial frame application allowed correction of the radius and ulna but also a gradual lengthening of the forearm and its soft tissues. The first part of deformity correction in this patient was over distracting the radius and ulna fracture sites. This then permitted translation and angular correction as needed. Once the correction was achieved, internal fixation was planned weeks after frame removal. This gave the tenuous soft tissues time to heal the pin site areas and for the “lengthened” dermis and other soft tissues time to heal further. The internal fixation healed without any events including infection.

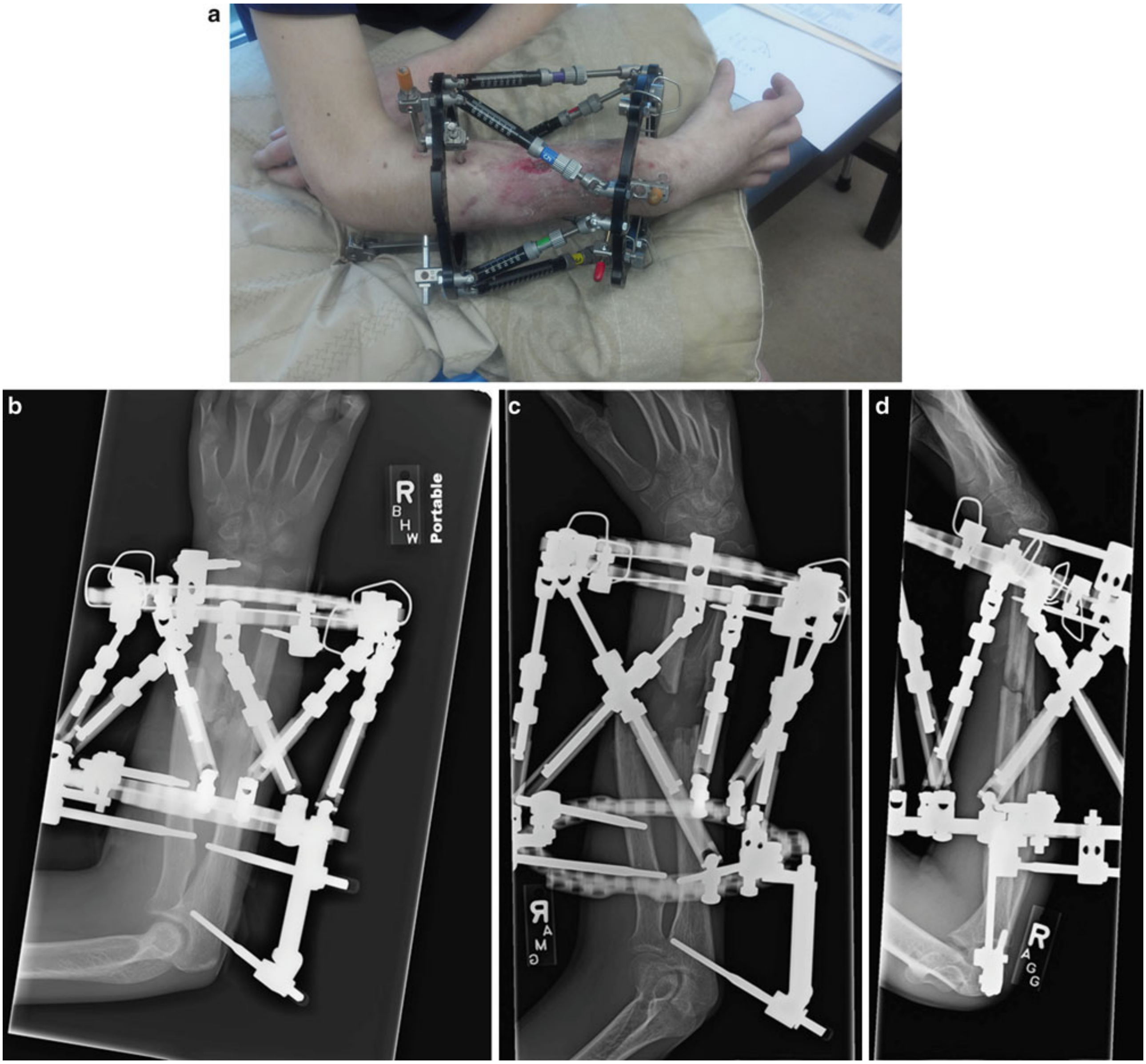

Fig. 5 (**a**) Clinical photograph at 6.5 weeks postinjury and immediately after spatial frame application. (**b**) AP forearm radiograph immediately after spatial frame application. (**c**) AP forearm radiograph 4 weeks after spatial frame application. Length over corrected to permit correction in all other planes. (**d**) Lateral forearm radiograph 7 weeks after spatial frame application. Deformity correction progressing as planned

6 Images During Treatment

See Figs. 5 and 6.

7 Technical Pearls

The spatial frame in this case had struts which are easily adjusted by the patient. A software program generates a prescription for the patient to follow at home. One of the most challenging aspects of this case was accurately inputting the mounting parameters of the spatial frame. Weekly office visits were necessary early on, and frequent prescription changes were required. The wrist fusion procedure was indicated because the three wrist extensor tendons were irreparable. Flexor carpi radialis (FCR) was transferred to the finger extensors. The finger extensor tendons were tenodesed together to create an even extension of the fingers. The FCR was released at its insertion site, tunneled dorsally, and the confluence of extensor tendon mass was passed through three separate slits made with a knife into the FCR.

Fig. 6 AP forearm radiograph 14 weeks after spatial frame application. Correction complete and soft tissues ready for internal fixation

Fig. 7 (**a**) Lateral radiograph after internal fixation of radius and wrist fusion. Fusion was done because of the extensive extensor tendon damage. (**b**) AP radiograph corresponding to figure (**a**). Ulna was healed at time of fixation procedure, and plating was not needed. (**c**) Clinical photograph of forearm. Volar and dorsal skin defects completely restored and healed. Finger ROM was −15° extension to full flexion

The flexor and extensor tendons were then sutured together with 4–0 fiberwire with the fingers in a resting position.

8 Outcome Clinical Photos and Radiographs

See Fig. 7.

9 Avoiding and Managing Problems

An infection was the biggest problem that could have occurred. If it occurred early on, it would have made internal fixation very challenging. Infection was avoided with repeated and aggressive debridements. It was also avoided by waiting 6 weeks for fixation and then selecting external fixation with a spatial frame. The final surgical procedure included radius fixation, wrist fusion, and tendon transfer 10 months after the day of injury. This surgery and the overall outcome were successful because the soft tissues were allowed to recover. This patient did however require a short course of antibiotics early on for pin site erythema. Further pin care consisted of soaking the entire arm in a large bucket filled with warm water and two capfuls each of Clorox bleach and Epson salt. Soakings lasted 20 min 2–3 times per week. Daily showering was encouraged. A final problem worth mentioning is follow-up radiographs. Making measurements on radiographs in the office can be difficult due to fixator parts overlapping the deformity. This can be circumvented by adding a temporary method of fixation with a strut or threaded rod and removing struts that block radiographic view of the forearm.

10 Cross-References

► Case 99: Mangled Upper Extremity Salvaged with Spatial Frame, Skin Grafts, Radial Lengthening, and Wrist Fusion

11 See Also in Vol. 2

Case 29: Infected Nonunion Tibia with Bone and Soft-Tissue Defect: Treatment with TSF, Intentional Temporary Deformation and Bone Transport

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Case 102: Fracture of the Humerus Treated Initially with a Flexible Intramedullary Nail and Later Converted to Circular External Fixation due to Non-union

Lane Wimberly, Alexander Cherkashin, and Mikhail Samchukov

Contents

Abstract

A fifteen year old male with a Gustilo-Anderson type II open distal shaft fracture of the humerus treated initially by irrigation with debridement, ulnar nerve exploration, and intramedullary flexible nail internal fixation that was converted to circular external fixation due to nonunion.

1 Brief Clinical History

The patient is a 15 year old male who fell from a golf cart and sustained an isolated type II open fracture of the distal humeral diaphysis with a large posterior-medial wound and ulnar nerve palsy (Fig. 1). He was treated urgently with operative exploration of the ulnar nerve, irrigation with debridement of the wound, open reduction and flexible nail intramedullary fixation of the humerus (Fig. 2), and intravenous antibiotics. At surgery, the ulnar nerve was found to be intact, and his nerve symptoms resolved over several weeks. Eight weeks after surgery, his implant became palpably prominent at the elbow, and radiographs revealed apparent callus bridging his fracture. The patient was scheduled for implant removal to prevent further migration of the nail. Upon removal, motion at the fracture site was noted, and he was placed into a long arm cast. No obvious infection was noted with implant removal. Three weeks later, he returned with mild pain and elevated infectious indices (CRP 1.8, ESR 58) and began empiric treatment with antibiotics (clindamycin) in an attempt to sterilize the presumed infection and achieve union. Six weeks after nail removal infectious indices normalized, but the radiographic appearance of the fracture (Fig. 3) demonstrated a varus deformity and no improvement in consolidation.

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Fig. 1 Preoperative radiograph demonstrating a fracture of the distal humerus

Fig. 2 Radiograph of the humerus after initial stabilization of the fracture with a flexible intramedullary nail

2 Preoperative Clinical Photos and Radiographs

See Figs. 1, 2, and 3.

3 Preoperative Problem List

- Nonunion of the humeral diaphyseal fracture
- Potential osteomyelitis
- Post-immobilization osteopenia
- Varus deformity of the humerus
- Elbow flexion contracture

4 Treatment Strategy

The preoperative plan included irrigation and debridement of the nonunion site with curettage of the bone segment contacting surfaces and the application of a TrueLok circular external fixator for stabilization with compression. The potential infection was managed acutely with antibiotics that were discontinued once final cultures were negative for bacterial growth. There was no further concern for infection that required treatment.

5 Basic Principles

The use of external fixation in the management of potential infection reduces the possibility of implant seeding and complications. In addition, it allows compressive fixation and the possibility of anatomic alignment in the face of angular bone deformity. In our case, we elected to manage the injury with local debridement of the nonunion tissue and acute compression with acute correction of the angular deformity. We did not perform a wide resection of infected nonunion that would necessitate significant shortening and subsequent lengthening or bone transport. Our strategy is a well-accepted and well-described operative strategy for humeral nonunion without significant bone loss (Cattaneo et al. 1993; Patel et al. 2000).

Fig. 3 Radiographs of the humerus 6 weeks after nail removal (14 weeks after fracture). Note the varus deformity and the failure of consolidation at the fracture site

6 Images During Treatment

See Figs. 4, 5, 6, and 7.

7 Technical Pearls

The application of circular external fixation for compression of a nonunion of the humerus creates challenges related to bone and soft tissue anatomy. The inability to use circumferential external supports on the arm leads to semicircular frame constructs. The potential risk of neurovascular injury by implants minimizes the use of tension wires. Our standard frame configurations for humeral external fixation include an arch attached to the proximal segment by three half pins and a 5/8 ring secured to the distal segment by a combination of one horizontal wire and two half pins or two wires crossing at the small angle and one half pin. Proximal and distal external supports are interconnected by three rapid adjust struts allowing for precise acute apposition of bone segments and gradual compression in the postoperative period, if necessary (Figs. 4, 5, 6, and 7).

8 Outcome Clinical Photos and Radiographs

See Figs. 8, 9, and 10.

Fig. 4 Intraoperative photograph of the humerus after application of the TrueLok circular external fixator before acute deformity correction and compression. The frame consisted of a proximal double-arch block with three half pins and a distal half ring with two half pins and a tensioned wire. The segments were interconnected by rapid adjust struts

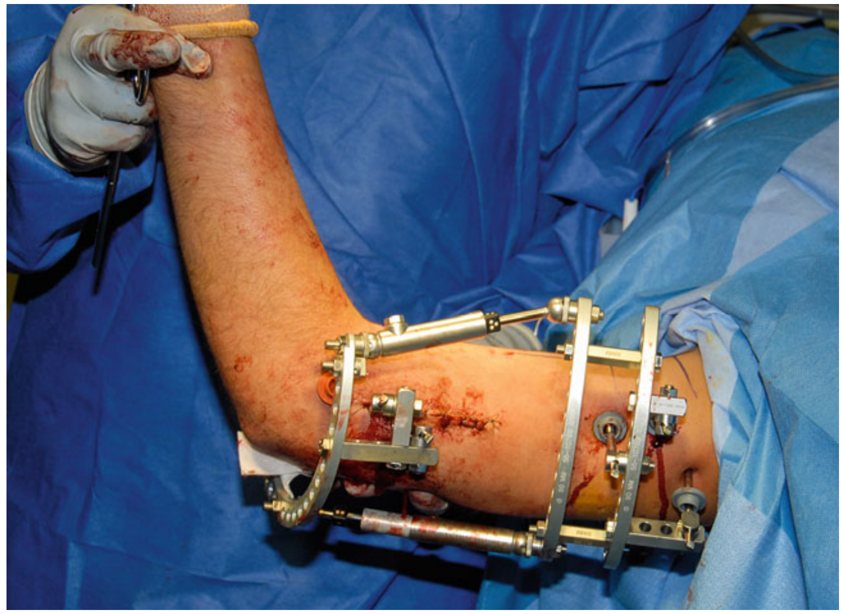

Fig. 5 Intraoperative photograph of the humerus after acute deformity correction and compression

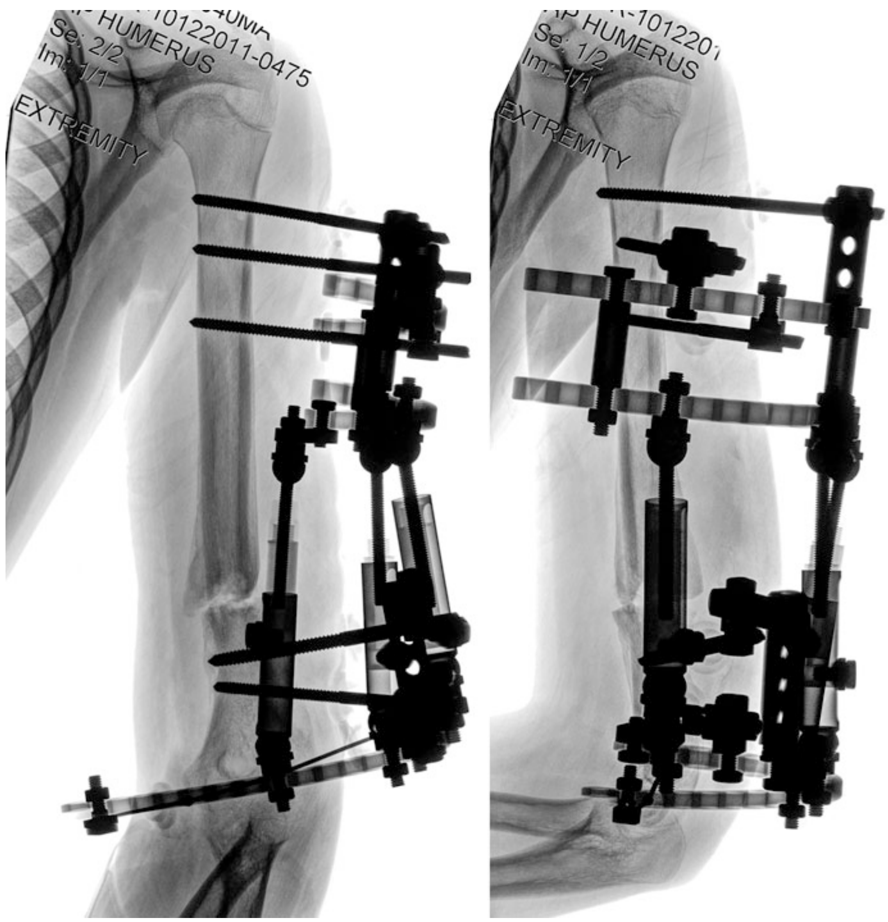

Fig. 6 Postoperative radiographs of the humerus demonstrating restored alignment with no translation between the contacting bone segment surfaces at the nonunion site. Note the third rapid adjust strut added to the frame at the end of surgery for more stable definitive fixation

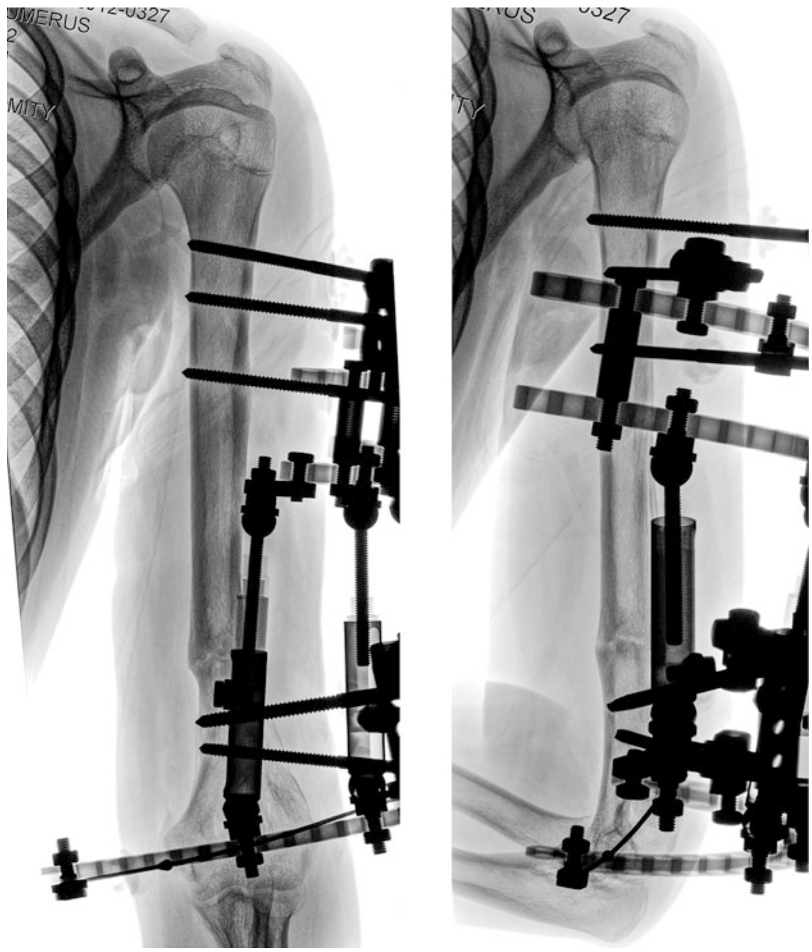

Fig. 7 Radiographs of the humerus 4.5 months after surgery demonstrating solid mineralized callus. Fixator was removed 10 days later

Fig. 8 Radiographs of the humerus 2 years after frame removal demonstrating complete remodeling of the callus with reconstitution of the medullary canal

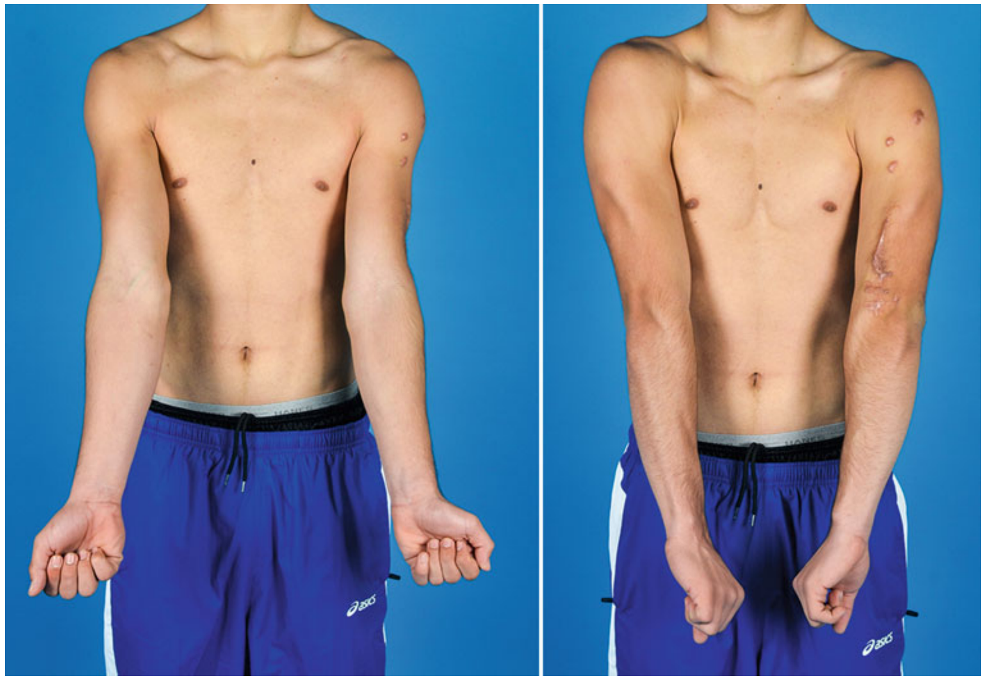

Fig. 9 External and internal rotation of the upper extremities 2 years after frame removal

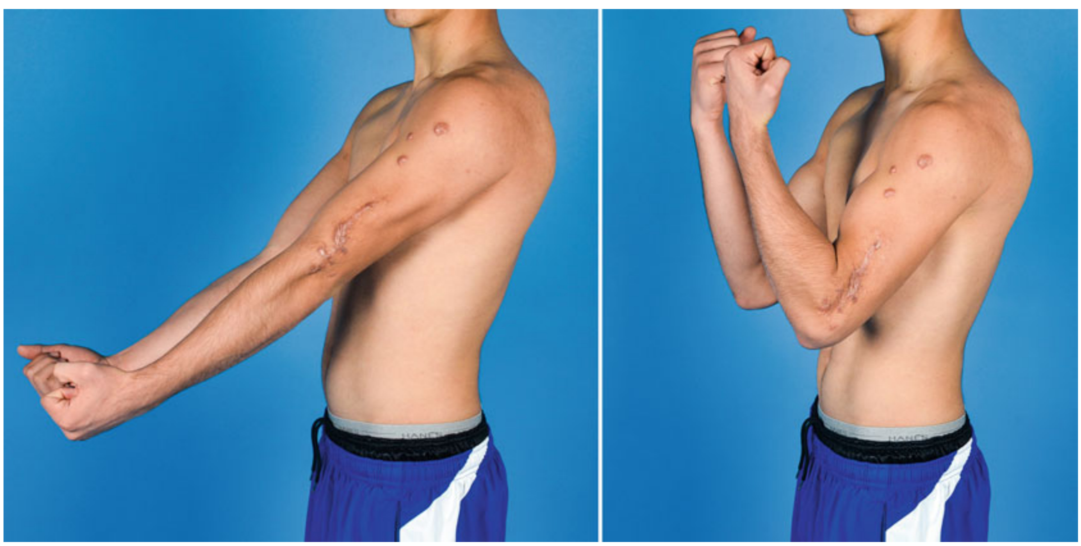

Fig. 10 Flexion and extension of the elbow 2 years after frame removal. The patient has no complaints and is happy with the appearance of his upper extremities. With his function completely restored, he has returned to the sport of boxing

9 Avoiding and Managing Problems

An iatrogenic radial nerve palsy was identified after surgery, and nerve exploration was performed on the first postoperative day. At exploration, the radial nerve was free from compression at the nonunion site and intact along its course from the spiral groove to beyond the elbow with no evidence of injury from the fixation pins. The radial nerve palsy likely developed as a traction neuropraxia during the nonunion site exploration and debridement. The injury had completely resolved 3.5 months after surgery.

Peripheral nerve injury is an uncommon, but regularly reported, complication of external fixation in the upper extremities with an incidence of 5–15 % (Kocaoğlu et al. 2001; Tomić et al. 2007). Intraoperative somatosensory evoked potential monitoring of peripheral nerves can be of benefit in these cases. The monitoring technique has proven to be a sensitive and reliable tool for early detection of nerve compromise which may allow acute corrective actions to minimize complications (Makarov et al. 1997, 2012).

10 Cross-References

► Case 87: Varus and Shortening of the Proximal Humerus

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Case 103: Humerus Nonunion Treated with Fixator Augmented Rod Technique

Mahmoud A. El-Rosasy

Contents

Abstract

Nonunion of a humerus shaft fracture after repeatedly failed surgical attempts at bone healing presents a difficult therapeutic problem especially in the presence of osteoporosis, bone defect, and joint stiffness. The incidence of nonunion of humeral shaft fractures is reported as 2–10 % when managed conservatively and around 15 % when managed by open reduction and internal fixation (Pugh DM, McKee MD, J Am Acad Orthop Surg 11:48–59, 2003). The use of external fixation (unilateral or modified Ilizarov) augmented by IM rods together with the routine use of ICBG is a viable option to treat humeral shaft nonunion following failed implant surgery (Patel VR, Menon DK, Pool RD, Simonis RB, J Bone Jt Surg Br 82:977–983, 2000). The proposed technique improves stability of fixation and meanwhile minimizes the operative complications. The IM rod is left in situ after fixator removal to act as a permanent splint to shorten the external fixator time and prevent refracture after fixator removal (El-Rosasy MA, Indian J Orthop 46:58–64, 2012).

1 Brief Clinical History

In the case of a 22 year old female patient, she has a 3 year old nonunited fracture of upper third of the right humerus shaft. The fracture was treated surgically by a conventional Kuntscher nail and two times autogenous iliac crest bone graft (ICBG). The prominent upper end of the nail caused impingement and limitation of shoulder abduction.

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Fig. 1 Preoperative radiograph shows a nonunited fracture of the upper third of the right humerus. The nonunion is fixed by a conventional nail with a distraction gap and prominent upper end of the nail (Reproduced from El-Rosasy (2012))

2 Preoperative Clinical Photos and Radiographs

See Fig. 1.

3 Preoperative Problem List

– Nonunited humerus shaft fracture with a history of repeated surgical treatment
– Retained IM rod
– Compromised both biological and mechanical environment at the nonunion site

4 Treatment Strategy

Trimming of bone ends to get the maximum bone contact and an inherently stable fracture and decortication of the bone ends. Autogenous ICBG to be applied around the nonunion.

5 Basic Principles

The planned surgery would address the biology of bone healing by minimal soft tissue stripping to freshen the bone ends and insertion of autogenous ICBG. On the other hand, the mechanical stability of the construct is ensured by retention of the IM rod after being shortened and application of a monolateral external fixator for compression of the nonunion.

6 Images During Treatment

See Fig. 2.

7 Technical Pearls

The proximal pins were inserted in the metaphyseal region taking care to keep a space of about 4 mm between the pin and the nail to avoid contamination of the IM rod if the pin site gets infected. The most distal pin was inserted first through the humeral condyles from lateral to medial (trans-capitellar-trochlear). The IM rod is left in situ after fixator removal to act as a permanent splint to prevent refracture after fixator removal.

8 Outcome Clinical Photos and Radiographs

See Fig. 3.

9 Avoiding and Managing Problems

The distal-most pin is a 6 mm half pin inserted until its tip was only engaging the medial cortex to avoid ulnar nerve irritation. The radial nerve has a helical path from the

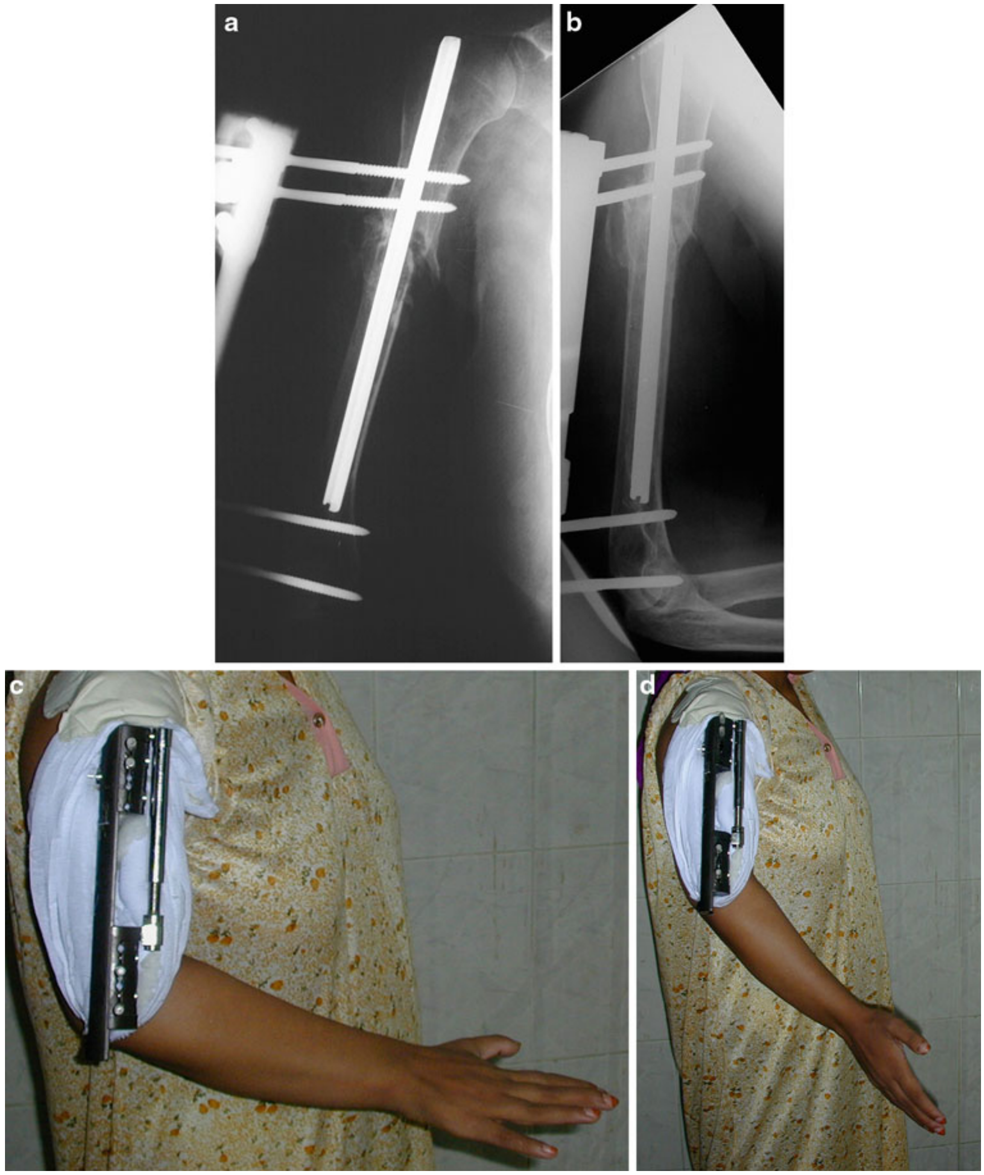

Fig. 2 (**a**, **b**) Postoperative radiographs show the application of a monolateral external fixator. The proximal half pins are inserted in the wide metaphysis with an interval of bone between the nail and the pins. The nail was shortened to relieve the impingement against the acromion. The distal pin was inserted trans-capitellar-trochlear, and the more proximal one was inserted above the olecranon fossa to allow free range of motion of the elbow. (**c**, **d**) Postoperative clinical photos show the application of a monolateral external fixator (Orthofix, LRS), range of motion of the elbow, and intact radial nerve (evidenced by active dorsiflexion of the wrist)

proximal to middle third; it runs posteriorly and laterally to anterolaterally after piercing the lateral intermuscular septum 101–148 mm proximal to the lateral epicondyle. The most common cause of radial nerve injury is damage by high location of pin in an attempt to insert pin closer to fracture during external fixation (Chou et al. 2008; Clement et al. 2010).

10 Cross-References

▶ Case 100: Reconstruction of the Elbow After Gunshot Injury with Dynamic Articulated Frame

▶ Case 102: Fracture of the Humerus Treated Initially with a Flexible Intramedullary Nail and Later Converted to Circular External Fixation due to Non-union

Fig. 3 (**a**, **b**) Follow-up radiographs show consolidation of the nonunion. The IM rod is retained as a permanent splint. (**c**, **d**) Follow-up clinical photos show the range of motion of the elbow

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