CARTILAGE SURGERY

AN OPERATIVE MANUAL

Cartilage Surgery
An Operative Manual

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To my patients, colleagues, and co-workers; because of working with all of you, it is a privilege and an honor to be an orthopaedic surgeon and a scientist.

Mats Brittberg, MD

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PREFACE

During the last 25 years, articular cartilage repair has become routine at many hospitals around the world. The goal of this type of surgery is to use functional repair tissue to provide pain relief and restore the functionality of the injured cartilage to a level similar to that of surrounding cartilage.

Many books about clinical cartilage repair have been written. Most of them are comprehensive texts that include vast amounts of information for surgeons to study.

Instead of producing yet another reference volume about cartilage repair, we wanted to write a book that actually can be used to quickly review surgical techniques in the operating room—an operative manual for cartilage surgery for use before, during, and after surgery by surgeons, scrub nurses, and staff involved in patient care during cartilage lesion treatment.

Surgeons have developed a variety of techniques to treat cartilage injuries. Some of the most familiar are the following:

Bone marrow stimulation–based repairs
Cartilage tissue–based repairs
Cartilage cell–seeded repairs

We have not attempted to include all of the many available techniques in our manual. We have selected some standard procedures, as well as some new technologies, to provide the surgeon with a range of options. In addition, we have included some basic chapters about cartilage tissue, treatment algorithms, and rehabilitation suggestions. We also have supplied the following references that we recommend to readers who need or want further information about cartilage repair.

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CONCLUSION

¨tis the chirgeon's praise, and height of art, not to cut off, but cure the vicious part.¨
Robert Herrick, 1591-1674

We hope that this book will be useful to you and your staff. Cartilage repair is a difficult task. To treat cartilage defects and concomitant injuries effectively, we must help patients understand that their treatment program will involve strenuous training and lengthy follow-up care. We hope that this book will be part of such a treatment program and that it will serve as a simple reminder of how to do what is best for the benefit of our patients.

Mats Brittberg, MD
Wayne Gersoff, MD

CHAPTER

1

Cartilage Morphology

Mats Brittberg

Hyaline cartilage provides the diarthrodial joint with a low-friction surface, resilience, and compressive stiffness, and this unique tissue is, under normal conditions, wear resistant.

Loss of cartilage function may lead to a painful joint with a decreased mobility. Many factors (epidemiological, biochemical, and morphological) are associated with cartilage destruction. However, only trauma is known directly to cause osteoarthritis.[1] It is well known that once the cartilaginous tissue has been destroyed, the intrinsic reparative ability is poor. Therefore, it is of uttermost importance to increase knowledge about the cartilage, the tissue reaction to trauma, and the intrinsic attempts to repair the defects as well as extrinsic methods.

CARTILAGE BIOCHEMISTRY AND MORPHOLOGY

The hyaline cartilage could be regarded as a composite gel with relatively low percentage chondrocytes (5%) embedded in a rich extracellular matrix consisting in negatively charged hydrophilic proteoglycans constrained by a three-dimensional collagen network.

The negatively charged proteoglycans have the ability to form large aggregates, which can bind water molecules within the positively charged collagen fibrils, thus generating a high osmotic pressure within the gel.

The collagen fibers are responsible for the structure of cartilage and consist mainly of collagen type II. They are highly cross-linked via collagen type IX fibers.[2]

Chondrocytes are the producers of the surrounding ground substance: matrix.

The cells have different appearances depending on where in the cartilage they are situated. The cells in the top layer appear flattened, whereas the cells in the deeper layer are more rounded and aligned along vertically orientated type II collagen.[3]

Collagen is the most important scaffolding material in the body, existing in several types. The major type in hyaline cartilage is named type II. It is built by three identical polypeptide alpha-chains. These chains are coiled to form a triple-helix and are produced by the chondrocyte in the form of procollagen. Outside the cell, this procollagen is transformed to tropocollagen, and these molecules aggregate to form the much larger molecule: collagen.

In the hyaline cartilage there also exist minor collagens like types IX, XI, V, and VI. Type IX contributes with covalent cross-linking of the type II fibrils, whereas type XI is thought to control the diameter of type II fibrils. The collagen gives the cartilage its strength and tensile stiffness.

Proteoglycans are large protein-polysaccharide molecules making up 5% to 10% of the wet weight of the cartilage.[4] They are composed by chains of the glycosaminoglycans keratan sulfate and chondroitin sulfate covalently bound to a central protein core molecule. Large aggregates are formed with several proteoglycan monomers via a link protein connecting the central protein cores to a chain of hyaluronic acid.

All the components of the proteoglycan aggregates are synthesized by the chondrocytes.

The proteoglycans are unevenly distributed throughout the cartilage layers with the highest concentration in the middle part and the lowest concentration in the superficial layers.[5] The proteoglycans give the cartilage its elasticity and resilience.

There is a difference in cartilage composition between the cartilage surface and the subchondral bone plate. These structural differences give rise to four separate layers or zones (see Fig. 1-1).

In the top zone, the **superficial zone,** there is first a cell-free fibril-layer, called the **lamina splendens**.[6] Beneath this thin layer, chondrocytes are dispersed in an elongated manner parallel to the surface, reflecting as well the tangential orientation of the collagen fibers. This is the **tangential layer**.

In the second zone, often called **the transitional layer,** the cells are larger, rounded, and randomly distributed between the oblique-oriented collagen fiber. In the third zone, the chondrocytes are even larger and arranged in typical columns because of the radial collagen fiber courses, **the radial zone**.

The fourth layer, finally, which is mineralized, is called the **calcified zone**. There exists a visible border between the third and fourth zone, the tidemark with a special affinity for basic dyes (e.g., toluidine blue).

The calcified zone provides an important transition to the less resilient subchondral bone. For a long time this was regarded more or less as an inactive zone, until Hunziker (1992)[7] noted that also the chondrocytes here could take up and incorporate (35S) sulfate into the pericellular and territorial matrix. Hunziker speculated that, following trauma, the metabolic activity here becomes temporarily impaired.[7]

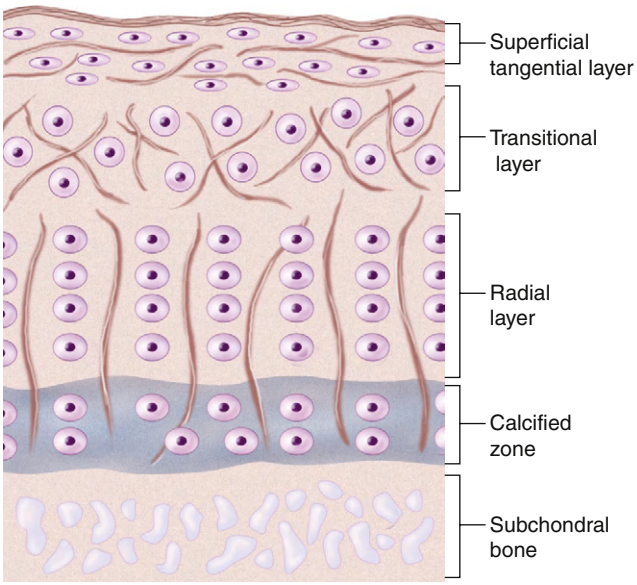

FIGURE 1-1 Schematic drawing of the different layers in a full-thickness osteocartilaginous biopsy.

Regarding experimental animals, it is important to know that it is only in adult animals that the division into zone I to zone III is possible.[8] In the immature animal, the cells are more randomly distributed with a gradient in cell size from the top to the calcified zone, with the cells in the deeper parts being largest. Thus, the articular cartilage organization during prepubertal growth imitates the structure of the growth plate, and during that time the biomechanical properties of the cartilage change with an increase in stiffness and in shearing and compressive resistance.[7,9]

METABOLIC EVENTS IN THE CARTILAGE

Under normal conditions, the components of the matrix have a slow turnover. The collagen has the slowest turnover rate compared to the much faster turnover of the proteoglycans.

The majority of the proteoglycans have a life span of about 600 days, but a small proportion of the proteoglycans in adult cartilage act as a fast fraction with a half-life of about 8 days. The proteoglycans are thus also more vulnerable to enzymatic degradation.[10,11]

The chondrocytes secrete different enzymes called metalloproteinases (collagenases, gelatinases, and stromelysin), which all control the degree of degradation. The degradation of proteoglycans is followed by an increased synthesis of proteoglycans, which then become integrated into the matrix.

This is a sophisticated and well-balanced process regulated by the chondrocytes, and a disturbance of any of these events could lead to destruction of the cartilaginous matrix. This happens in osteoarthritis where an early sign is an imbalance in synthesis and degradation of the matrix.

PATHOLOGY EVALUATION

With a biopsy from a cartilage area and with the help of a microscope, a lot of information about the composition and organization of the cartilage matrix can be made.

It is important to know that a biopsy with histology provides information about a very small part of the cartilage tissue and a small part of a repaired area. It is subsequently very important to know the following:

It is necessary to know the exact location from where the biopsy is taken and how it was taken. The International Cartilage Society (ICRS) has developed a mapping system, which is useful to utilize when describing the location.[12] A biopsy should be taken in the following manner:

- Perpendicularly to the articular surface.
- From the central part of a repaired area; sometimes one also needs to take a biopsy from the border zone between repair and adjacent normal cartilage.

A 2-mm biopsy going through all layers and down through bone is recommended. There are several types of instruments on the market, but it is easiest to employ a biopsy instrument used for bone marrow biopsies such as a Jamshidi needle.

A pathologist with special interest in cartilage tissue evaluation is involved in the assessment of the biopsies.

Biopsies can be either wax embedded for sections or frozen for cryo sections.

As recommended by the ICRS Histology Endpoint Committee,[13] **cartilage morphology** can be evaluated by **hematoxylin** and **eosin** staining. Normal and polarized light are used.

Additional stainings with toluidine blue, alcian blue, or safranin O are used for evaluation of **glycosaminoglycan content.**

Immunohistochemical staining is done for evaluation of degree of collagen types I and II (best done on frozen sections).

Mineralization is studied with von Kossa technology.

MOLECULAR BIOLOGY

In situ hybridization studies the genes that the chondrocyte expresses and indicates what the cells are capable to synthesize.[14]

HISTOLOGICAL REPAIR SCORES

Various histological scoring systems exists for analysis of osteoarthritic or normal, in vivo repaired, or tissue-engineered cartilage, but only a few have been validated:[15]

- *For assessment of osteoarthritic cartilage:* HHGS/Mankin score,[16] the OARSI system.[17]
- *For assessment of cartilage repair in animal studies:* O'Driscoll score,[18] Pineda scale,[19] Wakitani score.[20]
- *For assessment of cartilage repair in humans:* ICRS Visual Histological score II.[21]
- *For assessment of tissue-engineered cartilage:* The Bern score.[22]

IMAGING EVALUATION OF CARTILAGE REPAIR

To get a better total idea of the repair area, imaging techniques need to be used.

The clinical doctors need to know more about the type of cartilage lesion before arthroscopy in order to select the best repair choice about the quality of the induced repair, when to evaluate the symptoms post surgery, and when to intervene and how.

Arthrography combined with computed tomography (CT) provides information about the contour and surface characteristics of the cartilage and cartilage repair.[23] Combined with three-dimensional reconstruction of the bone structure, useful information is yielded.

Recent developments in MRI technology used in the field of musculoskeletal research have created new possibilities by providing precise and reliable quantitative information on the joint structure as well as changes over time.

The main advantages of MRI as a method for cartilage imaging are as follows:

- Noninvasiveness
- Reproducibility
- Accuracy

Quantitative measurement of morphology can be used to monitor loss of cartilage tissue, but there is extensive interest in using MRI to detect changes that precede gross tissue degradation that may occur in early disease.

Such mapping techniques to image compositional changes that may be sensitive to early cartilage damage include T2 mapping, delayed gadolinium enhanced MRI of cartilage (dGEMRIC), and T1rho.

Fat-suppressed three-dimensional gradient echo (**3D-GRE**)[24] allows the exact description of the thickness and surface of cartilage.

T2-weighted (dual) fast spin echo (FSE) techniques with or without fat-suppression[24] give the information about the normal and abnormal internal structure of hyaline cartilage.

dGEMRIC[25] relies on intravenous injection of a negatively charged MR contrast agent and the acquisition of a T1 map after equilibration of the contrast agent in the cartilage to estimate the glycosaminoglycan distribution within cartilage.

Quantitative T2 MR[26] mapping of articular cartilage is a noninvasive imaging technique that has the potential to characterize hyaline articular cartilage and repair tissue.[24] Normal articular cartilage demonstrates an increase in T2 values from the subchondral bone to the articular surface that has been correlated with type II collagen fiber matrix organization (anisotropy) in these zones.

Qualitative and quantitative T2 mapping helped differentiate hyaline cartilage from reparative fibrocartilage after cartilage repair at 1.5-T MR imaging.[24]

Cartilage T2 mapping at 1.5-T MR imaging shows promise as a noninvasive tool to study and differentiate cartilage composition after surgical cartilage repair procedures.[26]

One MRI technique, magnetization transfer (MT) imaging,[27] is known to generate a useful image contrast in cartilage in vitro, which is sensitive to the macromolecular content of the cartilage. Palmieri and coworkers[27] have studied cartilage repair with microfracture, comparing the repair with autologous chondrocyte implantation (ACI) repair. The differences between damaged and repaired cartilage magnetization transfer ratio (MTR) were too small to enable MT imaging to be a useful tool for postoperative follow-up of cartilage repair procedures. However, there was an evolution toward normal MTR values in the cartilage repair tissue (especially after ACI repair), while the MTR of microfracture repaired cartilage still showed a significant difference from normal cartilage at a 24-month follow-up.[27]

Furthermore, another technique called T1rho can potentially be used to noninvasively to quantitatively assess the biochemical and biomechanical characteristics of articular cartilage in humans during the progression of osteoarthritis.[28]

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CHAPTER

2

Patient Evaluation and Treatment Algorithms

Marco Delcogliano, Jason Boyer, Bert R. Mandelbaum

INTRODUCTION

The clinical consequences of articular cartilage defects of the knee are pain, swelling, mechanical symptoms, athletic and functional disability, and osteoarthritis. Full-thickness articular cartilage defects have a poor capacity to heal because of the cartilage's isolation from systemic regulation and its lack of vessels and nerve supply. The challenge to restore the articular cartilage surface is a multidimensional task faced by both basic scientists in the laboratory and orthopedic surgeons in the operating room. A growing number of patients are presenting for consultation in order to maintain their active lifestyles and hobbies. These patients wish to continue activities that have, in the past, been achievable only for younger and healthier knees. Since the late 1970s, different techniques to address articular cartilage injuries and defects have emerged as valid therapeutic options. Although options to treat these lesions have expanded, the difficulty facing practitioners is choosing which technique to best address the defects of each individual patient.

Although the regeneration of true hyaline cartilage is not yet a reality, a variety of methods have the potential to stimulate the formation of a new articular surface, including microfracture of subchondral bone, use of auto- or allografts, cell transplantation, targeted growth factors, and artificial matrices. Reports of the clinical results of these procedures have documented clinical improvement for most of the patients.[1,2,3,4] However, despite the availability of all of these techniques and the advances in imaging that have led to an increased understanding of the frequency and types of chondral lesions, patient evaluation and treatment selection still remain challenging. In evaluating a patient for cartilage repair, one must characterize not only the cartilage lesion itself but the various clinical factors and comorbidities embodied by each individual.

Several comorbidities such as ligamentous instability, deficient menisci, or malalignment of the mechanical limb axis or extensor mechanism often

coexist with the articular surface pathology. Moreover age-related, nonprogressive, superficial fibrillation of cartilage and focal lesions of the articular surface must be distinguished from degeneration of cartilage occurring as a part of syndrome of osteoarthritis.[5] As a consequence, the clinician must define, characterize, and classify local, regional, and systemic, medical, and family history factors that may influence the progression, degeneration, or regeneration of the defect. Careful patient evaluation is essential in selecting the proper treatment plan: lesions with different etiology and size require different treatments and the comorbidities may need to be treated in conjunction with symptomatic chondral injuries to provide a mutually beneficial effect. Thus, the evaluation and characterization of the patient as a whole is key to optimizing the results of surgery.

This chapter provides the guidelines for selecting the proper treatment algorithm.

CLINICAL MANAGEMENT

The initial step in the workup is the history. This should include mechanism of injury, time course, and quality of symptoms; review of previous treatment; and the effects of those treatments. Peterson et al. found that the average patient presenting for cartilage restoration had 2.1 previous treatments, usually with a different physician.[6] In this setting, access to operative reports, pervious imaging, and even direct communication with previously treating surgeons can provide information.

During the physical examination, the surgeon should be careful not to assume that the articular cartilage lesion is responsible for all symptoms but should attempt to delineate concomitant pathologies that may be contributing symptoms. It is important to recognize that not all chondral lesions cause symptoms. Conversely, not all symptoms are related to the chondral or osteochondral defect. Often concomitant pathology exists and can play a role in the symptoms that the patient maybe experiencing. In addition to the sites of point tenderness, effusion, crepitus, and catching, the examination should carefully assess alignment, range of motion, and patellofemoral tracking. Evaluation for ligamentous integrity is also valuable in considering concomitant pathologies of the knee. Other mechanical issues of obesity and gait patterns may exclude a patient from certain treatments because of potential inability to comply with often extensive rehabilitation protocols.

Required radiographs include standing anteroposterior, lateral, patellar skyline, a 45-degree flexion posterior anterior weight-bearing view, and a full-length alignment film. No cartilage restoration procedure should be performed in the setting of malalignment; therefore, if the mechanical axis bisects the affected compartment, a corrective osteotomy should be strongly considered as a concomitant or staged procedure.[7,8]

Access to MRI is important in developing and executing an effective clinical approach to cartilage repair surgery.

With a high-resolution fast spin echo sequencing technique in the saggital, coronal, and axial planes, articular cartilage surfaces can be well imaged and measured. This allows accurate characterization of not only the lesions in question but the state of all opposing cartilage surfaces and menisci.

Quantitative MRI techniques, such as T2 mapping, T1rho, and delayed gadolinium-enhanced MRI of cartilage (dGEMRIC), provide noninvasive information about cartilage and repair tissue biochemistry.

Diffusion-weighted imaging (DWI) and diffusion tensor imaging (DTI) demonstrate information regarding the regional anisotropic variation of cartilage ultrastructure.[9] These advantages provide preoperative information and may allow for a postoperative assessment of actual glycosaminoglycan content of repaired or replaced tissue.[10]

If the lesion involves the subchondral bone, then computer tomography scanning may also be necessary to assess defect geometry and depth, especially in the presence of osteochondral defects that may require bone grafting in addition to an articular cartilage restorative procedure.

An examination under anesthesia is required to better assess the knee instability. This is performed routinely before every knee arthroscopy. The first operation after the diagnosis of an articular cartilage defect is often not the definitive procedure. At times, arthroscopy is performed initially as a diagnostic tool to assess the lesion, in terms of its location, geography, surface area, and depth. The surrounding articular surfaces in the uninvolved compartments, the state of the menisci, and the presence or absence of additional pathology need also to be defined. If one is considering definitive treatment with autologous chondrocyte implantation (ACI), a biopsy should be performed at this time. Similarly, if a significant subchondral defect exists, primary bone grafting can be performed at the index operation.

LOCAL AND REGIONAL FACTS

To ensure uniform standards of evaluating articular cartilage repair, a universally accepted classification system is necessary. Many different grading systems for cartilage defects are cited in the literature, including those of Outerbridge,[11] Insall,[12] Bauer and Jackson,[13] and Noyes.[14] To avoid confusion, the International Cartilage Repair Society (ICRS) has developed a grading system to be used as a universal language when surgeons are communicating about cartilage lesions. The ICRS characterizes Grade 0 as normal, Grade 1 as superficial lesions and fissures, Grade 2 as lesions extending down to less than 50% of the cartilage depth, and Grade 3 as all lesions extending more than 50% of the cartilage depth and down to bone. Finally,

Grade 4 lesions are all that extend down through the subchondral bone plate (Fig. 2-1). This grading system is also included in a comprehensive method of documentation and classification, which encompasses a global description of not only the lesion but all of the local factors and comorbidities previously discussed.[15] The following variables are included in the standards:

- *Etiology*. Is the defect acute or chronic? This may be a difficult differentiation because there is a blend of acute and chronic combinations.
- *Defect thickness*. What is the thickness or depth of the defect as defined by the ICRS grade? (See Fig. 2-1). Penetration of the tidemark or the presence of subchondral cysts can affect the functional articular cartilage unit.

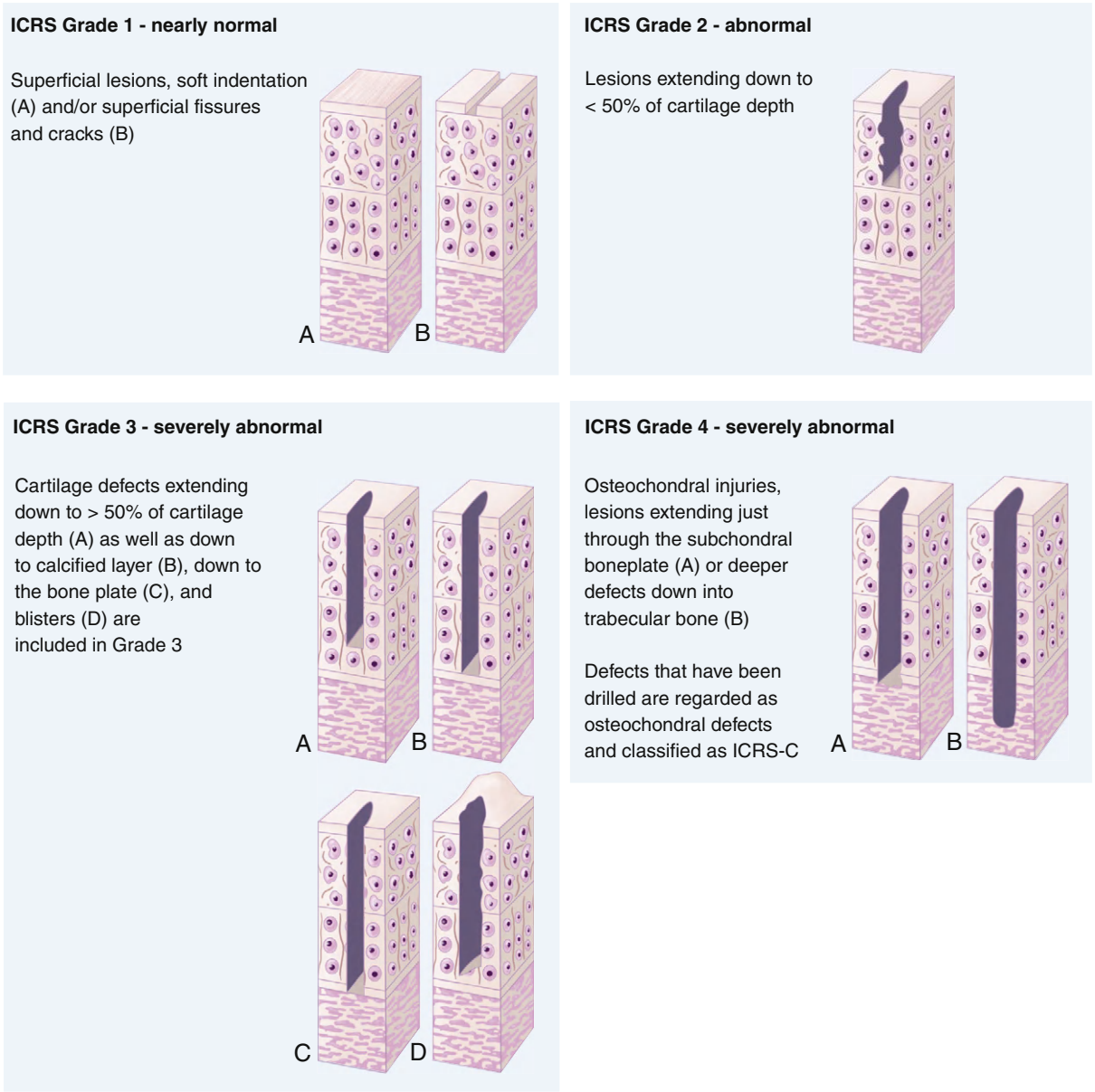

FIGURE 2-1 ICRS cartilage grading score.

- *Lesion size*. A probe accurately measures size in centimeters squared during arthroscopy. Defects less than 2 cm^2 have different treatment options than defects greater than 2 cm^2.
- *Degree of containment*. Is the defect contained or uncontained? Is the surrounding articular cartilage healthy or degenerative? As the degree of containment decreases, consequent loss of joint space is seen on radiographs.
- *Location*. Is the defect in the weight-bearing region of the knee? Is it monopolar or bipolar?
- *Ligamentous integrity*. Are the cruciate ligaments intact, partially torn, or completely torn? Is there residual instability, or has the knee been reconstructed?
- *Meniscal integrity*. Are the menisci intact? If not, has there been a partial, subtotal, or complete meniscectomy? Has meniscal repair or transplantation been performed?
- *Alignment*. Is the alignment normal, varus, or valgus? Is there patellofemoral malalignment? Has an osteotomy or realignment procedure been performed?
- *Dynamic alignment*.
- *Previous management*. If a prior cartilage restorative procedure has been performed, was the subchondral plate violated?
- *Radiological assessment*. Weight-bearing anterior-posterior (AP) or flexed posterior-anterior (PA) views, lateral views, and patellofemoral views are necessary for the evaluation of joint space narrowing and subchondral cyst formation.
- *MRI assessment*. New MRI sequences allow for the preoperative and postoperative evaluation of defects and articular cartilage repairs. Bone bruising, osteochondritis dissecans, and avascular necrosis can also be evaluated.
- *General medical, systemic, and family history issues*. Is there a rheumatologic history? Are there endocrine-related factors? Is there a family history of osteoarthritis or cartilage disorders?

A comprehensive analysis of the local and regional factors related to an articular cartilage lesion is utilized to develop a treatment plan. A flowchart has been created to summarize primary treatment options and secondary treatment options. There are separate charts for femoral and patellar defects. Primary treatment options should be considered first-line treatment choices. Secondary treatment options are considered if primary treatment fails or if other factors prevent the use of a primary treatment option (Figs. 2-2 and 2-3).

Emphasis must again be placed on the importance of looking at the entire picture when characterizing a cartilage lesion. It is imperative to consider each lesion in the context of alignment, ligamentous, and meniscal integrity (*macroenvironment),* as well as molecular-level factors such as chondrocyte function, synovium, chondropenia, and cartilage integrity (*microenvironment*).

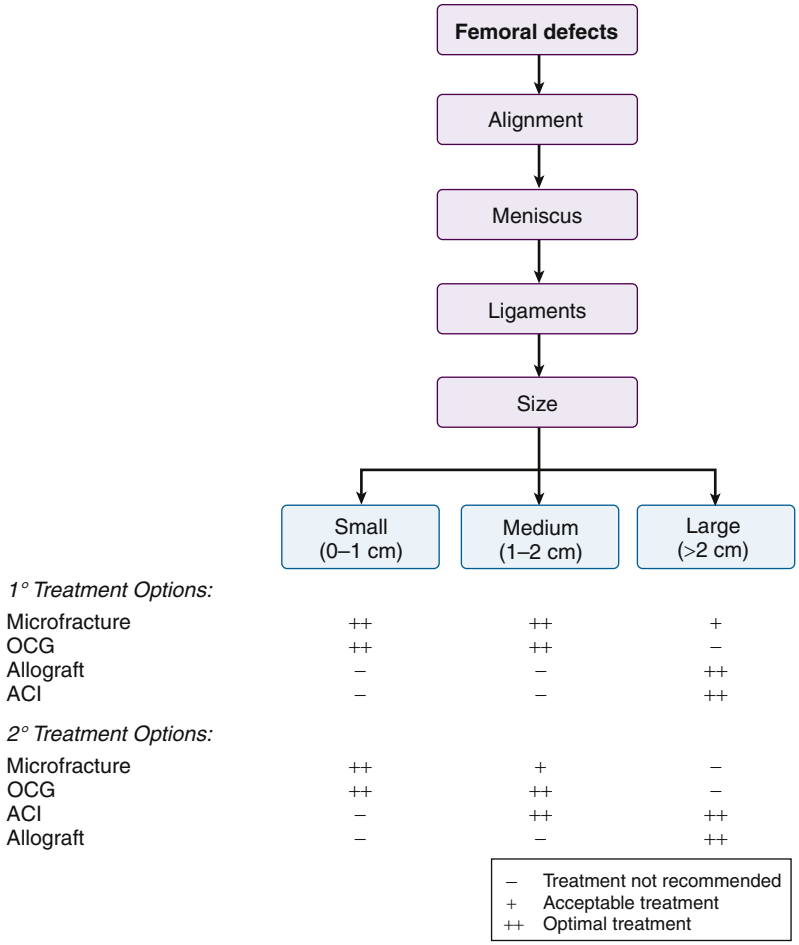

FIGURE 2-2 Algorithm for femoral defects. *ACI*, Autologous chondrocyte implantation; *OCG*, osteochondral grafts.

THE CLINICAL ALGORITHM: THE CHONDROPENIC PATHWAY

After completion of the comprehensive assessment described earlier, patients can then be stratified a clinical algorithm. This *chondropenic pathway* has been developed for the management of articular cartilage defects. The algorithm defines 10 patient-directed situations based on lesion size, depth, and associated issues such as alignment, ligament, and meniscal integrity. Each situation considers the problem category, the therapeutic options, and the current unresolved issues.

Situation No. 1

Problem. Meniscus tears and partial-thickness articular cartilage defect(s). (This is the most common condition the orthopaedic surgeon sees in practice.)

Treatment options. Arthroscopic debridement and partial meniscectomy followed by rehabilitation and physical and conditioning therapy.

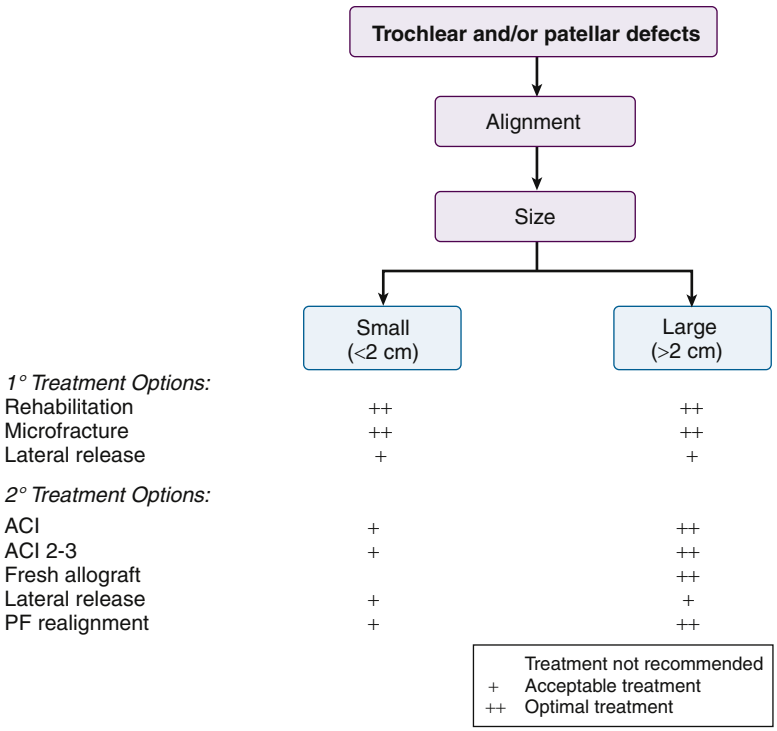

FIGURE 2-3 Algorithm for patellar and trochlear defects. *ACI,* Autologous chondrocyte implantation; *ACI 2-3,* autologous chondrocyte implantation generation 2 and 3; *PF,* patella femoral realignment.

Unresolved issues. Role of radiofrequency probes. Do they cause chondrocyte death or decrease regenerative and more degenerative or avascular consequences (bipolar, monopolar)? Why and when to use glucosamine and chondroitin sulfate and viscosupplementation?

Situation No. 2

Problem. Femoral articular cartilage defects less than 1 cm^2.
Treatment options. Debridement, microfracture, osteochondral grafting.
Unresolved issues. Do small defects heal sufficiently well with mesenchymal stem-cell stimulation techniques such as microfracture in the short and long term?

Situation No. 3

Problem. Femoral articular cartilage defects including osteochondritis dissecans size 1 to 2 cm^2.
Therapeutic primary options. Debridement, microfracture, osteochondral grafting, autologous chondrocyte implantation.
Therapeutic secondary options. Osteochondral grafting, autologous chondrocyte implantation.
Unresolved issues. Is a mesenchymal stem-cell stimulation technique an acceptable primary option?

Situation No. 4

Problem. Femoral articular cartilage defects including osteochondritis dissecans greater than 2 cm^2.

Therapeutic primary options. Autologous chondrocyte implantation, fresh allograft.

Therapeutic secondary options. Autologous chondrocyte implantation, fresh allograft.

Unresolved issues. What is the optimal and maximal size of lesion that osteochondral autografts can be applied?

Situation No. 5

Problem. Complex femoral articular defects with malalignment, ligament, or meniscal deficiency.

Therapeutic primary options. Osteotomy, meniscal repair or allograft, cruciate reconstruction(s), autologous chondrocyte implantation, fresh allograft, or osteochondral autograft depending on size.

Unresolved issues. How to optimally stage procedures so that index postoperative protocol does not compromise integrity of secondary or tertiary procedures. Which meniscus allograft, osteotomies, or ligament reconstruction procedure should be utilized?

Situation No. 6

Problem. Patellar or trochlear articular cartilage defects with no malalignment or instability.

Therapeutic primary options. Physical and conditioning therapy including tapping, bracing, and pelvic stabilization.

Therapeutic secondary options. Arthroscopy and lateral release, therapeutic tertiary options, autologous chondrocyte implantation plus anteromedialization or patellofemoral realignment osteotomy.

Unresolved issues: What are the definitive indications for arthroscopic lateral release? Does viscosupplementation have a role early in management of patellofemoral chondromalacia syndrome?

Situation No. 7

Problem. Patellar and trochlear articular cartilage defects, with significant malalignment, or instability.

Therapeutic primary options. Physical and conditioning therapy including tapping, bracing, and pelvic stabilization.

Therapeutic secondary options. Autologous chondrocyte implantation plus anteromedialization or patellofemoral realignment osteotomy.

Unresolved issues. Is the role of osteotomy beneficial early on to disease modifying such that it will prevent osteoarthritis (OA) of the patellofemoral joint?

Situation No. 8

Problem: Tibial articular cartilage defects—no significant malalignment or instability.

Therapeutic options. Osteotomy as required in relation to the degree of malalignment in combination with microfracture or autologous chondrocyte implantation depending on size of lesion.

Unresolved issues. Successful access may require release of collateral ligaments and detached meniscus insertions. Concomitant procedures protocols should not conflict with postoperative rehabilitative protocol.

Situation No. 9

Problem. Significant chondropenia and early OA (global Grade 3/4 articular cartilage defects in the 30- to 60-year-old patient with degenerative meniscal tears).

Therapeutic options. Nonsteroidal anti-inflammatory medications/COX-2 inhibitors, hyaluronic acid, glucosamine/chondroitin sulfate, bike for exercise, unloading braces, arthroscopy for mechanical symptoms, loose bodies and meniscal tears, osteotomy selectively as required in relation to the degree of malalignment or joint-space narrowing.

Unresolved issues. Is there a role for biological resurfacing procedures concomitant with realignment procedures?

Situation No. 10

Problem. Degenerative meniscal tears and global Grade 4 defects (late OA).

Therapeutic options. Nonsteroidal anti-inflammatory medications/COX-2 inhibitors, hyaluronic acid, glucosamine/chondroitin sulfate, bike for exercise, unloading braces, arthroscopy for mechanical symptoms, loose bodies and meniscal tears, osteotomy selectively as required in relation to the degree of malalignment or joint-space narrowing, total knee arthroplasty.

Unresolved issues. What is the role of arthroscopy in late OA other than alleviation of mechanical symptoms?

CONCLUSIONS AND FUTURE CHALLENGES

The challenges of articular cartilage repair and restoration continue despite recent advances. Marrow stimulation techniques, substitution replacement options, and biological replacement options each have a role in the treatment algorithm of articular cartilage defects. This treatment algorithm must take into account not only the characterization of the specific cartilage lesion but also the myriad of local and regional factors as well as the comorbidities attached to each patient. As of yet no single treatment option can reestablish

the hyaline cartilage seen in normal articular cartilage. The goal for future treatments is to develop new technologies and disease-modifying interventions that protect and preserve the joint over time by maintaining biochemical, biomechanical, and cellular integrity. Until these technologies exist, collaboration between the basic scientist and the clinician will continue to advance our current technologies in an effort to restore the violated articular cartilage surface.

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CHAPTER

3

Debridement of the Injured Cartilage

Mats Brittberg

INTRODUCTION

- Debridement of the injured cartilage
- Indications related to type of lesions
- Arthroscopic procedure or open

Cartilage lesions could be either traumatic or nontramatic. Common for all lesions are that they are irregular and need to be cleaned for a secure repair possibility, irrespective of which type of repair is to be used (Fig. 3-1):

- Defects that extend into the cartilage tissue but involve <50% of the cartilage thickness are classified as ICRS 2[1,2] (Figs. 3-2 and 3-3).
- These lesions are often unstable, with partly detached fragments that need to be debrided to form stable lesions.
- The prognosis for ICRS-2 partial-thickness lesions seems good, with diminished mechanical symptoms following a simple debridement that involves excision of the unstable cartilage fragments back to smooth edges and leaves the base intact.
- In the literature, the deep to bare-bone lesions seem troublesome. Lesions that extend through >50% of the cartilage thickness are classified as ICRS 3[1,2] (Figs. 3-3 and 3-4).
  There are four subgroups of this grade:
  - Deep defects that extend through >50% of the cartilage depth but not to the calcified layer are classified as ICRS 3a.[1,2]
  - Deep defects that extend through >50% of the cartilage down to the calcified layer are classified as ICRS 3b.[1,2]
  - Defects that extend down to but not through the subchondral bone plate are classified as ICRS 3c.
  - Finally, blisters are classified as ICRS 3d.[1,2]

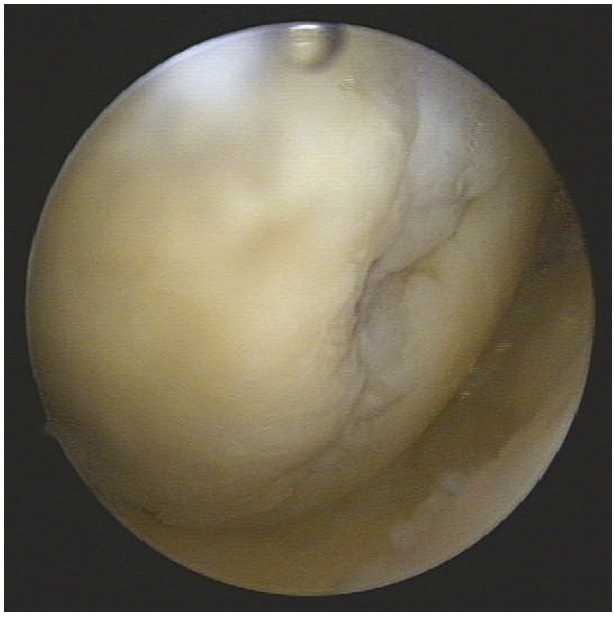

FIGURE 3-1 An irregular defect to be debrided. The defect has been treated before with bone marrow stimulation.

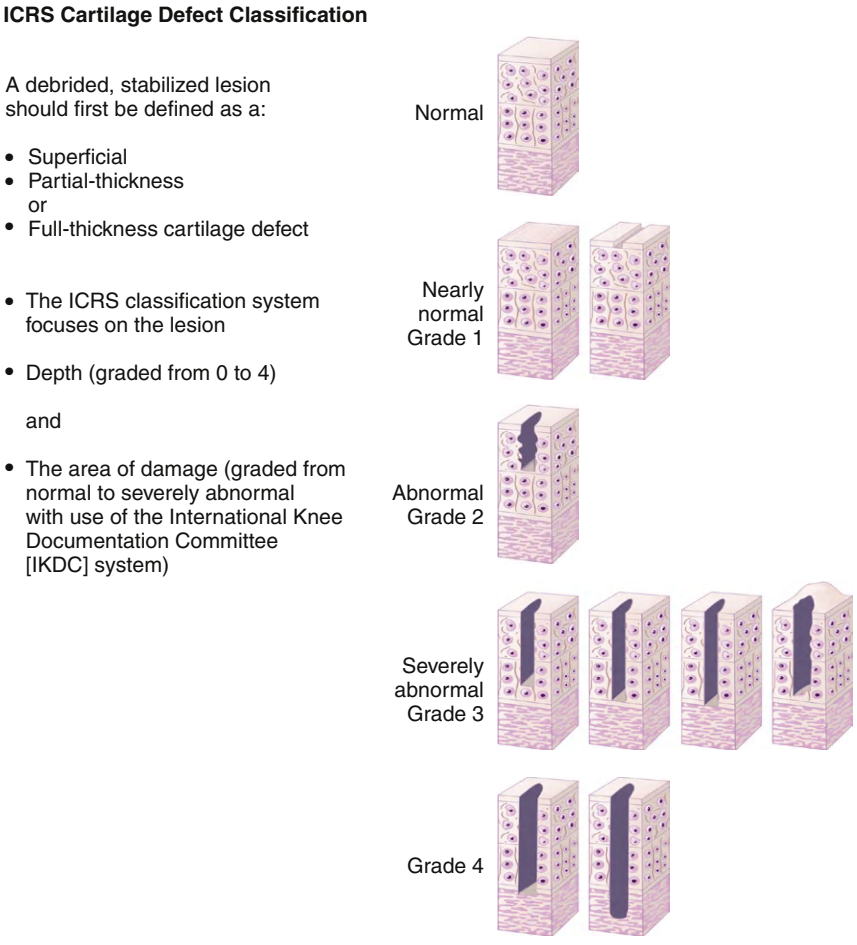

FIGURE 3-2 The ICRS cartilage defect classification.

ICRS Cartilage Defect Classification

- Defects that extend deeper but involve <50% of the cartilage thickness are classified as ICRS 2 (abnormal)
- These lesions are often unstable, with partly detached fragments that need to be debrided to form stable lesions
- The prognosis for ICRS-2 partial-thickness lesions seems good. With deminished mechanical symptoms following a simple debridement that involves excision of the unstable cartilage fragments back to smooth edges and leaves the base intact

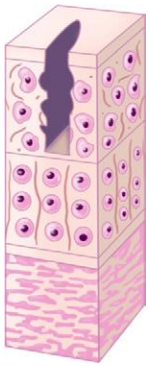

FIGURE 3-3 ICRS Grade 2.

ICRS Cartilage Defect Classification

- In the literature, the deep to bare-bone lesions seem troublesome. Lesions that extend through >50% of the cartilage thiskness are classified as ICRS 3

There are four subgroups:

- Deep defects that extend through >50% of the cartilage depth to the calcified layer are classified as ICRS 3a
- Deep defects that extend through >50% of the cartilage depth to the calcified layer are classified as ICRS 3b
- Defects that extend down to but not through the subchondral bone plate are classified as ICRS 3c
- Blisters are classified as ICRS 3d

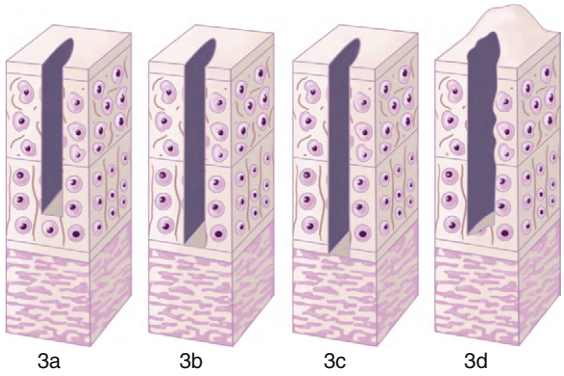

FIGURE 3-4 ICRS Grade 3 a-d.

All of the lesions in category ICRS 3 are simply defined as defects that extend through >50% of the cartilage thickness, through the cartilage but not through subchondral bone plate.

While debridement of unstable edges (as is suggested for ICRS-2 lesions) is suitable for ICRS-3 lesions, further treatment is recommended for these more extensive lesions.

Joint trauma may create cartilage defects that extend into the subchondral bone. These full-thickness osteochondral injuries are classified as ICRS 4[1,2] (Fig. 3-5). ICRS-4 lesions can be treated in the same manner as described for ICRS-3 lesions, but a lesion with extensive cavitations into the bone may require bone-grafting.

ICRS Cartilage Defect Classification

- Joint trauma may create cartilage defects that extend into the subchondral bone. These full-thickness osteochondral injuries are classified as ICRS 4
- Excluded from this grade are defects that are classified as osteochondritis dissecans (OCD)
- ICRS 4 lesions can be treated in the same manner as described for ICRS 3 lesions, but a lesion with extensive cavitation into the bone may require bone-grafting

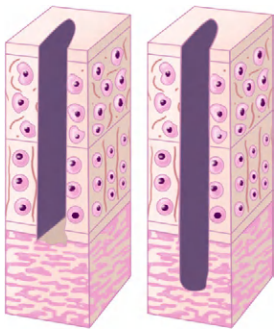

FIGURE 3-5 ICRS Grade 4.

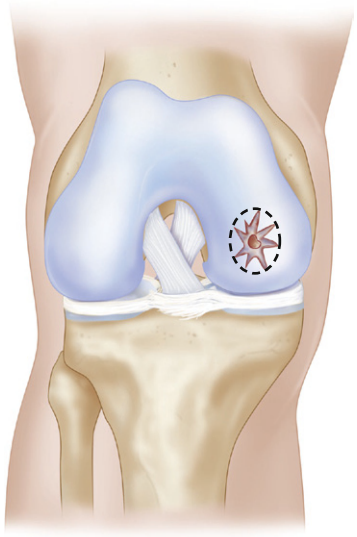

FIGURE 3-6 A cartilage lesion with loose flaps and central part down to bone on a medial femoral condyle. How much to excise as part of the debridement is outlined.

THE DEBRIDEMENT PROCEDURE IN DEFECTS GRADE 3 AND 4

After adequate exposure is obtained, the defect must be thoroughly debrided of all unhealthy cartilage surrounding the lesion. This includes all fissures and undermined cartilage, in addition to any fibrocartilage present in the base of the defect (Fig. 3-6).

The zone of damaged cartilage surrounding the chondral defect needs to be fully excised, and if you perform open surgery use a fresh scalpel blade, cutting vertically through the cartilage down to the level of, but not into, the subchondral bone (Fig. 3-7). A ring curette or a raspatorium can be used to remove the damaged cartilage or any fibrocartilage in the base of the defect.

When arthroscopic debridement is done, a raspatorium or ring curette is used.

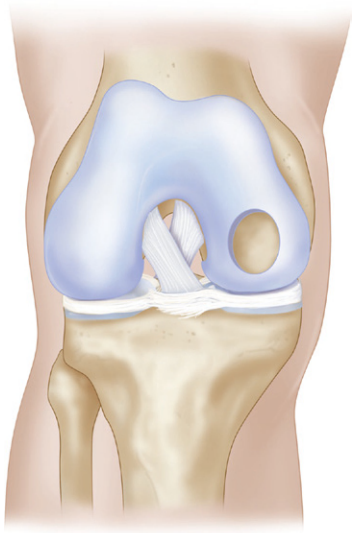

FIGURE 3-7 The defect in Figure 3-6 has been debrided.

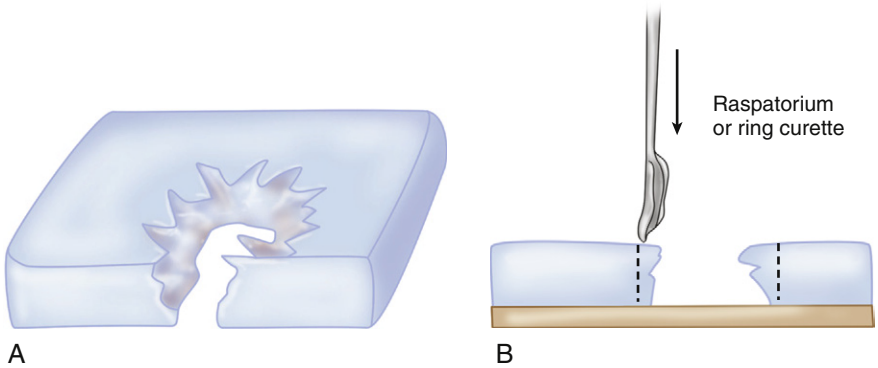

FIGURE 3-8 **A,** A ring curette or a raspatorium can be used to remove the damaged cartilage or any fibrocartilage in the base of the defect. **B,** Walls should be made as vertical as possible.

Vertical walls are formed with the raspatorium. A full radius shaver can be used after vertical walls have been formed. The shaver is used from the central part of the defect and conducted with sweeping movements, cleaning the defect toward the periphery (Figs. 3-8, *A-B* and 3-9, *A-B*).

Internal osteophytes in the subchondral bone can be the result of penetration of the subchondral bone either from injury or from prior surgical procedures, such as drilling, abrasion, or microfracture. These bony prominences, if small, can be addressed by gently tapping them back into the subchondral bone plate with a smooth, noncorrugated bone tamp.

Thermal debridement is also possible.[3] Electrocautery, laser, and radiofrequency energy devices can be used. However, earlier it was shown that these devices cause greater chondrocyte death compared to mechanical debridement and shaver use.[4] Recent publications show that the new radiofrequency devices now reach similar results regarding cell death as mechanical debridement:[5]

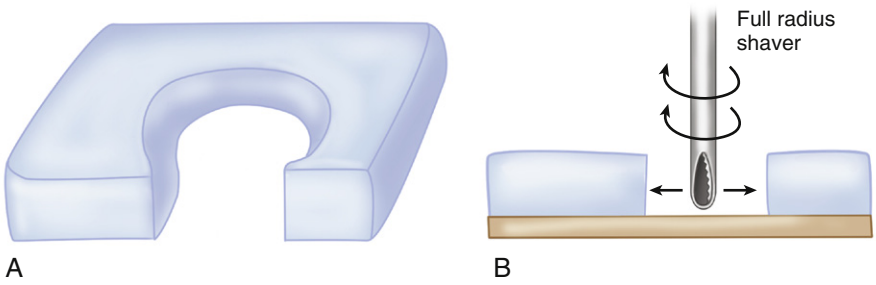

FIGURE 3-9 **A,** A shaver can be used after vertical walls have been formed. **B,** The shaver is used from the central part of the defect and conducted with sweeping movements, cleaning the defect toward the periphery.

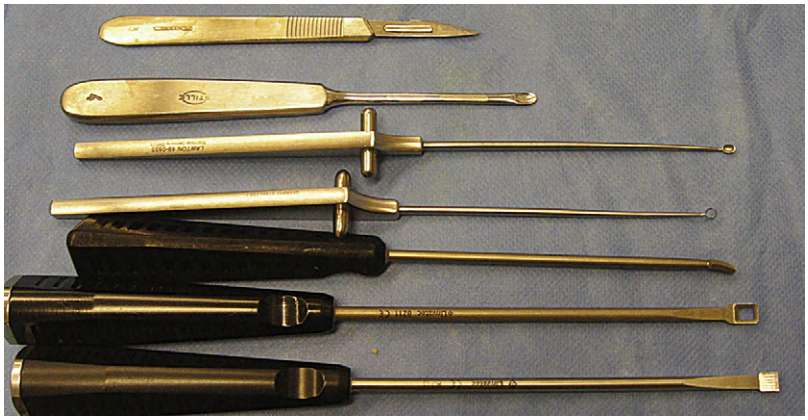

FIGURE 3-10 A typical debridement and cartilage repair instrument set. *From top, scalpel, Wiberg raspatorium, curved curette, ring curette, arthroscopic meniscal rasp, cartilage harvester, and angled wall debrider.*

- Once the defect is prepared, the dimensions need to be measured and recorded.
- In open surgery; to assist with obtaining the right size of implants if needed, a template made from either sterile paper or aluminum can be placed over the defect and outlined with a sterile marking pen, oversizing by 1 to 2 mm.
- The template is then cut out and used to help ensure an accurate size and shape of the desired implant.
- An arthroscopic ruler is also quite easy to use.

INSTRUMENTS FOR DEBRIDEMENT

- Ring curette (Fig. 3-10)
- Raspatorium (Fig. 3-10)
- Shaver-full radius resector
- Radiofrequency energy

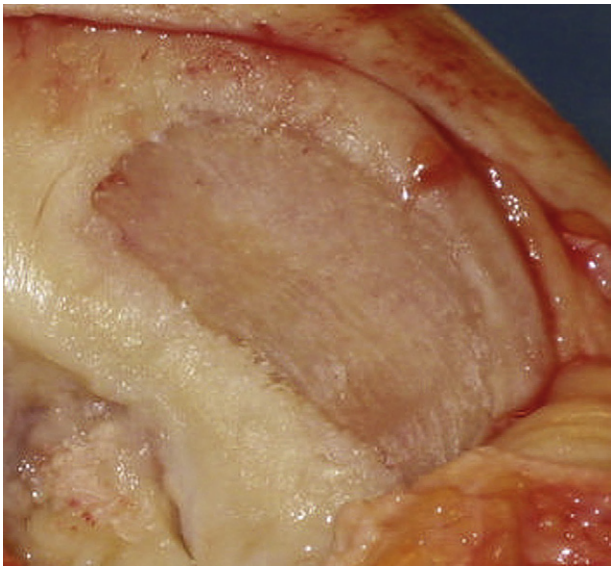

FIGURE 3-11 A radically debrided defect with a clean bare bone surface.

PEARLS AND PITFALLS

Radical excision is crucial. All flaps and fissures must be excised. The most common error is not to be radical enough (Fig. 3-11).

Start with a raspatorium or ring curette. A shaver can be used from a central position first when the defect has been debrided to vertical walls.

All of the lesions in category ICRS 3 are simply defined as defects that extend through >50% of the cartilage thickness, through the cartilage but not through the subchondral bone plate. Debridement of unstable edges (as is suggested for ICRS-2 lesions) is suitable also for ICRS-3 lesions, but further treatment is recommended for these more extensive lesions.

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CHAPTER

4A

Bone Marrow Stimulating Techniques

Drilling, Abrasion Arthroplasty, and Microfracture

Wayne Gersoff

INTRODUCTION

The principle of bone marrow stimulating techniques involves the penetration of the subchondral bone plate to provide vascular access channels to the area of chondral defect. This allows for mesenchymal cells to fill the defect and provide a repair tissue fill of the articular cartilage defect. Three techniques are commonly used: abrasion arthroplasty,[1] subchondral drilling,[2] and microfracture.[3]

STEPS COMMON TO ALL TECHNIQUES

1. During knee arthroscopy, identify the area of articular cartilage injury (Fig. 4A-1).
2. Utilizing an arthroscopic shaver or curette, debride the borders of the defect back to stable, vertical walls (Figs. 4A-2 and 4A-3).
3. Remove calcified cartilage from subchondral bone using a shaver or curette. Leave no loose flaps or debris in the lesion site. The defect is now prepared (Fig. 4A-4).

ABRASION ARTHROPLASTY

1. Using an arthroscopic burr—either round or oval—abrade the exposed subchondral bone to produce a punctuate bleeding surface. If using a tourniquet, let it down to confirm the presence of punctuate bleeding bone (Figs. 4A-5 and 4A-6).

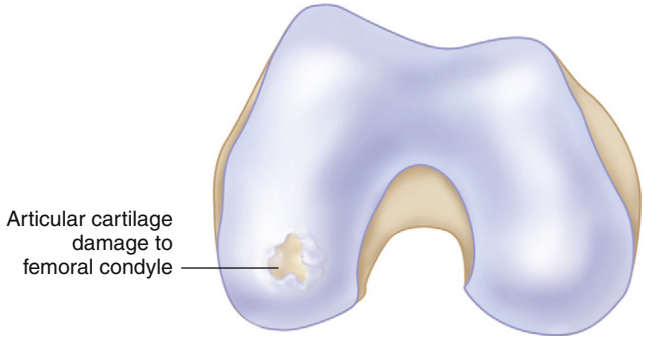

FIGURE 4A-1 Articular cartilage damage to femoral condyle.

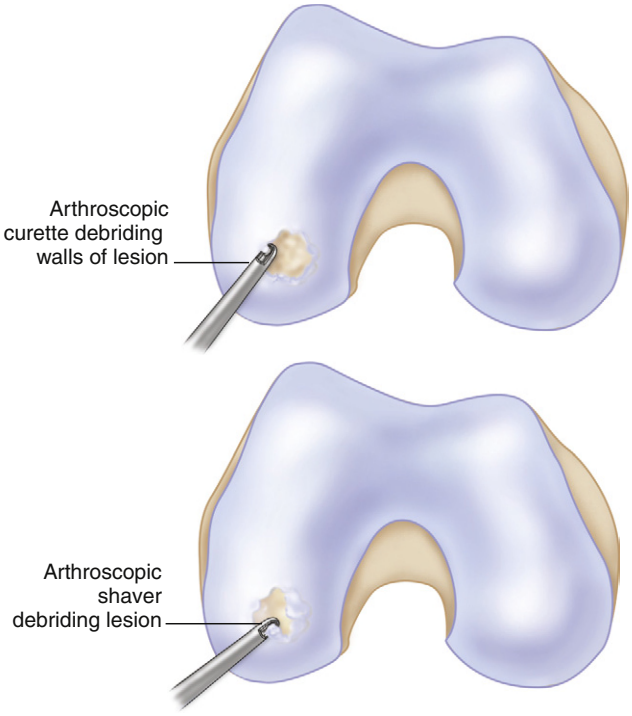

FIGURE 4A-2 and FIGURE 4A-3 Utilizing a shaver and curette to debride.

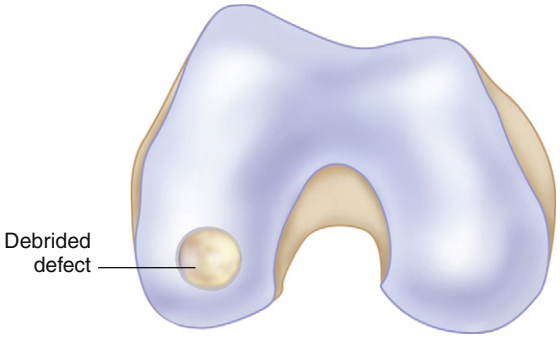

FIGURE 4A-4 Debridement of calcified cartilage.

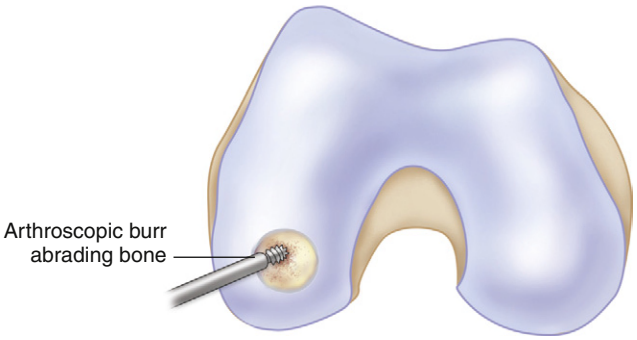

FIGURE 4A-5 A burr abrading bone.

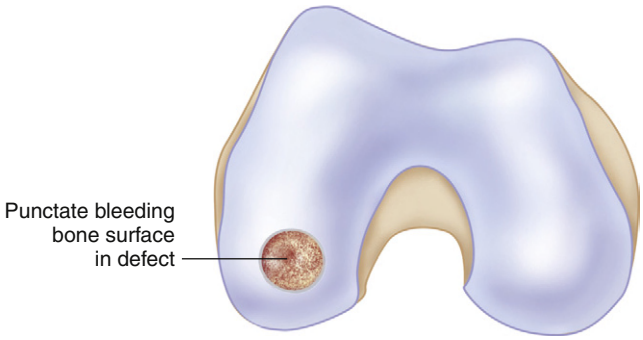

FIGURE 4A-6 Punctuate bleeding.

2. A smooth surface must be created, avoiding any divots. Any hypertrophic or sclerotic bone must be removed.
3. After completion of abrasion and confirmation of bleeding, avoid irrigating or disrupting coverage of the defect.

SUBCHONDRAL DRILLING

1. Select an appropriate size drill bit or K-wire and attach to the drill.
2. Starting in the periphery and progressing centrally, place multiple drill holes into the defect, penetrating the subchondral bone plate (Fig. 4A-7).
3. The drill hole should be placed 3 to 4 mm apart, and convergence should be avoided (Fig. 4A-8).
4. Confirm the presence of bleeding from drill holes. If applicable, the tourniquet should be released and water flow stopped (Fig. 4A-9).
5. Drill holes that are not bleeding may need to be drilled deeper.

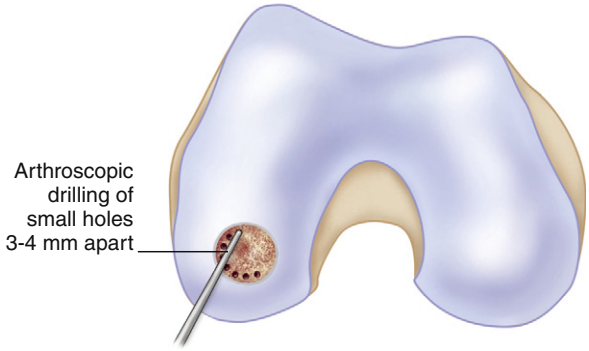

FIGURE 4A-7 K-wire penetrating the subchondral bone plate of defect.

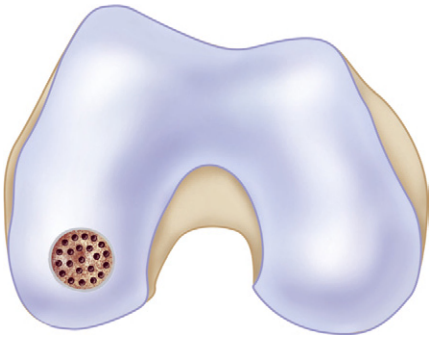

FIGURE 4A-8 Multiple drill hole placement.

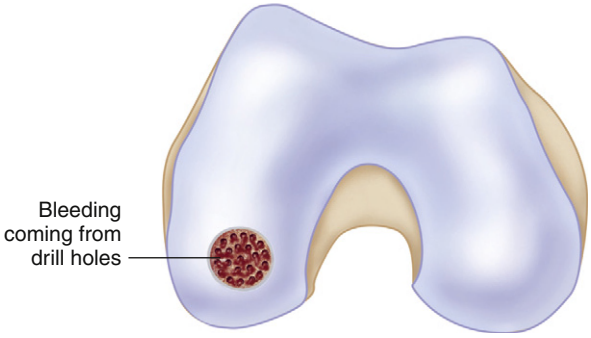

FIGURE 4A-9 Bleeding from drill holes.

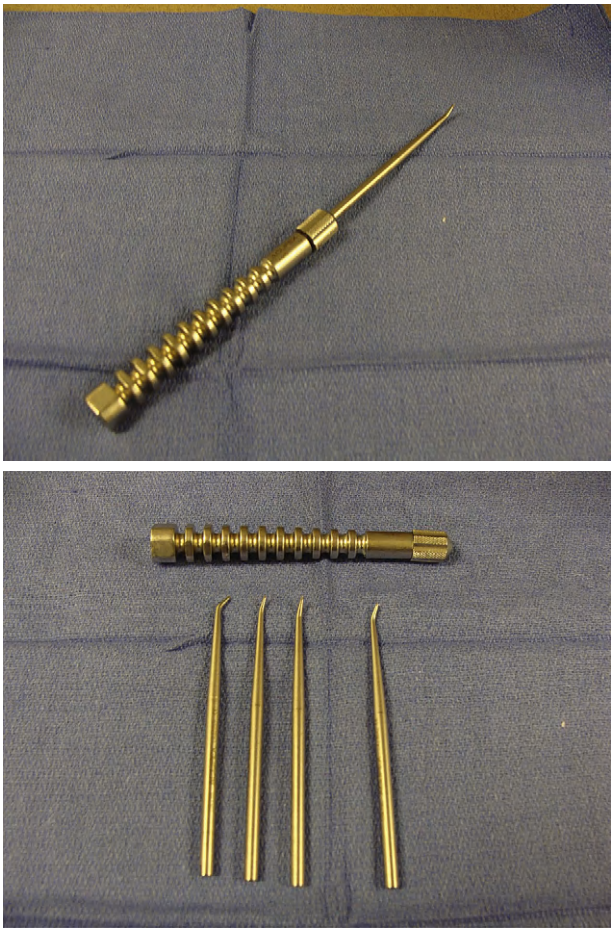

FIGURE 4A-10 Awls.

MICROFRACTURE

1. The microfracture awls come in various angles. Select the appropriate awl to facilitate access to the lesion (Fig. 4A-10).
2. Moving from the periphery to the center of the defect, use the awl to create holes penetrating the subchondral bone plate (Fig. 4A-11).
3. Holes should be placed 3 to 4 mm apart. Holes should be perpendicular to the bone surface and convergence avoided (Fig. 4A-12).
4. Remove any bony debris.
5. Deflate the tourniquet, if applicable. Drain the knee, and then turn water off. Confirm bleeding. Avoid disrupting the fibrin clot (Fig. 4A-13).

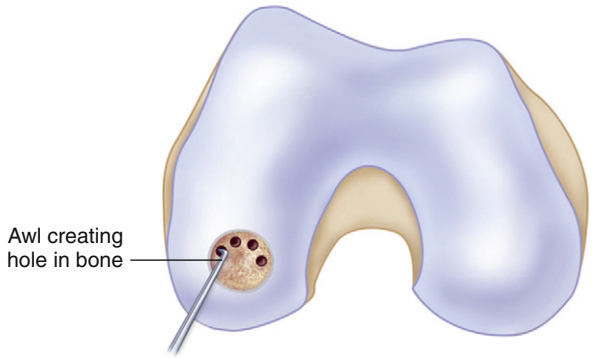

FIGURE 4A-11 Awl penetrating subchondral bone.

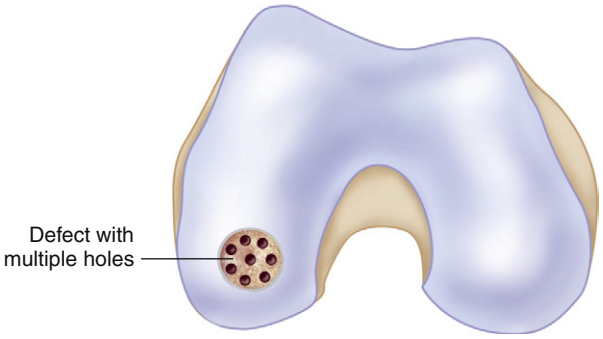

FIGURE 4A-12 Multiple holes.

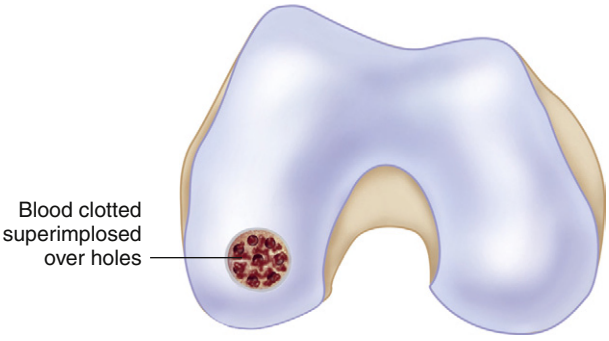

FIGURE 4A-13 Formation of clot in defect.

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CHAPTER

4B

Bone Marrow Stimulating Techniques

Carbon Fiber Resurfacing

Mats Brittberg

INTRODUCTION

The rationale behind using carbon fiber as a biomaterial is as follows:

1. Carbon is biocompatible and inert.
2. Carbon fibers are strong in tension.
3. The matrix of carbon fiber materials become infiltrated with connective tissue and, ultimately, organized collagen fibers, thus forming a strong "biological composite" material.

In 1987,[1] Minns et al. published a preliminary clinical experience in a new concept of biological resurfacing using carbon fiber implants in the form of pads or rods placed in defects within the knee that elicit a dense organized matrix of fibrous tissue that forms a new biological and functioning articular surface. No evidence of implant fragmentation has been seen since implantation in the 145 knees studied.[1]

Carbon fiber arthroplasty appears to be appropriate in the surgical management of ICRS Grades 3 and 4 articular cartilage lesions in the painful knee.[2,3,4,5]

- **Carbon fiber rods** (Medicarb, Surgicraft, England or Chopin pins, BMI Biomedical Implants GmbH, Hanstedt, N. Germany). The carbon fibers are fabricated from organic fibers such as polyacrylonitrile or rayon. A braided sheath of 12 rows of 9-micron diameter carbon fiber bundles is drawn around a central core of carbon fibers. The continuous braided rod is cut into individual rods of 12.5 mm in length; the average diameter is 3.2 mm. Porosity is about 50% (Fig. 4B-1).
- **Carbon fiber pads** (Medicarb, Surgicraft, England). The carbon fiber tows can be produced into layered nonwoven pads with a random loosely

FIGURE 4B-1 Carbon rod of 12.5 mm length; the average diameter is 3.2 mm. Porosity is about 50%.

FIGURE 4B-2 Carbon pad, approximately 4 mm thick in discs up to 22 mm in diameter. Porosity is about 85%.

arranged porous scaffold, the resulting pads being approximately 4 mm thick in discs up to 22 mm in diameter. Porosity is about 85% (Fig. 4B-2).

- **Transarthroscopic operative technique—carbon rods.** The cartilage lesion area is debrided as described in Chapter 3. A set of instruments for the different procedures is available (Fig. 4B-3).

With the arthroscope in the anterolateral portal, a special cannula with an obturator is inserted into an anteromedial portal.

The cannula is positioned in the defect, on the bony surface (Fig. 4B-4).

The obturator is removed. Through the cannula, a 3.2-mm drill bit is put and a hole is drilled until depth- stop (Fig. 4B-5).

The holes should be drilled at a minimum distance of 8 to 10 mm apart to maintain a reliable interposing bone between the holes.

The drill is withdrawn and an insertion guide is put into the cannula. The guide should fit to the level of the stop (Fig. 4B-6)

The depth is controlled with a special thin obturator. The obturator should fit to the level of the stop, and there should be no difficulty in the insertion (Fig. 4B-7)

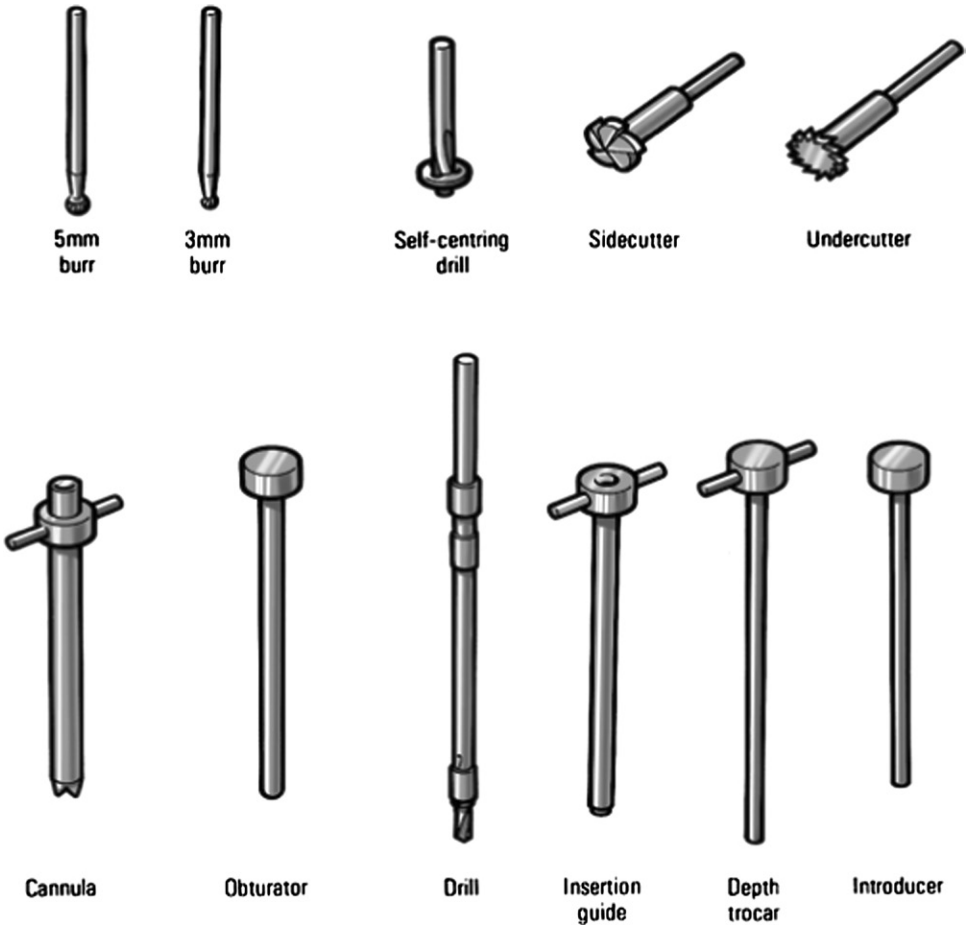

FIGURE 4B-3 Carbon rods and pads implantation set.

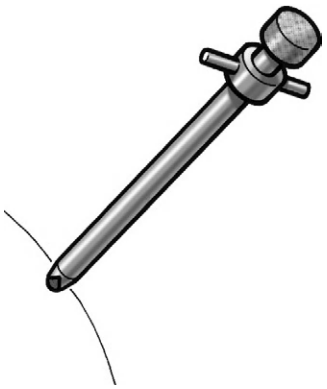

FIGURE 4B-4 The cannula is positioned in the defect, on the bony surface.

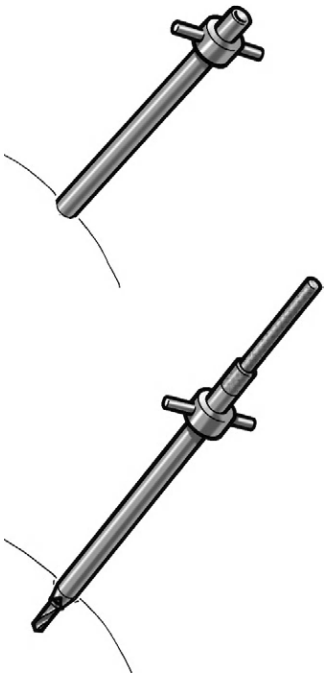

FIGURE 4B-5 A 3.2-mm drill bit is put through the cannula, and a hole is drilled until depth-stop.

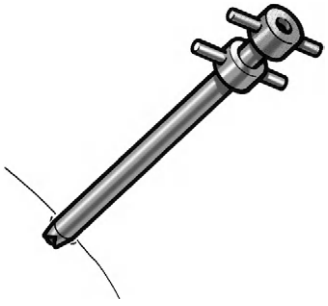

FIGURE 4B-6 An insertion guide is testing the drilled hole.

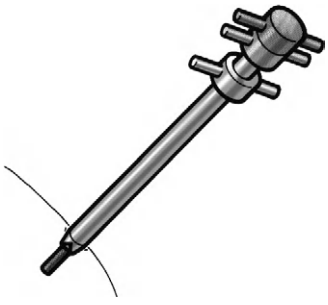

FIGURE 4B-7 The drilled depth is controlled with an obturator.

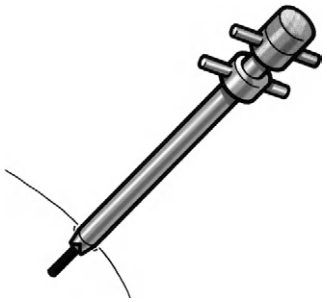

FIGURE 4B-8 A carbon rod is gently put into the cannula and pushed until it stops. It should then be flush with bony surface or slightly below.

FIGURE 4B-9 Multiple holes are drilled with the self-centering drill.

Finally, a rod is implanted through the insertion guide. The rod should slide in without any resistance (Fig. 4B-8). The top of the rod should be flush with the bony surface or slightly below. By no means should the top protrude above the bony surface.

CARBON PADS (NEEDS OPEN SURGERY)

The pads are mainly used for concave surfaces such as destroyed patellar surfaces.

The hard subchondral bone is opened by using a self-centering drill incorporating a 3-mm depth stop. Multiple holes are drilled (Fig. 4B-9).

The bony bridges are broken down using a side cutter (Fig. 4B-10)

The subchondral bone is undercut using an under cutter (Fig. 4B-11).

A caliper is used and placed into the defect with its tips in the undercut. The required size is read off the gauge (Fig. 4B-12).

A circular cavity is formed of a suitable size to accommodate one of the ranges of carbon pads available. The carbon material can be cut with scissors to fit, and several of the pads may be used to fill the area.

The pad should be soaked in saline, and the edges of the pad are eased carefully under the bony rim of the defect (Fig. 4B-13). No extra fixation is needed.

FIGURE 4B-10 The bony bridges are broken down using a side cutter

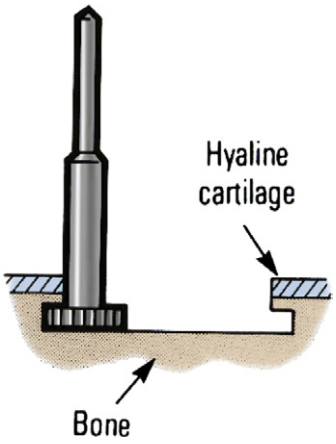

FIGURE 4B-11 The subchondral bone is undercut using an under cutter

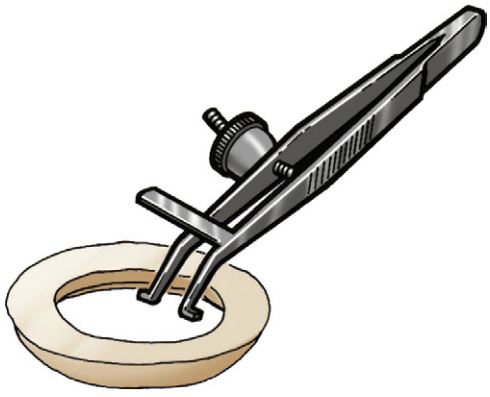

FIGURE 4B-12 The required size of the pad is read off the caliper gauge when pushing its tips under the bony rim.

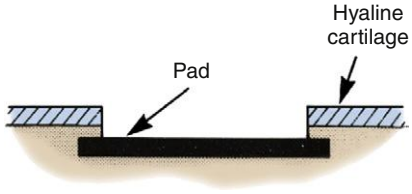

FIGURE 4B-13 The pad is pushed into the defect, and its edges are placed under bony rims.

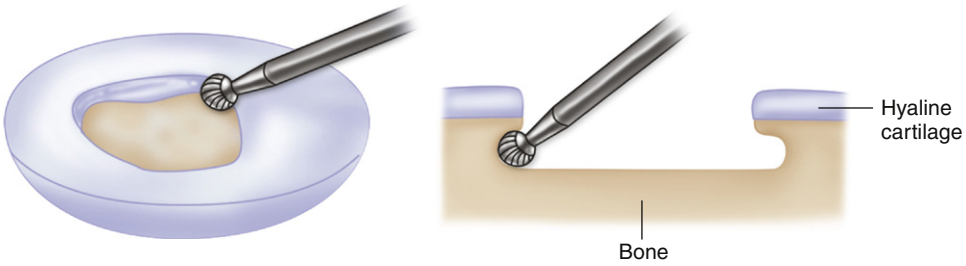

FIGURE 4B-14 A bone pool is made in the subchondral bone with 3- and 5-mm burrs when a special carbon instrument set is not available.

If the self-centering drill, side cutter, and under cutter are not available, the different stages can also be done using a 5-mm and a 3-mm burr. First the subchondral bone is removed to a depth of 3 mm with the 5-mm burr. The following undercut is made using the 3-mm burr into a depth of 2 mm (Fig. 4B-14).

HYBRID REPAIR

When a cartilage repair is partially insufficient at the borders to adjacent cartilage, one may use a carbon rod to induce a strong interpositional ingrowth of repair tissue. The author is using a carbon rod when autologous chondrocyte implantation (ACI), ACI repair tissue, or other induced repair tissue is showing insufficient repair with partial loosening of the grafted area. The loose area is then excised, and the bare area is debrided and treated by implantation of one or two rods. The strong induced fibrocartilaginous repair tissue will bridge the adjacent cartilage to the ACI repair tissue. (Fig. 4B-15).

CARBON ROD REVISION

Carbon rods can easily be taken away if the overlaying repair has been destroyed and a new carbon rod may be needed.

Drill through the old rod. A black mass of carbon will protrude through the drill hole and can be swept away with a shaver, a "vacuum cleaning" effect. A new rod can then be implanted.

How do you manage a carbon fiber—treated joint when implanting to do a prosthetic joint total knee replacement? Do the required resections as usual. The surfaces will appear as surfaces with black spots of carbon at the level of the respected surface.

Leave those spots even but excise the carbon only if it sprouts out, and use a small ladle to clean the drill holes from carbon debris.

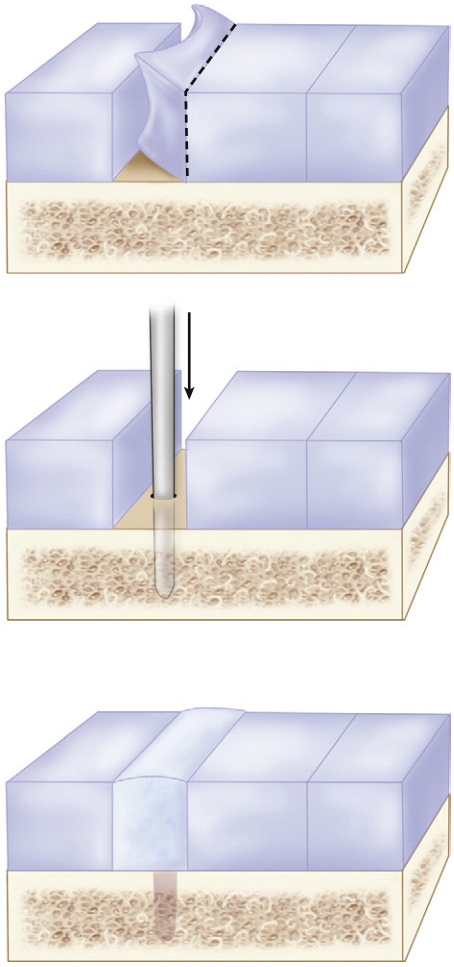

FIGURE 4B-15 Treatment of a partial loosening of a grafted cartilage repair area. A carbon rod is put into a predrilled hole in the defect border zone area. The repair tissue from the implanted carbon rod will bridge and support the earlier graft to the adjacent cartilage.

If the intent is to replace the patella surfaces with a plastic cup, do the normal resections, drill central holes for the central patella cup peg into the carbon, and use bone cement as it is normally used for arthroplasty fixation.

PEARLS AND PITFALLS

The technique is ideal to use in combination with other techniques such as autologous chondrocyte implantation (ACI).

Especially when there is a border insufficiency, the rods can augment and support the surroundings. As the technique is done transarthroscopically, the extra repair is done easily.

It is important that the carbon fibers are to be used implanted flush with the bony surface or preferably 1 mm below the bony surface, especially when treating kissing lesions and bipolar defects.

The biological response of carbon fiber in the knee was reported by Muckle and Minns,[4] in which minimal synovitis was observed except in knees that also displayed an associated instability.

If there is no shouldering cartilage, just bare bone on both sides, "kissing lesions," do not use the carbon implants.

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CHAPTER

4C

Bone Marrow Stimulating Techniques

Autologous Matrix-Induced Chondrogenesis (AMIC)

Peter Behrens, J.P. Benthien

INTRODUCTION

Chondral and osteochondral defects may affect any major joint, but they more often affect the large weight-bearing joints such as the knee and ankle joints. They may be of traumatic or hereditary origin (osteochondrosis dissecans). The original hyaline cartilage may as yet not be restored, so a permanent loss of the original cartilaginous surface is inevitable and responsible for premature arthritis and eventually destruction of the affected joint. However, a stable fibrous cartilage may develop from mesenchymal stem cells invading the defects from the underlying blood vessels, which will yield the patient pain free and slow down the process of joint destruction. Several methods in cartilage reconstruction are available such as ACT/ACI (autologous chondrocyte transplantation/implantation),[1] matrix-induced autologous chondrocyte transplantation/implantation (MACT/MACI)[2,3,4,5,6] and microfracturing. The membrane-associated chondrogenesis is well documented in vitro. A variety of collagen scaffolds is commercially available and may be applied. Fixation is possible either with fibrin glue (allogenic or partially autologous) or sutures.

An advantage of the autologous matrix-induced chondrogenesis (AMIC) procedure is that it is a one-step process for the patient, allowing the blood clot yielded after microfracturing to stay at the desired location and the chondrocytes to develop on a collagen scaffold in situ. Any collagen matrix will suffice.

SURGICAL PRINCIPLES AND OBJECTIVE

Step 1

Arthroscopy for diagnostic evaluation of the joint, arthroscopic debridement, accompanying meniscus lesions, or ligament instabilities can also be treated, and the cartilage lesion can be identified.

Step 2: Miniarthrotomy

Debridement of lesion: degenerated and detached cartilage is completely removed, microfracturing with a sharp awl or pick, and, if necessary, a mallet to perforate the subchondral bone every 5 mm; a template is made that matches the size of the defect, not overlaying the defect (Figs. 4C-1, 4C-2, and 4C-3).

Step 3

One may use the foil of the packed surgical sutures as a template for sizing the collagen membrane: the template is used to draw the defect size accurately onto the membrane, and then the membrane is placed into the defect; to stabilize the moistened matrix, it is useful to use a sterile paper (e.g., from the gloves).

Step 4

In the meantime, a 10-ml blood sample is taken from the patient; derive the serum by centrifugation (using a hand centrifuge) or allow it to settle, discard 50% of the thrombin of the commercially available fibrin glue (double syringe system: one syringe is thrombin and the other is fibrinogen, for example Tissucol/Tisseel, Baxter Biosciences, Vienna, Austria), replace it with the autologous serum, and mix it so you get the partial autologous fibrin glue (PAF).

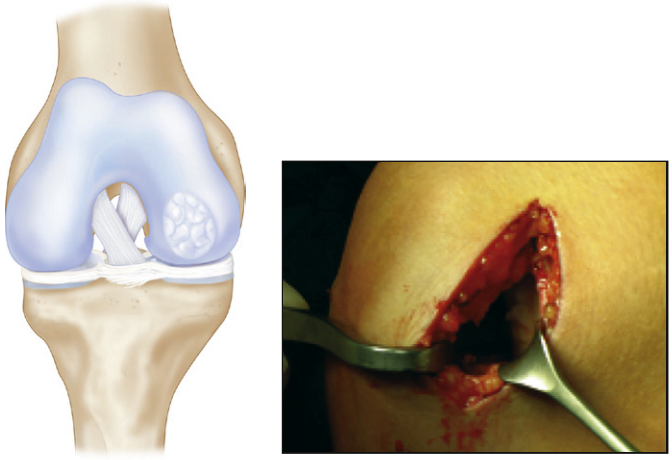


FIGURE 4C-1 Identify the lesion and perform a miniarthrotomy after arthroscopy.

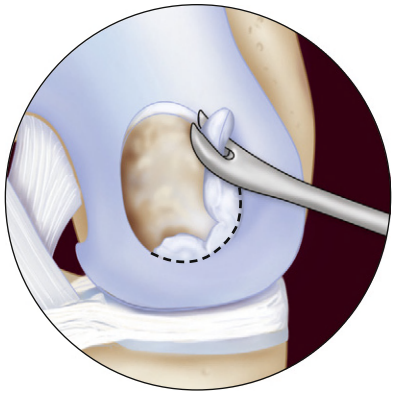
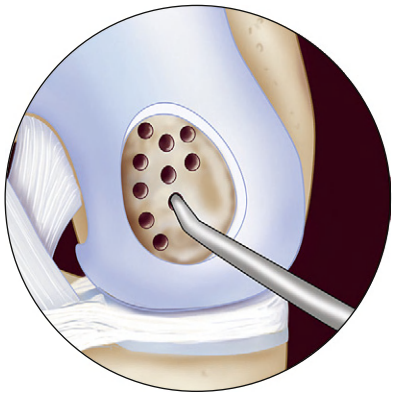


FIGURE 4C-2 Thorough curettage of the lesion is mandatory before microfracturing may be performed. An aluminium template is helpful for defining the lesion's extent. At this time, a bone graft may be implanted in osteochondral lesions.



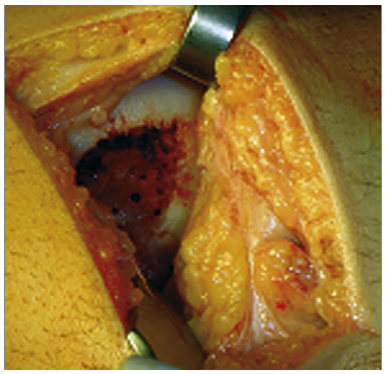


FIGURE 4C-3 After curettage of the lesion, the microfracturing may be performed every 5 mm.

Step 5: Fixation of Matrix with PAF

The matrix is glued directly onto the prepared defect and is adjusted digitally. Finally the knee joint is held in an extended position for 5 minutes (Fig. 4C-4, *A-H*).

Afterward, flex the knee 10 times to test the stability and correct position.

Step 6

If necessary, add autologous bone graft to build up the defect to the level of the original surrounded bone (e.g., osteochondral defect).

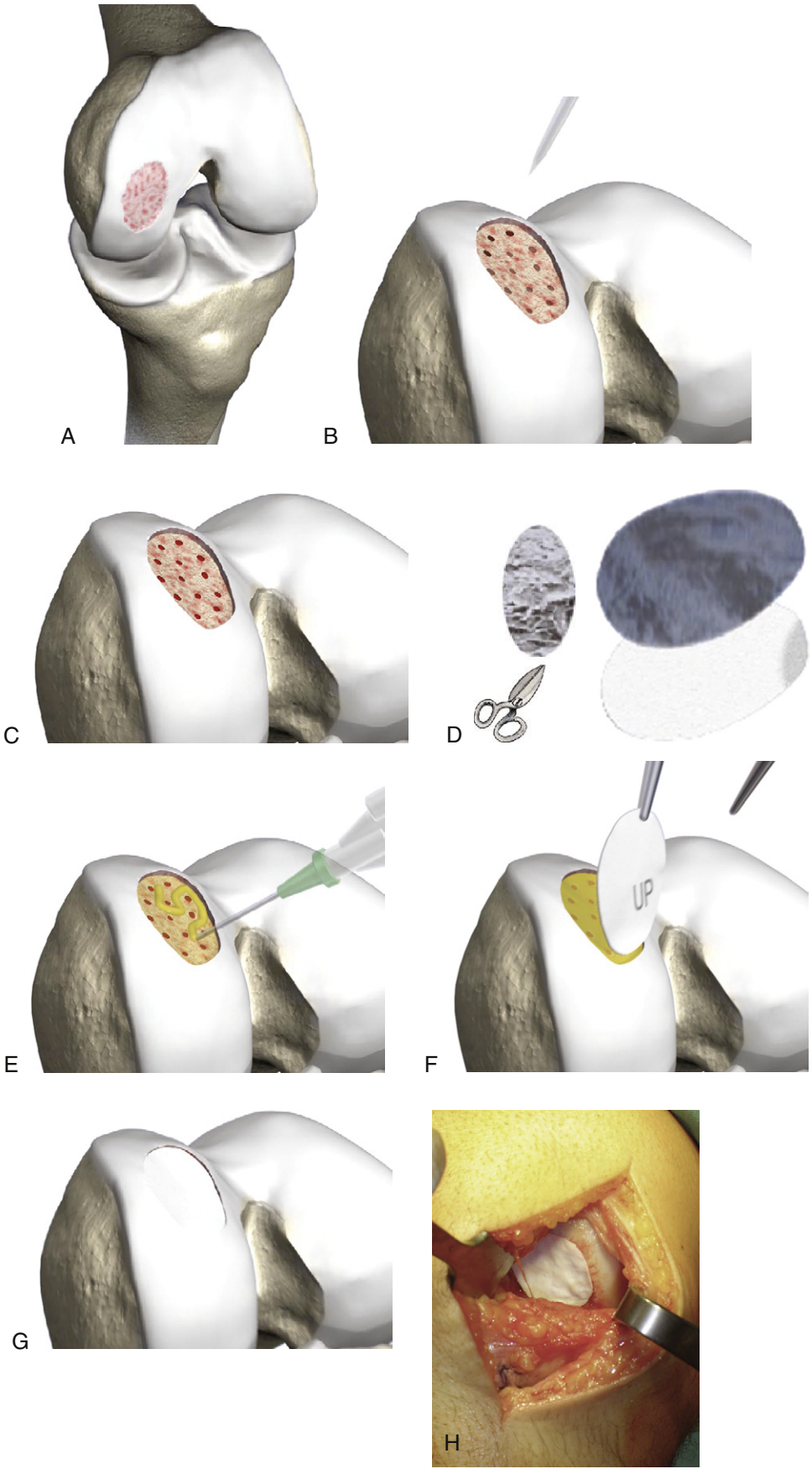


FIGURE 4C-4 The repair with AMIC, seen in a sequence. **A, B,** and **C,** Cartilage defect, preparation by microfracturing with sharp awl or pick, and removal of debris. **D,** Preparing a template that matches the defect size. **E** and **F,** Glue is directly applied, and matrix is glued directly onto prepared defect. **G** and **H,** Matrix in place.

Step 7

Close the wound using standard techniques; drainage without suction can be used.

Step 8

Postoperative treatment: immobilize the knee for 7 days in extension.

Starting with continuous passive motion (CPM) for 4 to 6 weeks.

Femoral and tibial defects: non–weight bearing for 6 weeks, afterward building up full weight bearing within 2 weeks.

Patellar and trochlear defects: non–weight bearing 2 weeks, up to the 4th week, 50% body weight, afterward building up to full weight bearing within 2 weeks.

POSTOPERATIVE TREATMENT

Thrombosis prophylaxis should be used from the start of the operation. Medication, ice application, lymph drainage, and muscle stimulation or electrotherapy can be part of the postoperative treatment.

Advantages

- One-step surgery, easy treatment, repeatable
- Protects and stabilizes blood clot
- Prevents bleeding into synovia
- Provides matrix for bone derived mesenchymal stem cells
- Matrix-induced chondrogenesis
- Easy availability and coverage of defects with collagen matrix
- Treatment of osteochondral defects (OCDs)
- Partial autologous fibrin glue is readily available

Disadvantages

- Arthrotomy still necessary (open surgery)
- Not for kissing lesions
- High patient compliance
- Collagen allergy

Indication

- Symptomatic cartilage defects Grade 3 or 4 (Outerbridge, ICRS classification)
- Osteochondral lesions (e.g., posttraumatic or osteochondrosis dissecans)

- 18 to 55 years of age
- Defect size more than 1.5 cm[4]
- Intact, normal surrounding cartilage
- Intact corresponding cartilage (Grade 2 acceptable)

Patient Information

Common surgical risks include postoperative infection, thrombosis, hemorrhage, wound healing disturbances, diminished weight bearing, and long period of rehabilitation.

Preoperative Workup

- Standard weight-bearing radiographs in two planes, anteroposterior and lateral views
- MRI in T1 and T2 saturation with contrast fluid
- Before surgery, antibiotic single shot prophylaxis

Surgical Instruments

- Standard set for knee arthroscopy
- For microfracturing, a set of probes with straight and 45-degree angled sharp points and a light hammer
- Aluminium template for an imprint and measurement of the defect
- Fibrin glue, for example, Tissucol, the fibrinogen part only, mixed with autologous serum
- Centrifuge
- Collagen matrix

Anesthesia and Patient Positioning

- Spinal or general anesthesia
- Prone position of the patient
- Tourniquet is advisable for better views

Postoperative Treatment

- Maximum weight bearing 15 to 20 kg, depending on the patient's weight.
- Removal of drain on days 1 or 2 after surgery.
- Maximum flexion of the knee 30 degrees for 2 weeks following the operation. Assisted active physical therapy may be applied, minding the weight and range of motion limits. Isometric quadriceps training, straight length raising, and hamstring isometrics are possible.
- Flexion is raised to 60 and 90 degrees for another 2 weeks, respectively. The patient is seen in the outpatient clinic 6 weeks after the appointment.
- After 6 weeks, progressive exercising is possible with light biking in a slight resistance setting.

Special Considerations

Suturing the membrane is possible. The author's preferred fixation method is with fibrin glue, which may be yielded partially autologous or allogenic.

The partial autologous fibrin glue substitutes the commercial thrombin component. This is very important because of the TGF-ß growth factor, which is an important mediator for attaching mesenchymal stem cells.[7]

The knee should be fully flexed and extended about 10 times after membrane fixation, and the collagen membrane should be checked to be sure it has not dislocated.

DANGERS, ERRORS, AND COMPLICATIONS

The patients must be compliant and aware of a lengthy postoperative therapy. The absence of work may be considerable.

Undersizing the matrix is mandatory, especially when the fixation with fibrin glue is chosen. An oversized membrane is likely to dislocate!

The patient should be aware that an arthrotomy is performed, and that the risks of an intraarticular infection are higher than with simple arthroscopy.

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CHAPTER

4D

Bone Marrow Stimulating Techniques

TRUFIT Plugs

Tim Spalding

INTRODUCTION AND BACKGROUND

This chapter details the surgical technique for the implantation of TRUFIT CB plugs. This process involves creating perpendicular access to the articular surface via an arthroscopic or open approach, thereby creating a flush surface with one or two plugs. The technique can be expanded to allow implantation of multiple plugs.

The TRUFIT plug (Smith & Nephew, Andover, Massachusetts, United States) has been designed as a multiphase implant with tailored degradation (Fig. 4D-1). The implant is composed of a polylactic acid (PLA), polylactic glycolide (PLG), and polyglycolic acid (PGA) copolymer, with calcium sulphate, PGA fibers, and surfactant.[1,2,3] The bilayer design provides cartilage and bone phases, and initially the cartilage phase is softer and malleable enough to be physically contoured to joint curvature. The plug acts as a porous scaffold that provides structural support while allowing the growth of new healing tissue. The calcium sulphate resorbs in the first several months, and the remaining polymer dissolves over a 12- to 36-month period, allowing for complete filling of the defect by repair tissue.[3]

INDICATIONS/CONTRAINDICATIONS

TRUFIT plugs are indicated for the repair of full-thickness articular cartilage or osteochondral lesions.[5] The optimal lesion size is less than 2 cm^2 to ensure that the plugs are well shouldered by normal surrounding articular cartilage. However, the indication is extended for longitudinal patterns of defects in the articular surface when plugs can be inserted in a line. TRUFIT plugs are

FIGURE 4D-1 The TRUFIT CB (cartilage/bone graft substitute) plug.

not indicated for larger areas where they would be positioned in a circle or group unless a 2 mm or more bone bridge is maintained between plugs.

SURGICAL POSITIONING

Surgery is performed under general or local anesthesia, and the patient is positioned supine on the operating table with a side post applied.

For **femoral condyle lesions,** the knee is positioned over the edge of the table against the side post and the angle of knee flexion is controlled by pushing the leg against the side of the table (Fig. 4D-2). This makes repositioning of the leg easier than the alternative of positioning the knee at 90 degrees on the table against a foot piece, which holds the knee more rigidly.

For **lesions on the trochlea,** the leg is positioned nearly straight on the operating table and is supported over a removable sterile bolster (Fig. 4D-3), such as a sandbag or a 3L irrigation fluid bag in a sterile Mayo cover, for example.

SURGICAL APPROACH

Regarding the surgical approach, a decision has to be made as to where the lesion is and whether the surgeon is choosing an arthroscopic or a mini-open approach. When considering arthroscopic or a mini-open approach, there are various scenarios that make it more difficult for an arthroscopic technique.

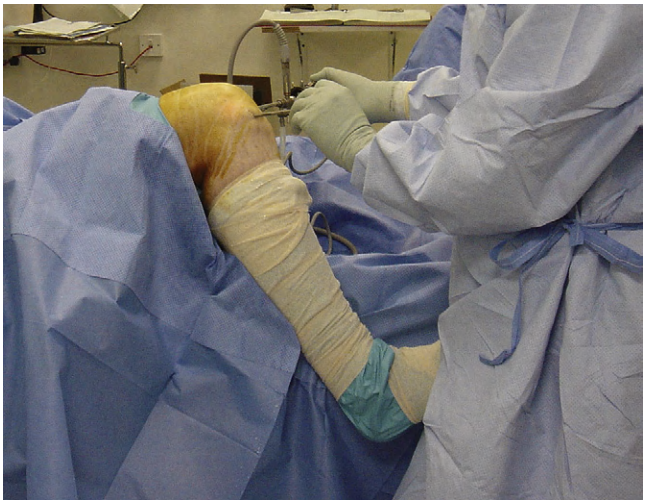


FIGURE 4D-2 Patient positioned with leg supported against a side post.

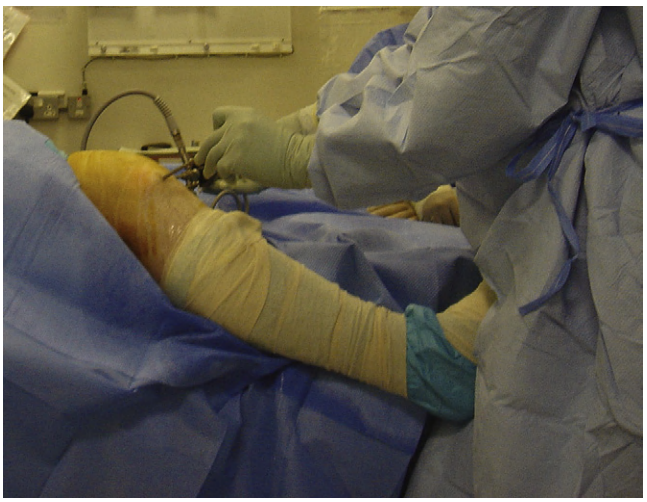


FIGURE 4D-3 Patient positioned with the knee flexed over a bolster.

It may be quicker to make a small open arthrotomy rather than persevere arthroscopically, and it is certainly easier to visualize the surface to obtain a perpendicular approach.

Arthroscopic surgery, however, allows much better postoperative comfort for the patient and will produce a more cosmetic scar. A mini-open approach should be considered when there have been multiple previous operations, as this will create a more rigid envelope around the knee, restricting movement of the instruments. Space to approach the lateral femoral condyle with the knee in flexion is much tighter than on the medial side, and this makes it much more difficult when inserting two or more plugs.

The central trochlea is also more difficult to approach arthroscopically and again takes a fair amount of levering on the patella. In addition, some knees are simply tight and do not allow easy access. Arthroscopic portals are established to optimize the approach for arthroscopic repair, remembering that

the overriding principle is to obtain perpendicular access for the TRUKOR instruments:

- For **femoral condyle lesions,** *transverse incisions* are preferred, as these allow easier levering and redirection of the instruments in the transverse plane. Movement in the anterior-posterior direction is achieved by flexing the knee.
- For **trochlea lesions,** *longitudinal incisions* that are placed next to the patella tendon are indicated, as these can be extended superiorly to help access the trochlea. There is less need to move medially or laterally when addressing the lateral or medial facet of the trochlea. The central trochlea can be reached by levering on the patella after engaging the TRUKOR sleeve.

SURGICAL TECHNIQUE

The technique for implanting the TRUFIT plugs is illustrated and detailed in Figures 4D-5 through 4D-14. The instrumentation comes in three parts. The reusable drill bits and sizing instruments are presented in a sterile box (Fig. 4D-4, *A*). All that is needed beyond these items and the standard arthroscopic instruments is a mallet. The sizers are used to determine the defect size and are matched to the size of the disposable TRUKOR drill sleeve (Fig. 4D-4, *B*) and TRUFIT CB plug kit (Fig. 4D-4,*C*).

The initial part of the operation is to explore the defect and then map the sizes of the required plugs.

It is important to remove excessive synovium and the prominent areas of the fat pad, as this will make it much easier to insert the instrumentation later.

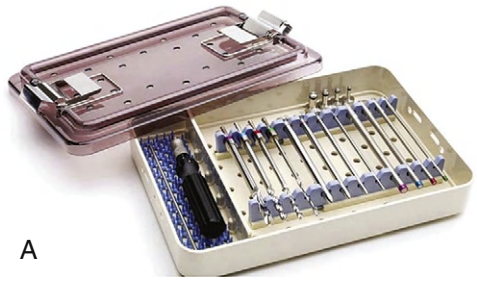
With good fluid input, it is possible to distend the joint enough to maintain the clear view and keep clear access for the instruments.

A full diagnostic arthroscopy needs to be performed, and the true edge of the defect is probed with the hook to ensure there is no remaining unstable cartilage. Once a plan of the plug insertions has been made, the chosen drill sleeve and plug kit are opened.

The main principles of the technique are to do the following:

- To achieve perpendicular implantation of the TRUFIT CB plugs
- To achieve a flush surface level with the surrounding articular cartilage, taking into account the level of the articular cartilage damage
- To ensure that a 2-mm bone bridge is left between multiple plugs

It is not necessary to fully cover the whole defect, and the area surrounding the plugs can fill in with fibrocartilage.



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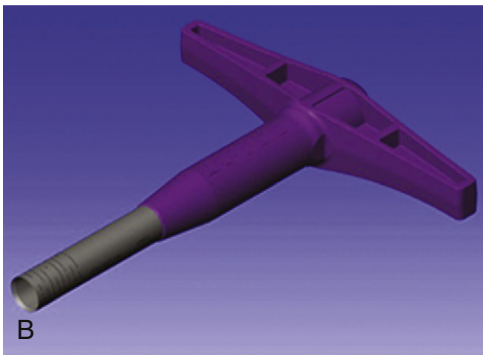

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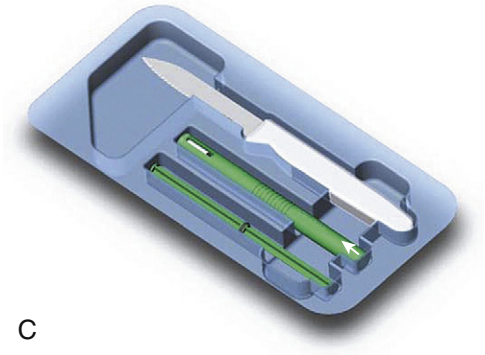

C

FIGURE 4D-4 A, Instrument set containing sizers that can be used for impacting the plugs and drill bits that attach to reusable handle. B, Disposable TRUKOR drill sleeve. C, The TRUFIT plug is preloaded in a delivery device, which is packaged with a measuring tamp and a trimming knife.

Specific Steps of the Technique

Step 1

The lesion is probed and sized, taking into account the extent of the unstable cartilage (Fig. 4D-5).

Step 2

The round-ended obturator is inserted into the chosen TRUKOR drill sleeve to facilitate insertion of the sharp sleeve into the knee (Fig. 4D-6).

Step 3

Once against the defect, the obturator is backed out and the drill sleeve is seated onto the articular surface, taking care to keep it perpendicular (Fig. 4D-7). Keeping the obturator in the tube prevents sudden loss of fluid pressure and allows the joint to remain distended.

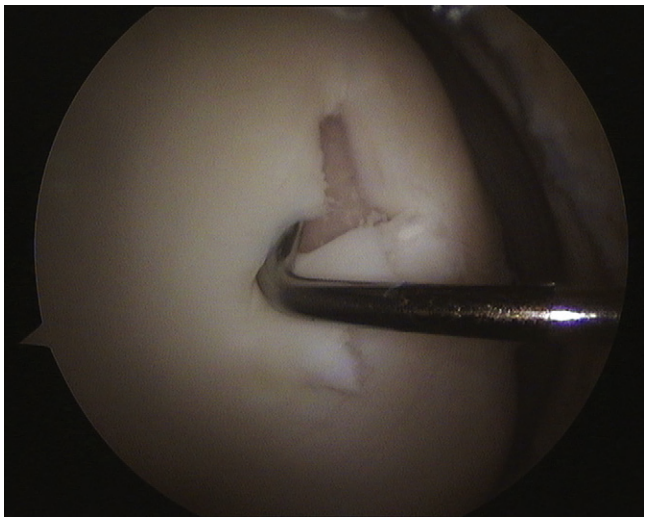

FIGURE 4D-5 Sizing lesion on the medial femoral condyle of a right knee.

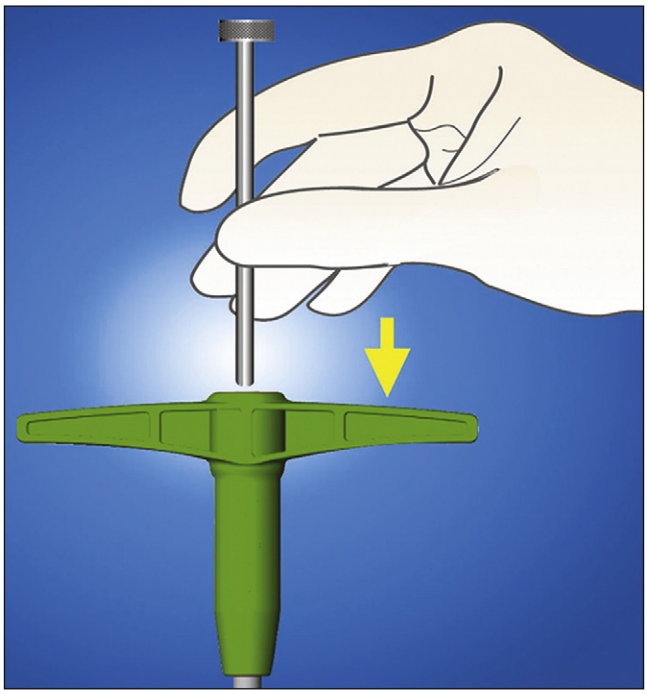

FIGURE 4D-6 Round-ended obturator is inserted into the chosen TRUKOR drill sleeve to facilitate insertion of the sharp sleeve into the knee.

Step 4

To check the alignment of the drill sleeve, it must be checked from at least two angles. Figure 4D-8, *A*, initial view of the cartilage damage. Figure 4D-8, *B*, mapping defect with a 9-mm sizer. Figure 4D-8, *C*, checking that the 9-mm sizer covers most of the area. Figure 4D-8, *D*, the sleeve is gently impacted to the 2-mm line, and this line is then viewed from two or three directions

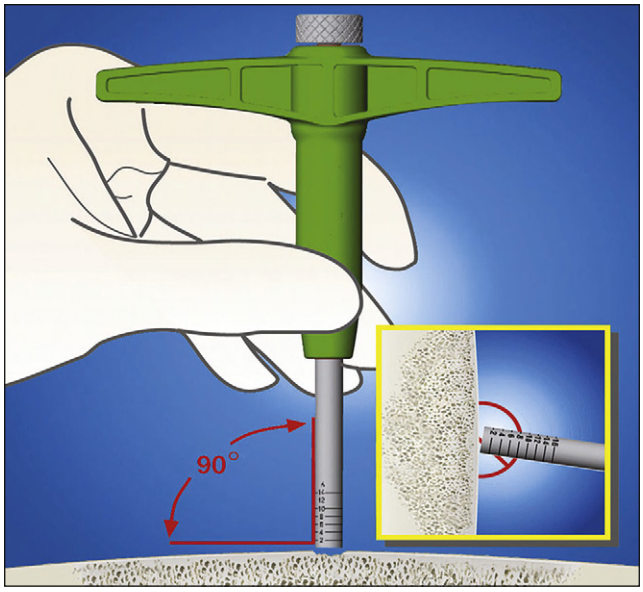

FIGURE 4D-7 Once against the defect, the obturator is backed out and the drill sleeve is seated on to the articular surface, with care taken to keep it perpendicular.

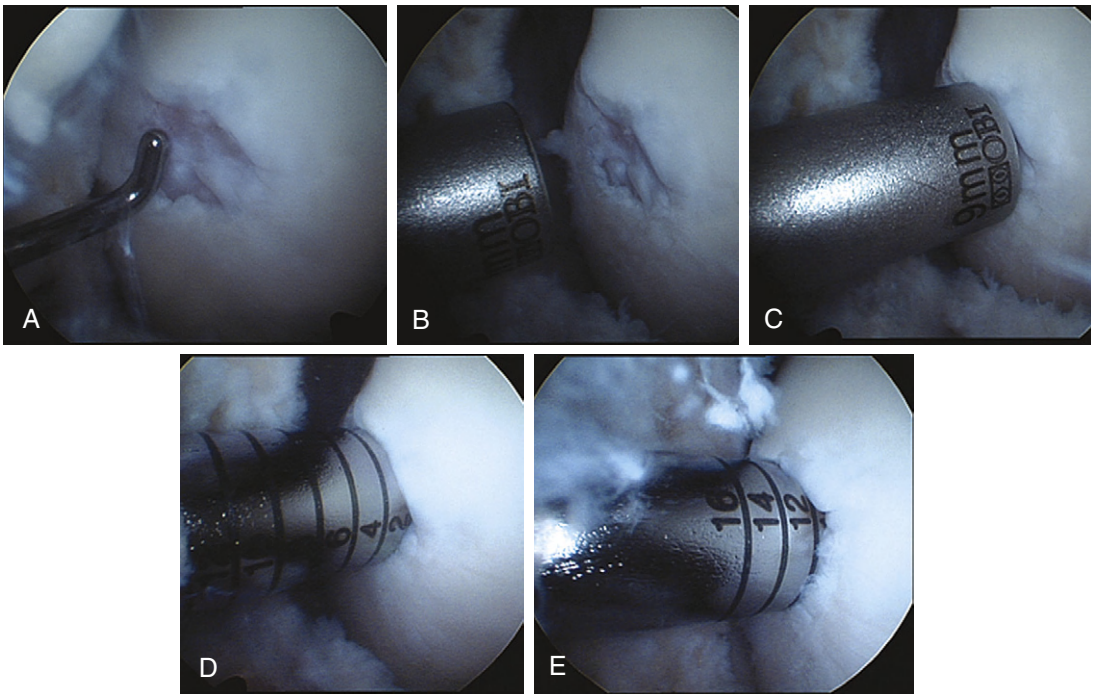

FIGURE 4D-8 To check the alignment of the drill sleeve, it must be checked from at least two angles: **A,** initial view cartilage damage, **B,** mapping defect with 9-mm sizer, and, **C,** checking that the 9-mm sizer covers most of the area. **D,** The sleeve is gently impacted to the 2-mm line, and this line is then viewed from two or three directions to confirm perpendicular entry. **E,** Final depth at 12 mm maximum.

to confirm perpendicular entry. Figure 4D-8, *E*, the final depth is at 12 mm maximum.

Step 5

The obturator is then fully removed and the drill sleeve impacted into the bone for 8 to 10 mm, using a mallet (Fig. 4D-9). Throughout the impaction, care is taken to ensure the sleeve is maintained perpendicular to the approach.

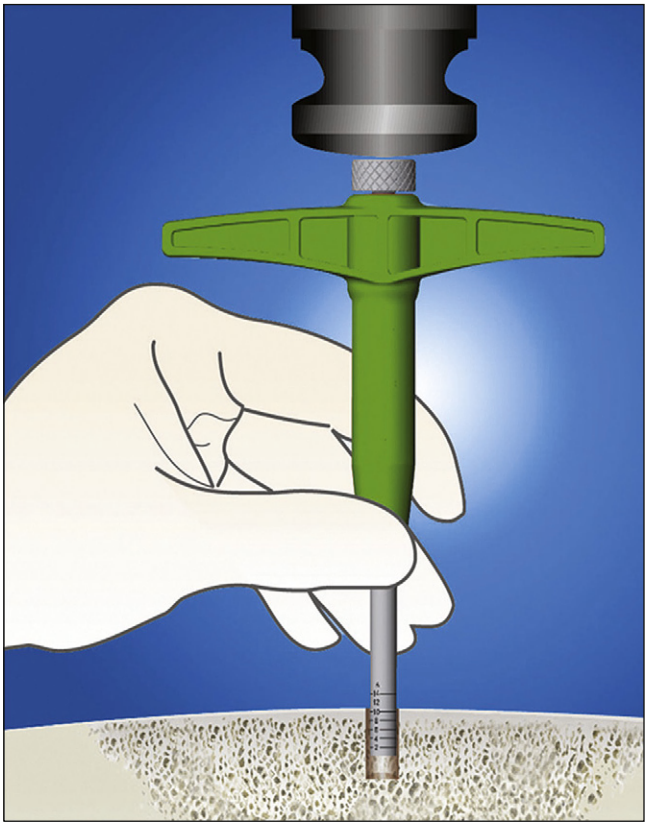

FIGURE 4D-9 The obturator is then fully removed and the drill sleeve impacted into the bone for 8 to 10 mm, using a mallet.

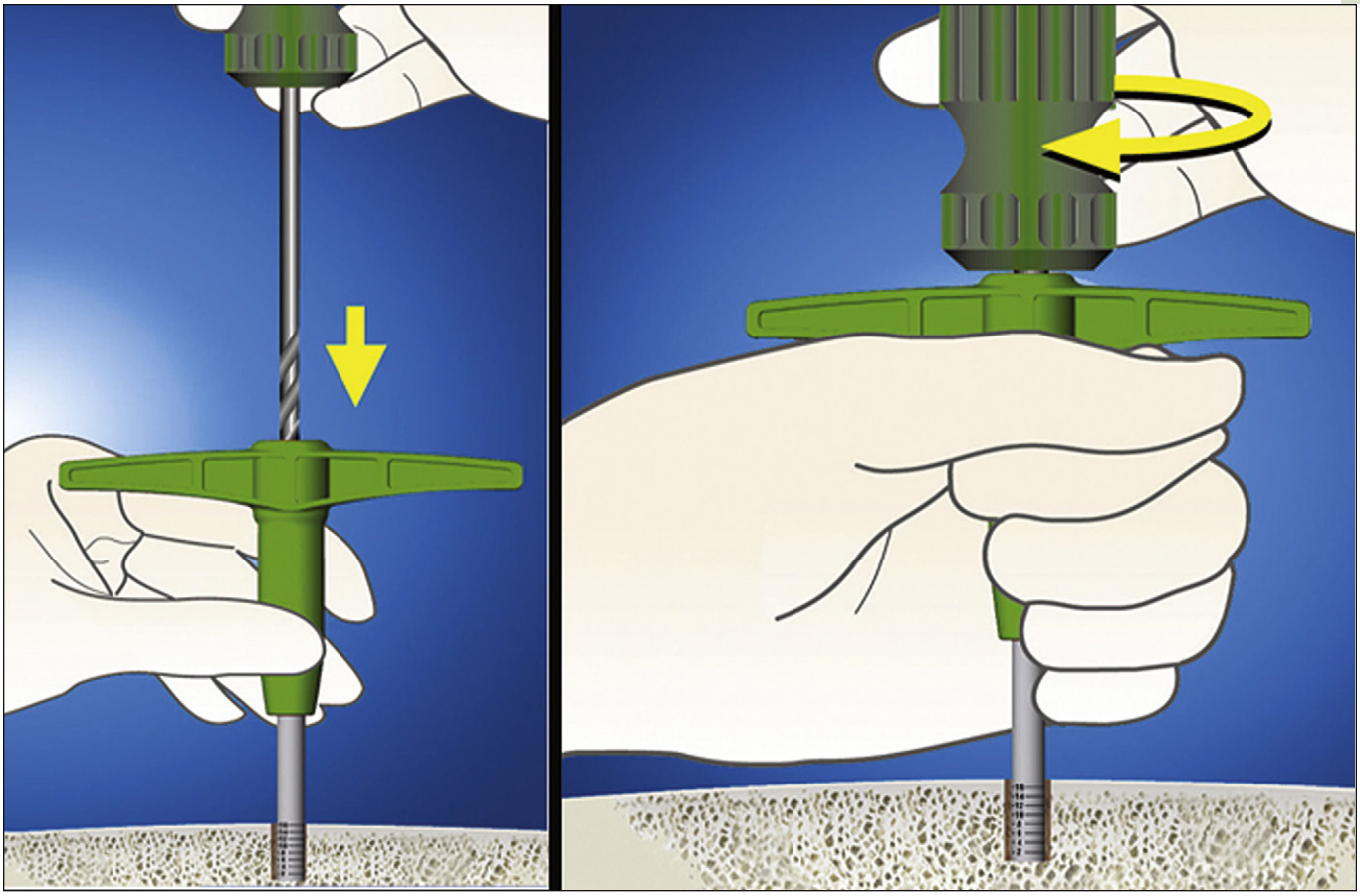

FIGURE 4D-10 The TRUKOR hand drill is inserted and drilled into the bone using firm pressure and twisting.

Step 6

The TRUKOR hand drill is inserted and drilled into the bone using firm pressure and twisting (Fig. 4D-10). A power drill is not usually required, as the drill bit is so sharp.

Step 7

Both the drill and the drill sleeve are then removed simultaneously (Fig. 4D-11). The drill captures the excised bone to leave a clean defect, and it is not usually necessary to clear the defect of any debris.

Step 8

The TRUFIT delivery device is opened and the measuring tamp is inserted into the outer sleeve in the direction of the arrow until contact with the pre-loaded implant is made (Fig. 4D-12).

At this point, the implant should not extend beyond the delivery device.

The measuring tap end is inserted through the skin, into the knee and the defect.

The outer sleeve is slid down until the lip of the outer sleeve is placed snugly against the surface of the articular surface. This automatically adjusts the implant to the correct position for trimming.

Firm pressure is applied to the sizing tube over the plug to ensure that the plug does not move and the tube is removed.

Tip: It is important to ensure that the tamp is fully bottomed out by pushing on the extruded plug. Bear in mind that the outer sleeve needs to be referenced off the intended height of the articular cartilage, not the bottom of the defect; otherwise a false level is achieved.

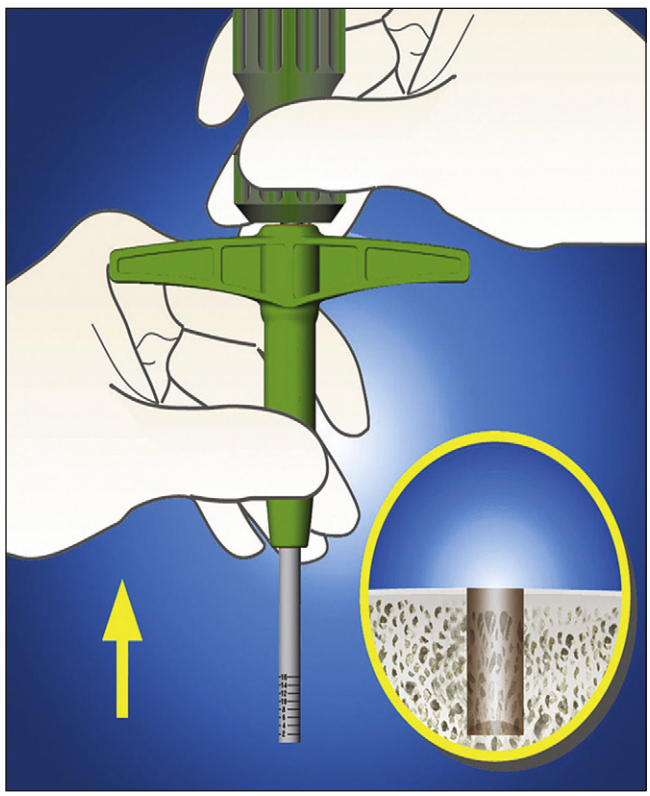

FIGURE 4D-11 Both the drill and the drill sleeve are then removed simultaneously.

Step 9

The excess of the protruding plug is then cut, using the sharp, supplied knife (Fig. 4D-13). Using the lip of the delivery device as a guide, it is best to use a firm downward motion rather than a sawing action.

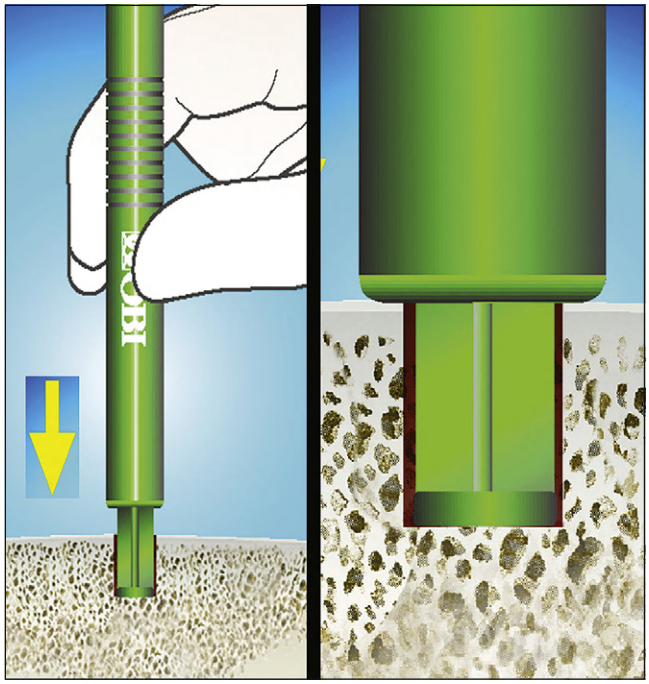

FIGURE 4D-12 The TRUFIT delivery device is opened and the measuring tamp is inserted into the outer sleeve in the direction of the arrow until contact with the preloaded implant is made.

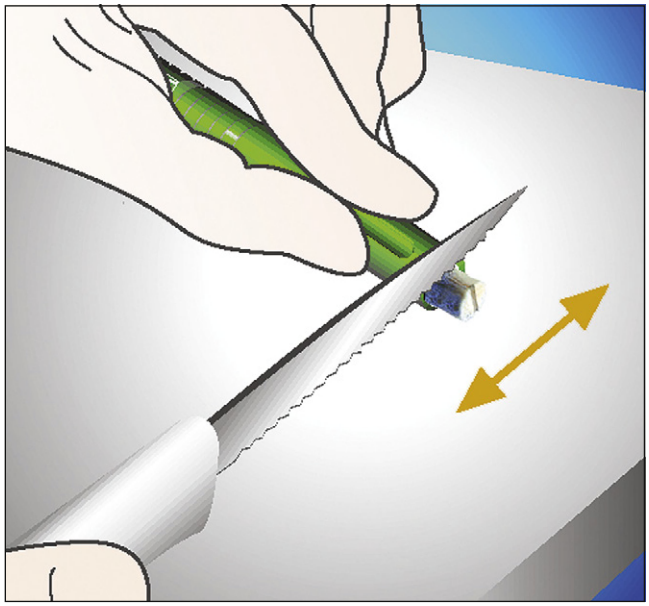

FIGURE 4D-13 The excess of the protruding plug is then cut, using the sharp, supplied knife.

Tip: Leave a slightly oblique cut with a 1-mm step at one side, as this will allow the plug to bottom out early and will prevent overinsertion.

Step 10

The plug is then delivered into the knee within the delivery device and press-fit into the defect, by pushing on the measuring tamp, either manually or by lightly tapping the plug with a mallet (Fig. 4D-14).

To achieve a flush surface, either the tamp or the metal sizing rod can be used.

Tip: If one edge of the plug is slightly proud, then a smaller metal sizing rod can be used as this can be manipulated to round off the surface prominence.

Step 11

In Figure 4D-15, *A-C*, photographs of the same operation as in Figure 4D-8 show insertion of the plug and final impaction into place using the plastic tamp and the metal sizing rod. Note that the arthroscope is oriented more tangentially along the articular surface than the more usual view of looking down onto it.

Final positioning is checked by orienting the scope in a different direction to ensure that no edge has lifted up. The knee is cycled and again checked for any impingement from the edge.

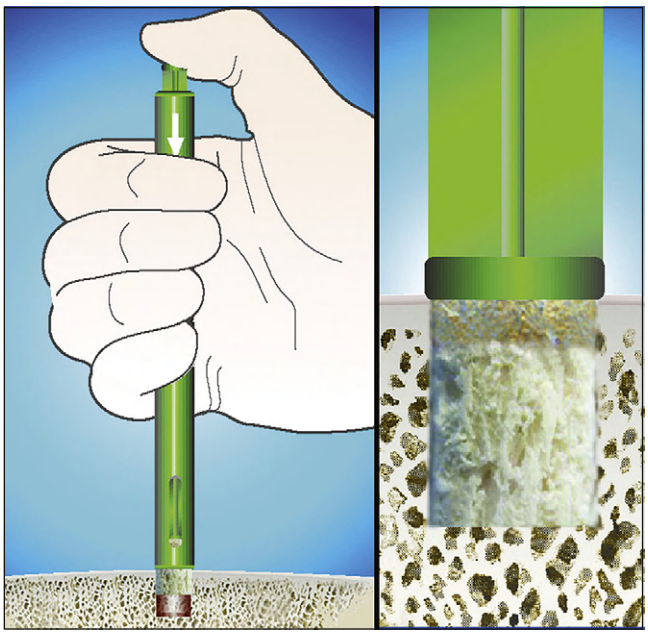

FIGURE 4D-14 The plug is then delivered into the knee within the delivery device and press-fit into the defect, by pushing on the measuring tamp, either manually or by lightly tapping the plug with a mallet.

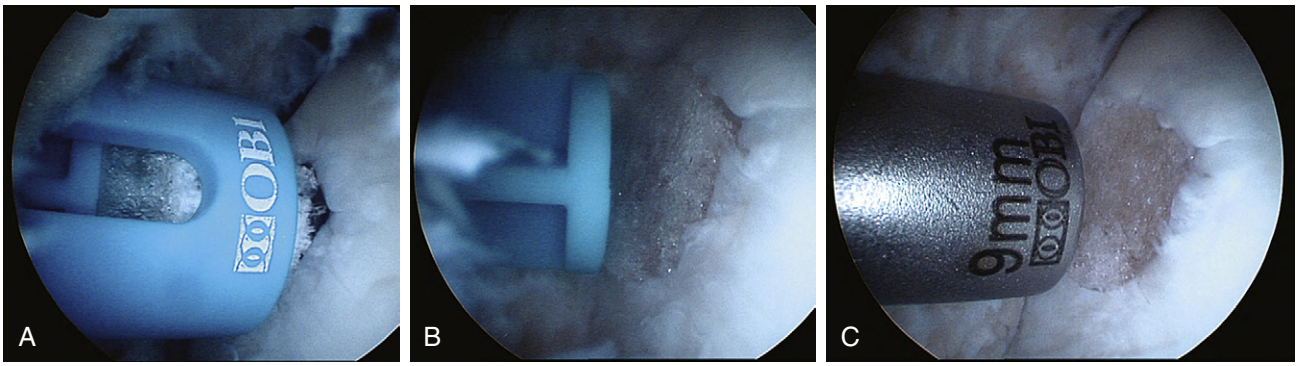

FIGURE 4D-15, A to C Photographs of the same operation as in Figure 4D-8 showing insertion of the plug and final impaction into place using the plastic tamp and the metal sizing rod.

PEARLS AND PITFALLS

- The assistant has a key role in helping to orient the arthroscope, (Fig. 4D-16, *A-C*) so that a good perpendicular view is obtained, while the surgeon holds the coring device steady in the knee (a), during assessment of the depth (b), and on implantation (c).
- Adequate synovial resection must be achieved to allow a good view and ease of insertion of the instruments.
- The arthroscope needs to be positioned and rotated using the light lead in two directions to ensure that insertion is perpendicular at all times.
- The surgeon needs to keep a firm grip on the TRUKOR instruments to avoid loosening of the plug.
- The height of the intended insertion needs to be referenced to the height of normal articular cartilage, rather than in the base of the defect. The plug is cut slightly oblique, leaving 1 mm proud, as this can then bottom out first, avoiding overimplantation and a recessed surface.
- If the plug is slightly proud on one edge, then the smaller size metal tamp or a fine burr can be used to mold the final appearance.
- When approaching the femoral condyle, if the lesion is very close to the notch, then the transpatella tendon portal can be used, allowing a more central access. Likewise, when approaching the trochlea, the medial portal can sometimes be used for the lateral aspect of the sloping trochlea and vice versa for the medial aspect.
- It is easier to insert two or three smaller plugs than it is to insert one large plug when using the arthroscopic technique, as the instruments for the larger plug tend to obscure the view.

REHABILITATION

The overriding principle is that the surface needs to be protected from weight bearing for a short period of time after implantation.

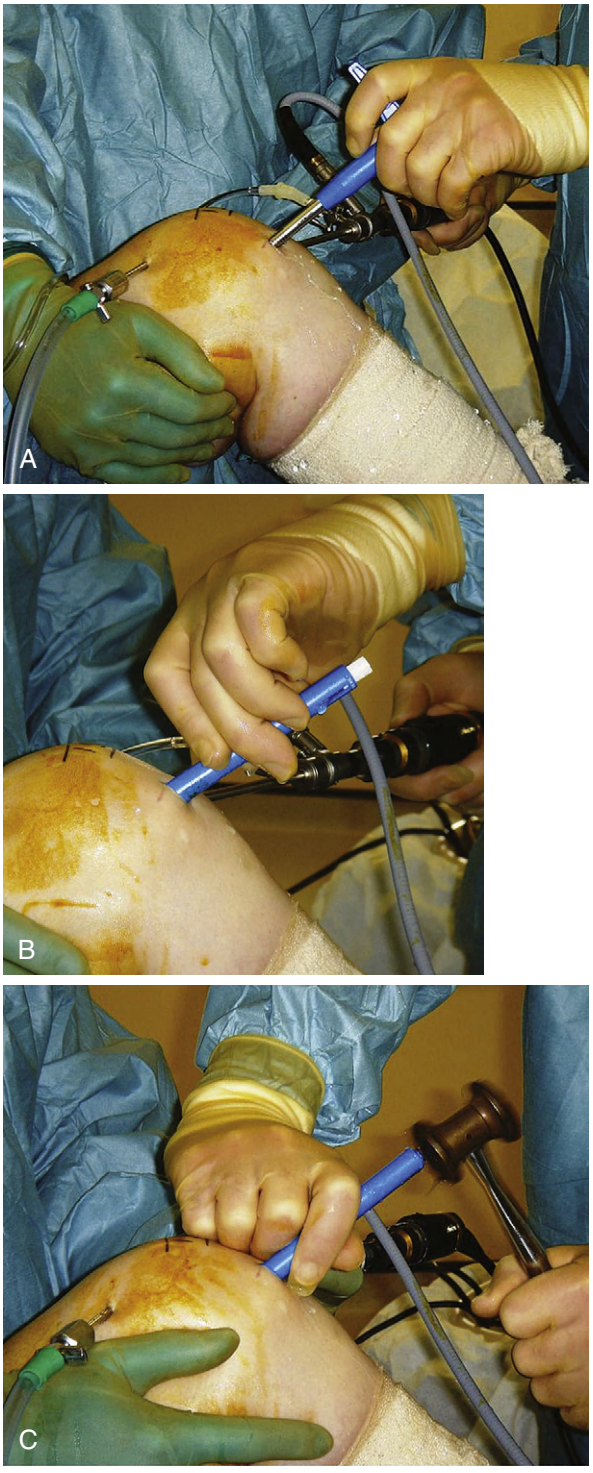

FIGURE 4D-16 The assistant has a key role in helping to orient the arthroscope, so that a good perpendicular view is obtained while the surgeon holds the coring device steady in, **A,** the knee, **B**, during assessment of the depth, and, **C,** on implantation.

On the femoral condyle, partial weight bearing is required for the first 4 weeks, whereas on the trochlea, full weight bearing is allowed with the aid of a brace, which prevents loading of the patellofemoral joint.

About 0° to 20° is allowed on walking for the first four weeks, but in sitting or non–weight bearing, a full range of movement is allowed.

Early full range of movement is encouraged for all areas of repair using either a continuous passive motion machine (CPM) or a static bicycle with 500 revolutions, three times a day. Significant loading of the joint surface should be avoided for at least 3 months and return to sport allowed as symptoms progress over the subsequent 3 to 6 months.

RESULTS

It has been shown that functional scores improved over 12 to 18 months after implantation in a small series of 24 patients.[4] Analysis of sequential MRI imaging has shown recovery of the subchondral laminar and gradual remodeling of the bone while the thickness of the articular cartilage is maintained during the differentiation with no or minimal loss of thickness.[4]

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CHAPTER

5

Osteochondral Mosaicplasty

László Hangody, Gábor Vásárhelyi, László Rudolf Hangody

INTRODUCTION

Full-thickness defects of weight-bearing articular surfaces have poor healing capacity and cause pain, effusion, and impaired joint function. Fibrocartilage-type repair promoted by different marrow stimulation techniques has limited value because of moderate biomechanical features of the regenerative tissue. Cell therapies—such as autologous chondrocyte implantation—and osteochondral transfer techniques aim to create more durable hyaline cartilage surface in the defected area. Transplantation of autologous osteochondral blocks has been used for several decades and results in long-lasting survival of the transplanted hyaline cartilage. However, this technique had only limited practical value because of missing proper donor areas and congruency problems. Mosaicplasty is a recent modification of osteochondral transplantation using several small osteochondral cylinders instead of one big block of bone and cartilage tissue. By linear graft harvest from the less weight-bearing periphery of the trochlea donor site, availability can be managed and a mosaic-like implantation technique can provide proper contouring in the defected area. After preclinical experimental work, mosaicplasty was introduced into the clinical practice on February 6, 1992.

SURGICAL PRINCIPLES AND OBJECTIVE

Step 1. Arthroscopic examination is performed to determine size, type, and exact site of the defected area as well as other intraarticular conditions. Depending on size and location, an arthroscopic or miniarthrotomy procedure can be determined.

Step 2. Preparation of defect site is done by sharp curettage and abrasion arthroplasty.

Step 3. Graft harvest is performed by tubular harvesting chisel from the less weight-bearing periphery of the femoral condyles above the level of sulcus terminalis.

Step 4. Mosaic-like implantation of the grafts is applied into drilled tunnels to cover the defect.

Goal. Repair of defected surface by composite cartilage layer consisting of transplanted hyaline cartilage and smaller amount of fibrocartilage created by previous abrasion arthroplasty. Average content of hyaline cartilage in the composite tissue is about 80%.

Advantages

- Durable gliding surface in the defected area
- One-step procedure
- Minimal surgical costs
- Relatively short rehabilitation

Disadvantages

- Application is limited by donor site access (1.0 to 4.0 cm^2)
- Possible donor site morbidity
- Healing of graft ⇔ host tissue interfaces is not always optimal
- Technical difficulties

Indications

- Symptomatic, focal chondral or shallow osteochondral defects of the weight-bearing articular surfaces. Optimal outcome can be achieved at 1.0 to 2.5 cm^2 defect size, but indication can be extended until 4.0 cm^2. Smaller femoral condylar defects can be treated arthroscopically, whereas bigger defects and patellofemoral, tibial damages require a miniarthrotomy approach.
- The best outcome can be achieved at femoral condylar defects. Tibial results are slightly decreased, whereas patellofemoral implantations have moderate long-term success.
- Underlying biomechanical problems should be clarified and addressed by concomitant procedures such as anterior cruciate ligament (ACL) reconstruction, high tibial osteotomy, and meniscus surgery.
- Age should be under 50 to 55 years.

Contraindications

- Osteoarthritis or advanced degenerative changes
- Tumor, metabolic, or synovial diseases
- Osteoporosis

- Instabilities or malalignments (these biomechanical issues should be corrected during the same surgery or before the mosaicplasty)
- Limited range of motion (ROM)—less than 120-degree knee flexion

Patient Information

- Depending on biomechanical status, concomitant procedures may be necessary parallel with the mosaicplasty (ACL reconstruction, high tibial osteotomy, meniscus surgery, etc.).
- There may be altered weight-bearing status and limited walking ability in early postoperative period. Possible donor site discomfort may occur.
- Common surgical risks include intraarticular hemorrhage, wound-healing problems, septic complications, and thromboembolism.

Preoperative Workup

- Standard weight-bearing radiographs in two planes (AP should be a long radiograph to determine the exact axis). Magnetic resonance imaging (MRI) is needed. Gadolinium enhanced magnetic resonance imaging can be useful.
- Single shot antibiotics before the inflation of tourniquet is recommended.
- Proper thrombosis prophylaxis is advised for 6 weeks after the surgery (Clexane 60 mg/day sc.).

Surgical Instruments

A standard arthroscopy set is required, including a leg holder. A low-speed powered drill is also necessary. Several companies provide high-level instrumentation for cylindrical osteochondral transfer. The senior author developed an instrumentation that offers special advantages for multiple graft transplantation (MosaicPlasty Complete System, Smith & Nephew, Inc., Andover, Mass).

This instrumentation provides five different diameters, from 2.7 mm to 8.5 mm, and supports an arthroscopic technique as well. Beside these reusable instruments disposable chisels, drill bits, and tamps are also available to provide ideal conditions for precise graft harvest and tunnel preparation (Dispoposplasty System, Smith & Nephew, Inc., Andover, Mass). A fluid management system may support the procedure.

Anesthesia and Positioning

For arthroscopic or open mosaicplasty, regional, spinal, or general anesthesia is need. The use of tourniquet is highly recommended. The procedure should be performed in supine position allowing 120-degree flexion during the surgery.

SURGICAL TECHNIQUE

The following explanations relate to the figures identified.

Step 1

An arthroscopy is performed to examine the intraarticular conditions. The type, site, and size of the defect is determined, and the quality of other chondral surfaces as well as donor site availability are checked (Fig. 5-1).

Choosing a procedure (arthroscopic or miniarthrotomy) depends on the type, size, and exact location of the defect determined during arthroscopy.

Because placing the grafts perpendicular to the surface is paramount to the success of the operation, the first task is to determine whether an arthroscopic or open procedure is required.

Patellotrochlear and tibial lesions always require an open procedure.

Most of the femoral condylar defects can be managed arthroscopically. Take care in making the viewing and working portals.

Use a 1.2-mm K-wire or 18-gauge spinal needle initially to locate the portal sites.

Step 2

Use a full-radius resector or curette and a knife blade to bring the edges of the defect back to good hyaline cartilage at a right angle (Fig. 5-2).

Clean the base of the lesion with an arthroscopic burr or half-round rasp to viable subchondral bone. Abrasion arthroplasty of the defect site promotes fibrocartilage grouting from the bony base (Fig. 5-2).

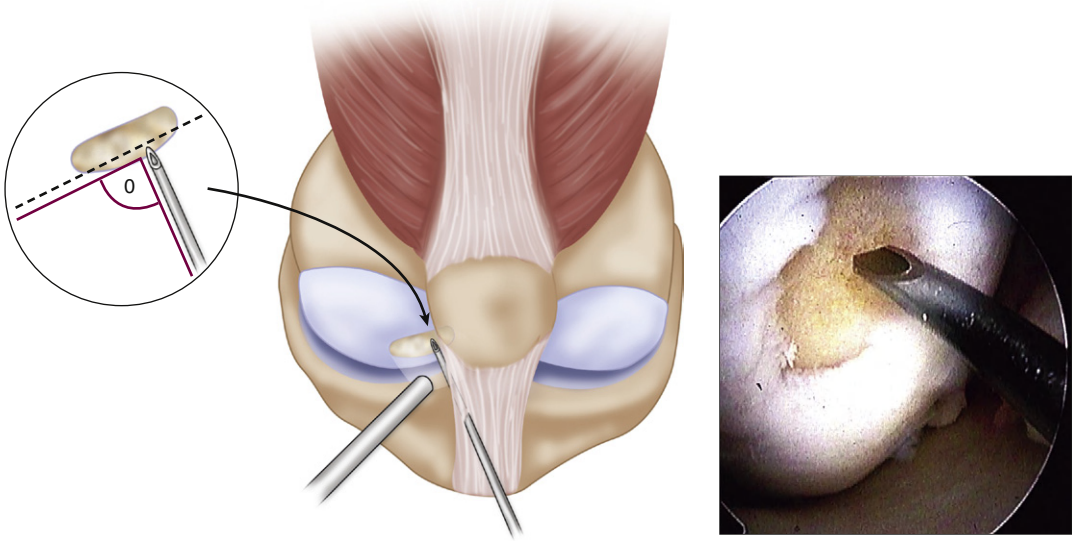

FIGURE 5-1 Determination of perpendicular approach to the defect.

Step 3

Because tapping the cutting edge of the guide into the bony base and removing it can mark the defect site, use the drill guide to determine the number and size (2.7, 3.5, 4.5, 6.5, and 8.5 mm in diameter) of grafts needed (Fig. 5-3).

Step 4

Filling of the defect by same-sized contacting rings allows a filling rate of about 70% to 80%, but use of additional sizes to cover the dead spaces and cutting the grafts into each other can improve the coverage up to 90% to 100% (Fig. 5-4).

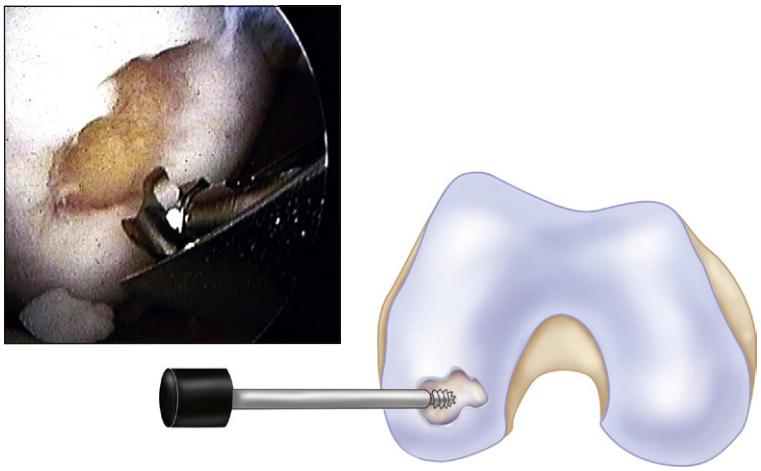

FIGURE 5-2 Abrasion arthroplasty of the subchondral bone.

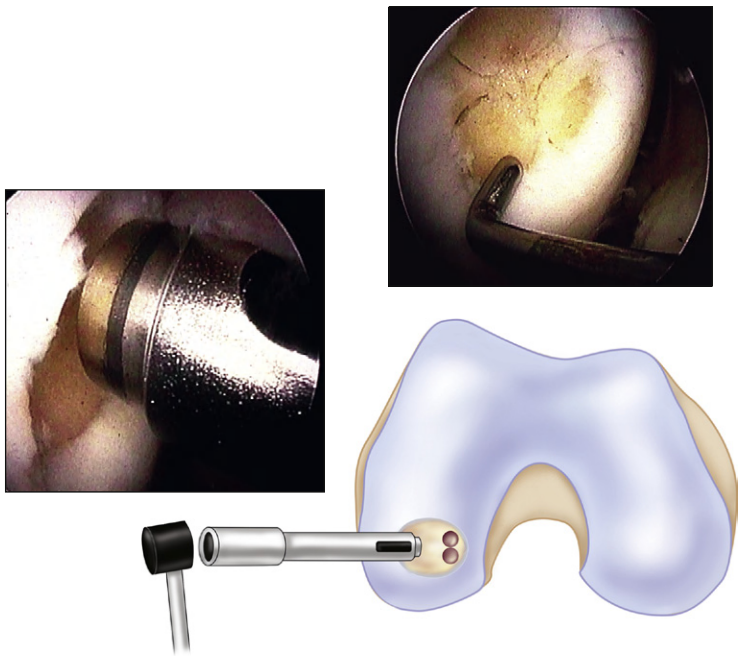

FIGURE 5-3 Planning the optimal filling.

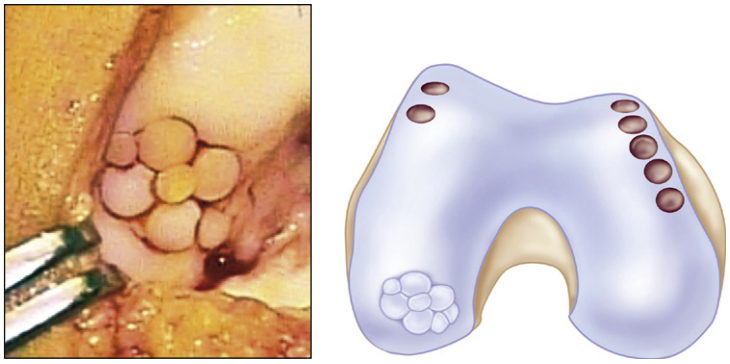

FIGURE 5-4 Maximal filling by overlapping grafts.

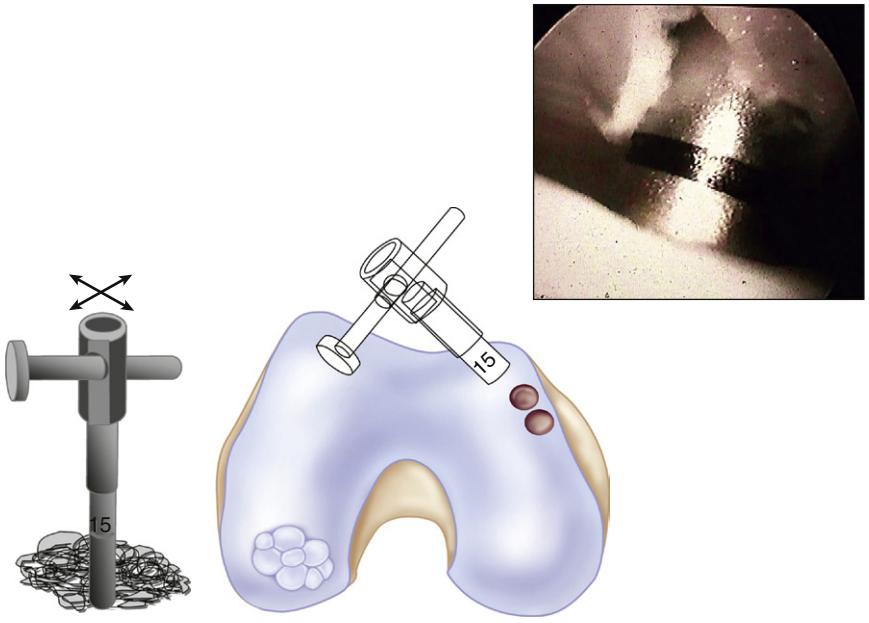

FIGURE 5-5 Graft harvest by tubular chisel from the medial periphery of the patellofemoral joint.

This way of filling is technically more demanding and requires more graft harvest. Finally, measure the depth of the defect with the laser marks of the dilator.

Step 5

The medial femoral condyle periphery of the patellofemoral joint above the line of the notch is the most preferred harvest site (Fig. 5-5).

The lateral femoral condyle above the sulcus terminalis and, in exceptional cases, the notch area can serve as additional donor areas.

Grafts harvested from the notch area have less favorable features because they have concave cartilage caps and less elastic underlying bone.

In case of arthroscopic mosaicplasty, the medial patellofemoral periphery has easier access than the lateral one as fluid distension can promote lateral

positioning of the patella and may provide easier perpendicular positioning for the harvesting chisel.

The best view for harvesting grafts is obtained by introducing the scope through the standard contralateral portal. Extend the knee and use the standard ipsilateral portal to check the perpendicular access to the donor site. Extended position should provide perpendicular access to the most superior donor hole. Gradual flexion allows the harvest of additional grafts from the lower portions of the patellofemoral periphery. If the standard portals do not allow a perpendicular approach, use a spinal needle or a K-wire to determine the location of additional harvesting portals.

Once the necessary portal has been determined, introduce the proper-sized tube chisel filled with the appropriate harvesting tamp.

Once the site has been clearly identified, the chisel is located perpendicular to the articular surface and driven by a hammer to the appropriate depth.

The minimal length of the graft should be at least two times its diameter, but, as a rule, take 15-mm-long grafts to resurface chondral lesions and 25-mm-long plugs for osteochondral defects.

It is important to hold the chisel firmly to avoid its shifting at the cartilage–bone interface, producing a crooked graft. By flexing the knee, lower sites can be obtained. The lower limit is the level of the top of the intercondylar notch (sulcus terminalis). Insert the appropriate harvesting tamp into the cross-hole in the tubular chisel and use it as a lever. The chisel should be toggled, not rotated, causing the graft to break free at the chisel tip. Eject the grafts from the chisel by sliding the appropriately sized chisel guard over the cutting end. Use the tamp to push out the graft onto gauze in a saline-wetted basin.

Step 6

Flex the knee again and establish good distension. Reintroduce the drill guide using the dilator as an obturator. Place these tools perpendicularly to the defected surface (Fig. 5-6).

By rotating the arthroscope, the drill guide and the perpendicularity of the laser mark can be seen from different angles, ensuring proper orientation. Tap the cutting edge of the guide into the subchondral bone. Insert the appropriately sized drill bit and drill to the desired depth. Generally, a recipient hole a few millimeters deeper than the length of the graft is desirable to minimize high intraosseal pressure.

Step 7

Insert the conical-shaped dilator into the drill guide again. Tap it to the desired depth, depending on the actual features of the recipient bone. Stiff bone needs more dilation than normal or soft bone. Hold the drill guide firmly, and remove the dilator from the hole (Fig. 5-7).

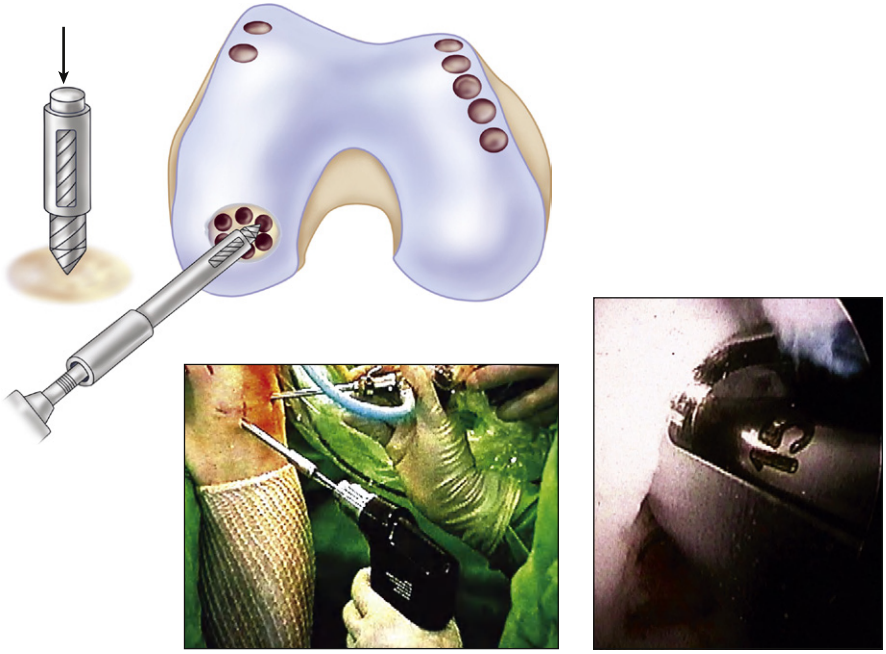

FIGURE 5-6 Recipient tunnels are created by drilling.

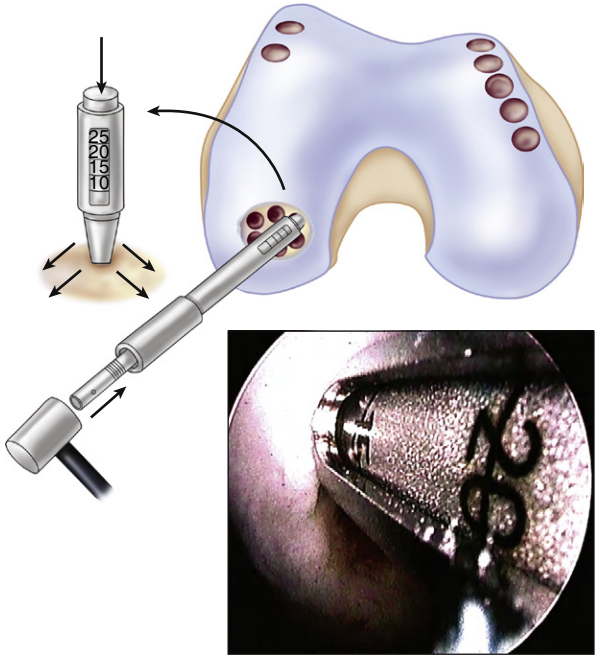

FIGURE 5-7 Dilation of the recipient tunnels by conical dilator.

Step 8

Adjust the delivery tamp by turning the handle to initially allow the graft to sit slightly higher than the depth of the defect. This will minimize the likelihood of overpenetrating the graft (Fig. 5-8).

Stop the inflow to eliminate the graft being forced out of the tube by fluid flow.

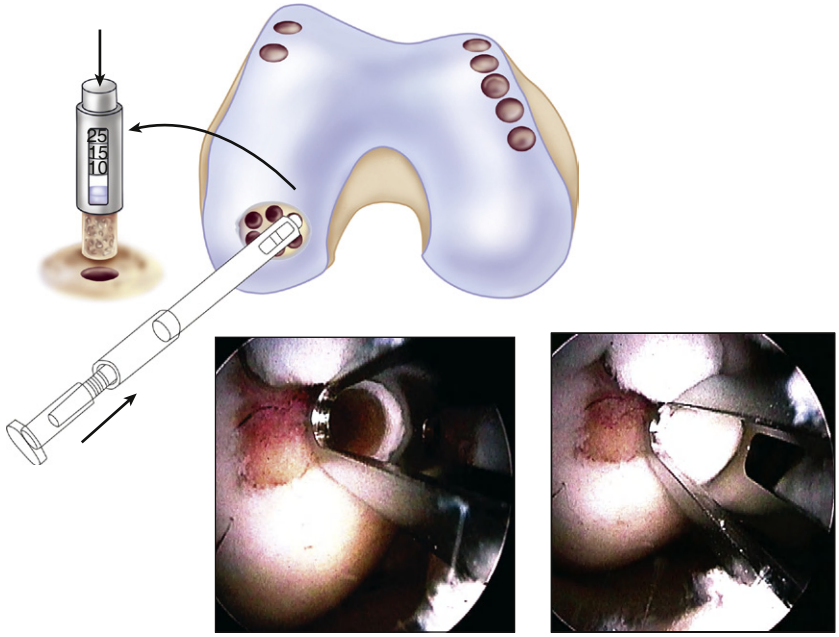

FIGURE 5-8 Insertion of the graft through drill guide.

Deliver the graft under direct visualization into the recipient hole through the drill guide with the delivery tamp.

Insert the graft deeper by turning the delivery tamp handle counterclockwise.

The graft should be matched to the original articular surface.

Remove the drill guide to inspect the graft. If the graft is protruded, reinsert the drill guide and tap the graft down gently with a tamp of the appropriate size. Insert subsequent grafts in a similar manner by placing the drill guide immediately adjacent to the previously placed grafts.

Step 9

Such step-by-step graft implantation has several advantages. Dilation of the actual recipient hole allows an easy graft insertion (low insertion force on the hyaline cap), but dilation of the next hole affects surrounding bone to the previously implanted grafts, which can result in a safe press fit fixation (Fig. 5-9).

Step 10

Finally, when the grafts have filled all of the holes, move the knee throughout its range of motion, provoking varus or valgus stress also, depending on the site of the resurfaced area (Fig. 5-10).

Close the portals and introduce suction drainage into the joint through a superior portal. Use an elastic bandage to fix the appropriate dressing.

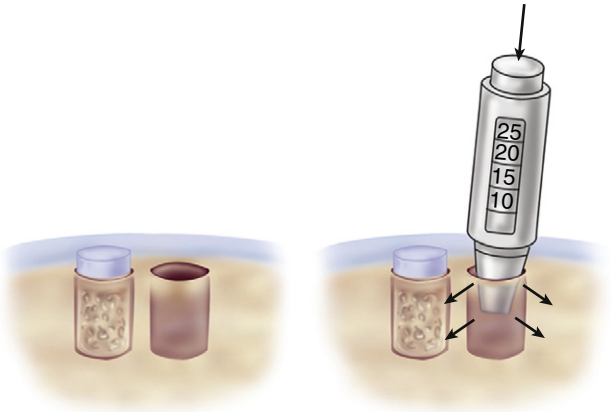

FIGURE 5-9 Dilation of the neighboring recipient tunnel can finalize the press fit fixation of the previously implanted graft.

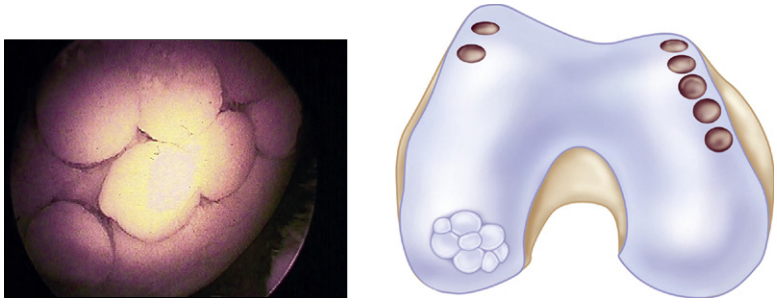

FIGURE 5-10 Filling of the defect by seven grafts harvested from the medial and lateral femoral periphery of the patellofemoral joint.

OPEN MOSAICPLASTY

An open procedure may be chosen in the learning curve or when an arthroscopic approach is not practical because of the size or location of the lesion. Arthroscopic or open mosaicplasties have the same steps and technique. If an arthroscopic approach is impractical, it may be necessary to create a medial or lateral anterior sagittal incision or an oblique incision to perform a miniarthrotomy mosaicplasty.

SPECIAL CONSIDERATIONS

Mosaicplasty is often combined with concomitant procedures such as ACL reconstruction and high-tibial osteotomy. In such cases, mosaicplasty should be done first, as this procedure often requires 120-degree (or more) flexion and different stressed positions. After finishing the mosaicplasty, the fixation of the grafts is safe enough to tolerate special stresses during the concomitant procedure.

POSTOPERATIVE MANAGEMENT

Postoperatively, the drain should be removed at 24 hours.

Appropriate pain and cool therapy as well as nonsteroidal antiinflammatory drugs can reduce the complaints of the patient.

Postoperative thrombosis prophylaxis is recommended.

Routine use of a continuous passive motion machine (CPM) is not necessary, but can be useful to lessen swelling and to provide optimal contouring if the initial clot is between the grafts and at the donor tunnel surfaces.

Immediate ROM exercises are encouraged, a non-weight-bearing and partial loading period of a few weeks is necessary. Usually 2 weeks non–weight bearing followed by 2 weeks partial loading (30 to 40 kg) are ordered before full weight bearing. Detailed rehabilitation recommendations are presented in Tables 5-1 and 5-2.

ERRORS, HAZARDS, AND COMPLICATIONS

One of the most common problems is neglecting the main instructions of the protocol. Perpendicular harvest and implantation of the grafts are crucial for successful transplantation.

Oblique harvest and insertion may result in steps on the surface. Careful control from different angles by the arthroscope can eliminate such problems.

Another frequent mistake is to implant a graft deeper than the desired level. First of all, appropriate use of the delivery tamp can help avoid too deep insertion. If the graft has been inserted too deep, the following steps are recommended:

- Insert the drill guide next to the previously implanted graft.
- Drill the appropriate recipient hole.
- Remove the guide and use the arthroscopic probe to lift the previously implanted graft to the proper level (Fig. 5-11). The recipient hole adjacent to the implanted graft should provide enough room for such manipulation.

As soon as the expected graft level has been achieved, continue the recommended protocol for the rest of the insertions. Dilation of the adjacent tunnel will provide perfect press fit fixation of the previously implanted graft.

Septic or thromboembolic complications may result in a negative influence on the clinical outcome. Correct aseptic conditions, one-shot antibiotics, and thrombosis prophylaxis can decrease the chance of these complications.

TABLE 5-1 Mosaicplasty Rehabilitation Protocol[a]—General Viewpoints

Ambulation[c]	
Two-crutch ambulation, non–weight bearing	Immediate
Two-crutch ambulation, partial loading (30-40 kg)	2-4 weeks
Discontinue crutches, full weight bearing	4-5 weeks
Functional Exercises	
Form walking, gait evaluation	4-5 weeks
Step-up	4-5 weeks
Step-down	5-6 weeks
Range of Motion	
Early range of motion encouraged	
CPM in case of extended lesions 2-4 cm^2 (in painless range)	Immediate (first week)
Full extension, flexion as tolerated	Immediate
Stationary bicycle	3 weeks
Strength Return	
Quadriceps	
Open chain exercises, leg raises	Immediate
Concentric contraction to full extension	1 week (or earlier if tolerated)
Concentric contraction against resistance	2 weeks
Isometric exercises in different angles	Immediate
Eccentric exercises against resistance	3-4 weeks
Hamstrings	
Isometric exercises in different angles	Immediate
Concentric and eccentric strengthening	1-2 weeks
—against resistance	3-4 weeks
Closed Chain Exercises [d]	
Pushing a soft rubber-ball with foot	Immediate
Closed chain exercises with half weight bearing	2-3 weeks
—with full weight bearing	5-6 weeks
Stationary bicycle with resistance	2-4 weeks (if 90° knee flexion achieved)
Stairmaster	6-8 weeks
Proprioception Return	
Balance exercises standing on both feet	5-6 weeks
Standing on one foot (hard ground)	6-8 weeks
Standing on one foot (trampoline or AeroStep)	8-10 weeks
Return to Activity	
Jogging	10 weeks
Straight line running	3 months
Directional changes	4-5 months
Shear forces	5 months [e]
Sport specific adaptations	5 months
Sport activity	5-6 months [f]

[a]Uzsoki Hospital and Sanitas Private Clinic, Budapest, Hungary.
[b]The main point of the rehabilitation is to ensure the early motion of treated joint to promote appropriate nutrition of transplanted cartilage. Cool therapy can be used during the first week to avoid postoperative bleeding and decrease postoperative pain. In a case of a concomitant procedure requiring external fixation of the affected joint (e.g., meniscus reinsertion), limitation of ROM for a short period by bracing can be allowed.
[c]Extent, type (chondral or osteochondral), and location of the defect may modify weight bearing (see next page).
[d]Partial loading promotes to transform connecting tissue (between transplanted plugs) into fibrocartilage, so these exercises are mainly important in the half-weight-bearing period. On the other hand, with some closed chain exercises (e.g., cycling), it is possible to ensure cyclic loading that makes the fluid and nutrition transport much more efficient between synovial-fluid and hyaline cartilage.
[e]Approximately 4 to 5 months are needed to form a composite hyaline-like surface on transplanted area, which tolerates shear forces.
[f]Depending on depth and extent of the defect. If strength, power, endurance, balance, and flexibility are not satisfying, sport activity is allowed only later.

TABLE 5-2 Mosaicplasty Rehabilitation Protocol—Special Viewpoints

Weight Bearing at Different Defects of Knee	
Femur or tibia condyle, chondral defect, d < 15 mm	
Non–weight bearing	1 week
Partial weight bearing	1-3 weeks
Femur or tibia condyle, chondral defect, d ≥ 15 mm	
Non–weight bearing	2 weeks
Partial weight bearing	2-4 weeks
Femur or tibia condyle, osteochondral defect	
Non–weight bearing	3 weeks
Partial weight bearing	3-5 weeks
Patellar defect, d < 15 mm	
Partial weight bearing	2 weeks
Patellar defect, d ≥ 15 mm	
Partial weight bearing	3 weeks
Quadriceps Strengthening and Patellar Mobilization—Differences at Patellar Defects	
Vastus medialis strengthening	
Isometric exercises in extension	Immediate
Patellar mobilization	Immediate
Isometric exercises in different angles	1 week
Open chain exercises	2 weeks
—against resistance	3-4 weeks
Eccentric exercises against resistance	4-5 weeks
Closed chain exercises	2-3 weeks
The treatment of underlying causes can also modify the rehabilitation program. The most frequent combinations at knee applications are the following:	
LCA-reconstruction combined with mosaicplasty:	
2-4 weeks non–weight bearing (up to the mosaicplasty)	
2 more weeks partial weight bearing	
5-90° ROM for 4 weeks	
Mainly closed chain exercises for quadriceps strengthening	
Hamstring strengthening in open and closed chain	
Proprioceptive training	
Meniscus reinsertion combined with mosaicplasty:	
4 weeks non–weight bearing	
2 more weeks partial weight bearing	
5-45° ROM for 4 weeks	
Retinaculum patellae reconstruction combined with mosaicplasty:	
2-4 weeks non–weight bearing (up to the mosaicplasty)	
2 more weeks partial weight bearing	
0-45° ROM for 4 weeks	
High tibial osteotomy (HTO) combined with mosaicplasty:	
Weight bearing (for 4 weeks only with crutches and only in extension) is up to the mosaicplasty, pain, and degree of the correction of the varus (lower correction: non–weight bearing; overcorrection: early weight bearing)	

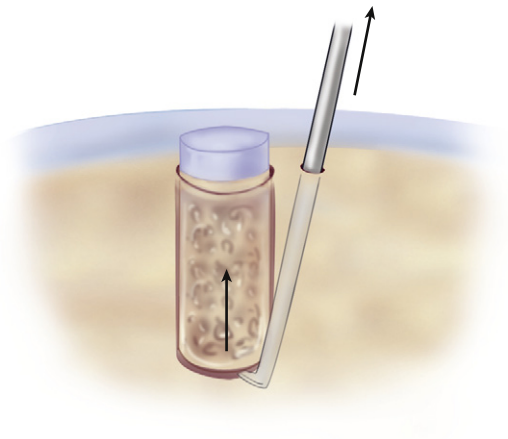

FIGURE 5-11 Elevation of the graft by arthroscopic probe.

According to 17 years of follow-up, long-term donor site morbidity does not occur frequently. Patellofemoral complaints, such as pain or swelling after strenuous physical activity, follow the mosaicplasty procedure in fewer than 3% of cases. However, excessive postoperative bleeding occurs in 8% of cases. Precise postoperative drainage, cool therapy, and elastic bandages can diminish the chance of this complication.

RESULTS

Between February 6, 1992, and December 31, 2008, 1179 mosaicplasties were performed at the authors' institution: 849 implantations on femoral condyles, 171 in the patellofemoral joint, 36 on the tibia condyles, 101 on talar domes, 8 on the capitulum humeri, 3 on humeral heads, and 11 femoral heads. Two thirds of the cases were operated on because of a localized Grade 3 or Grade 4 cartilage lesion, whereas the rest of the patients underwent surgery because of osteochondral defects. In 81% of the patients, concomitant surgical interventions were also carried out, which influenced the clinical results of the mosaicplasty procedures. The majority of these concomitant procedures were ACL reconstructions, realignment osteotomies, meniscus surgeries, and patellofemoral realignment procedures.

Femoral, tibial, and patellar implantations were evaluated by the modified Hospital for Special Surgery (HSS), modified Cincinnati, Lysholm, and International Cartilage Repair Society (ICRS) scoring systems, whereas possible donor-site disturbances and morbidity were evaluated by the Bandi scoring system. Patients with talar lesions were subjected to Hannover ankle evaluations. Analysis of clinical scores has shown good to excellent results in 92% of patients with femoral condylar implantations, 87% of tibial resurfacings, 74% of patellar or trochlear mosaicplasties, and 93% of talar procedures. Moderate and severe donor-site disturbances were present in 3% of patients according to the Bandi score[1] (evaluations were done in a 1- to

10-year interval). Postoperative complications were four deep infections and 56 painful hemarthroses. Arthroscopic or open debridement resolved all deep infections, and 12 cases of hemorrhage also required arthroscopic or open debridement. The remaining patients with hemarthroses were treated by aspiration and cryotherapy. Four patients had minor thromboembolic complications.[1-8]

Several independent centers have published retrospective or comparative studies about the clinical outcome of autologous osteochondral mosaicplasty technique. Marcacci et al. (2005) (in a 2-year follow-up publication), Chow et al. (2004), Gudas et al. (2005), and Solheim et al. (1999) reported the same clinical efficacy.[9,10,11] Horas et al. (2003) reported outstanding clinical results of mosaicplasty in a comparative, prospective study of mosaicplasty versus autologous chondrocyte transplantation.[12] Nakagawa et al. (2004) published trochlear results, and Matsusue et al. (2001) reported successful tibial outcomes.[13,14] Duchow et al. (2000) and Kordás et al. (2005) discuss important details of press-fit implantation.[15, 16]

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CHAPTER

6

Mega-OATS

Peter U. Brucker, Jochen Paul, Andreas B. Imhoff

INTRODUCTION

Large osteochondral defects in the weight-bearing zone of the medial or lateral femoral condyle, especially in young patients, create a challenge for orthopaedic surgeons. Addressing both the cartilaginous and the osseous defect, mosaicplasty represents a modified technique of the conventional osteochondral autologous transplantation system (OATS) technique by transplantation of multiple OATS plugs into the defect area.[1,2] However, this technique is limited because of the availability of the plugs at the donor site. Additionally, a primary stability of multiple plugs as well as restoration of the anatomical congruence at the cartilaginous surface level is technically demanding and often infeasible.

In the 1960s and 1970s, the posterior femoral condyle of the knee was already recognized as a potential donor site for osteochondral tissue.[3,4] The transfer of the posterior femoral condyle using an anterior approach was started in the 1990s at our department at Klinikum Rechts der Isar in Munich, Germany. The autologous Mega-OATS procedure is a technical advancement of the posterior femoral condyle transfer.[5,6] Contrarily, the allogenic Mega-OATS technique illustrates an alternative procedure sparing the posterior femoral condyle as the donor site.[7] In both autologous and allogenic Mega-OATS techniques, an almost anatomical restoration of the condyle curvature as well as an optimal congruence to the adjacent cartilaginous surface can be achieved. Nevertheless, comorbidities such as malalignment and ligamentous instabilities must be addressed before or ideally simultaneously with the Mega-OATS procedure.

Isolated Mega-OATS procedures as well as Mega-OATS procedures combined with additional procedures (malalignment correction, ligamentous stabilization, meniscus surgery, etc.) were clinically and imaging based (radiological, MRI) reevaluated in the short- and mid-term follow-up. Overall, the reevaluations demonstrated a considerable improvement regarding function, pain reduction, and swelling as well as resumption of sporting activities compared to preoperatively.[5,6,8,9]

INDICATIONS

The indication criteria for the Mega-OATS technique are similar to the OATS procedure. However, because of the size of the osteochondral lesion, a conventional single plug OATS technique or a press-fit technique of a limited number of osteochondral cylinders is insufficient for adequate coverage of the defect. Therefore, the Mega-OATS technique is an alternative procedure to the mosaicplasty in which multiple osteochondral plugs are transplanted.

The indication criteria of the Mega-OATS procedure include the following:

- Large traumatic or posttraumatic osteochondral lesions
- Large osteochondritis dissecans with partial (Grade 3B according to König and Imhoff)[10], or complete detachment (Grade 4B according to König and Imhoff)[10] and evidence of avital areas of the osteochondral fragment detected by intravenous fluid-enhanced MRI
- Focal osteonecrosis combined with limited cartilage defect

CONTRAINDICATIONS

The contraindication criteria for the Mega-OATS technique include the following:

- Degenerative arthrosis of the knee joint
- Diffuse uni- and bicompartmental cartilage degeneration of the knee joint
- Acute or chronic (osteo)arthritis of the knee joint
- Chondrocalcinosis
- Uncorrectable ligamentous instabilities
- Not simultaneously addressable or uncorrectable osseous malalignment of the knee joint
- Open epiphyseal plate and incompleted adolescence
- Advanced biological age beyond the 5th decade
- Postoperative continuation of professional activities or competitive sports involving continuous or repetitive maximal loads with high knee flexion angles (e.g., pavior, downhill ski racer)
- Limited compliance

SURGICAL TECHNIQUE

Surgical Equipment

- Standard surgical equipment for knee surgery including condyle retractors
- Blade chisels of various widths

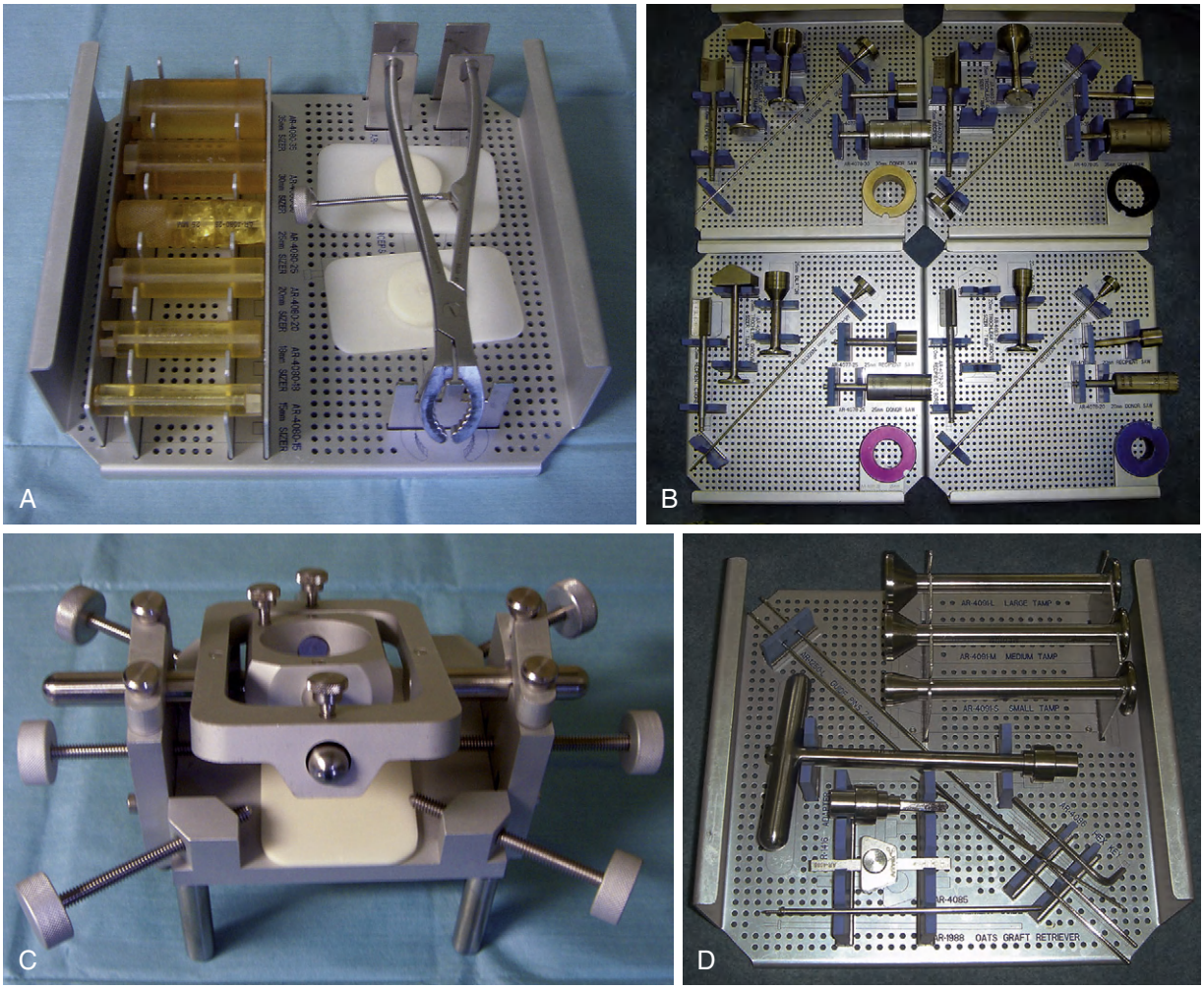


FIGURE 6-1 **A,** Specially designed Mega-OATS instruments. **B,** Devices for measuring the osteochondral defect size. Preparation of the recipient socket and the Mega-OATS cylinder (20 to 35 mm diameter). **C,** Special workstation for harvest of the Mega-OATS cylinder. **D,** Devices for implantation of the Mega-OATS cylinder into the recipient socket or readjusting the Mega-OATS cylinder within the recipient socket.

- Mega-OATS devices including the Mega-OATS workstation (Arthrex, Naples, Fl.) (Fig. 6-1, *A-D*)
- Arthroscopic devices for concomitant and arthroscopically addressable lesions, if necessary

Anesthesiology and Positioning

- General or spinal anesthesia
- Perioperative single-shot antibiotics
- Supine positioning including a lateral thigh pillar
- Femoral tourniquet as proximal as possible because of the necessity of a maximally flexed knee position for harvest of the posterior femoral condyle
- Tiltable leg component of the operating table if necessary for additional knee arthroscopy

- Circular disinfection of the corresponding lower extremity and covering with sterile drapes; if necessary, additional disinfection of the ipsilateral iliac crest for optional harvest of cancellous bone for a subsequent underlying bone plasty in cases of deep osseus femoral condyle defects
- Holder for stabling of the lower extremity in a flexed hip and knee position

Exposure

Before the Mega-OATS procedure, a primary arthroscopy for addressing concomitant lesions is optional (e.g., meniscal and cruciate ligament pathologies). Therefore, a standard anterolateral parapatellar portal for the camera and an anteromedial parapatellar portal for the arthroscopic devices are applied.

Alternatively, a central skin incision may be performed ahead of the arthroscopy, sparing separate skin incisions for the arthroscopic procedure.

In detail, the central skin incision is performed starting at the patella and ending at the tibial tuberosity. In cases of an additional high tibial osteotomy, the skin incision may be extended distally.

According to the localization of the defect, an anteromedial (conventional, alternatively minimally invasive subvastus approach) or anterolateral arthrotomy of the knee joint is accomplished.

Partial resection of the Hoffa's fat pad is occasionally necessary for sufficient exposure of the osteochondral lesion.

In a maximal flexed knee position, the border of the osteochondral defect at the medial or lateral femoral condyle is marked using a sterile pen (Fig. 6-2).

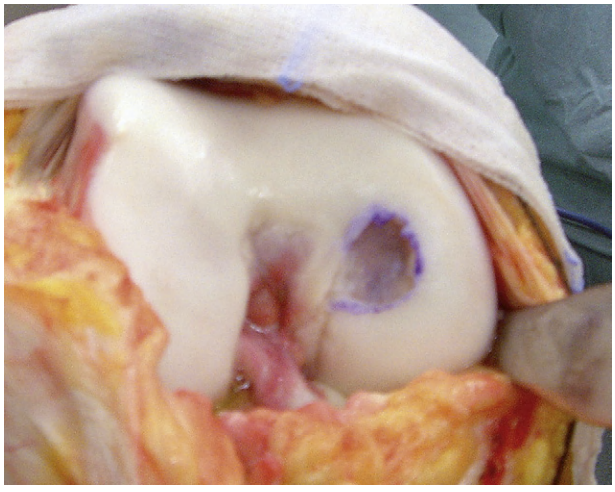


FIGURE 6-2 Exposition of the large osteochondral defect within the weight-bearing zone of the medial femoral condyle following anteromedial arthrotomy.

Mega-OATS Harvest, Preparation, and Implantation

The defect size is measured with a ruler or the Mega-OATS template (Fig. 6-3, *A*).

A K-wire is perpendicularly positioned in the center of the lesion, serving as a guidance device for the hollow drill (diameter 20 to 35 mm) (Fig. 6-3, *B*).

The hollow drill creates a stable osteochondral skirt around the defect.

A trephine, equally sized as the hollow drill, is used for preparation of the recipient socket.

Sterile pads may be utilized to avoid dispersion of drilling debris into the joint.

The depth of the socket is defined by the extension of the osseous defect or the necrotic zone. Intraoperatively, the correct drilling depth is accomplished by occurrence of bleeding of the subchondral surfaces within the defect socket. Then, the size of the transplant cavity is measured with the Mega-OATS depth measurement guide (Fig. 6-3, *C*).

A cancellous bone plasty is essential if the depth of the cavity exceeds the depth of the transplant. Additionally in cases of a sclerotic defect bed, multiple drillings may be necessary for sufficient healing.

According to the osteocartilaginous defect size and depth, the posterior femoral condyle is harvested by a blade chisel osteotomy in a maximally flexed knee position.

In detail, the direction of the posterior femoral condyle osteotomy is parallel or in elongation to the posterior cortex of the femoral diaphysis (Fig. 6-4, *A-B*).

To keep the correct plane with the blade chisel from sliding out, the cut of the blade must be turned regularly.

To secure the posterior femoral condyle against transplant slippage, the posterior condyle may be temporarily fixed with a K-wire before completion of the osteotomy (Fig. 6-4, *C*).

Condyle or Hohmann retractors are used for protection of the posterior capsule, including the neurovascular structures, the intercondylar soft tissue, and the collateral ligament.

In cases of critical size of the osteochondral defect area (30 to 35 mm diameter), the harvesting of the posterior femoral condyle may occur before the preparation of the defect bed for securing of an adequately sized Mega-OATS cylinder.

The Mega-OATS cylinder is harvested out of the removed posterior femoral condyle using a specially designed Mega-OATS workstation. The

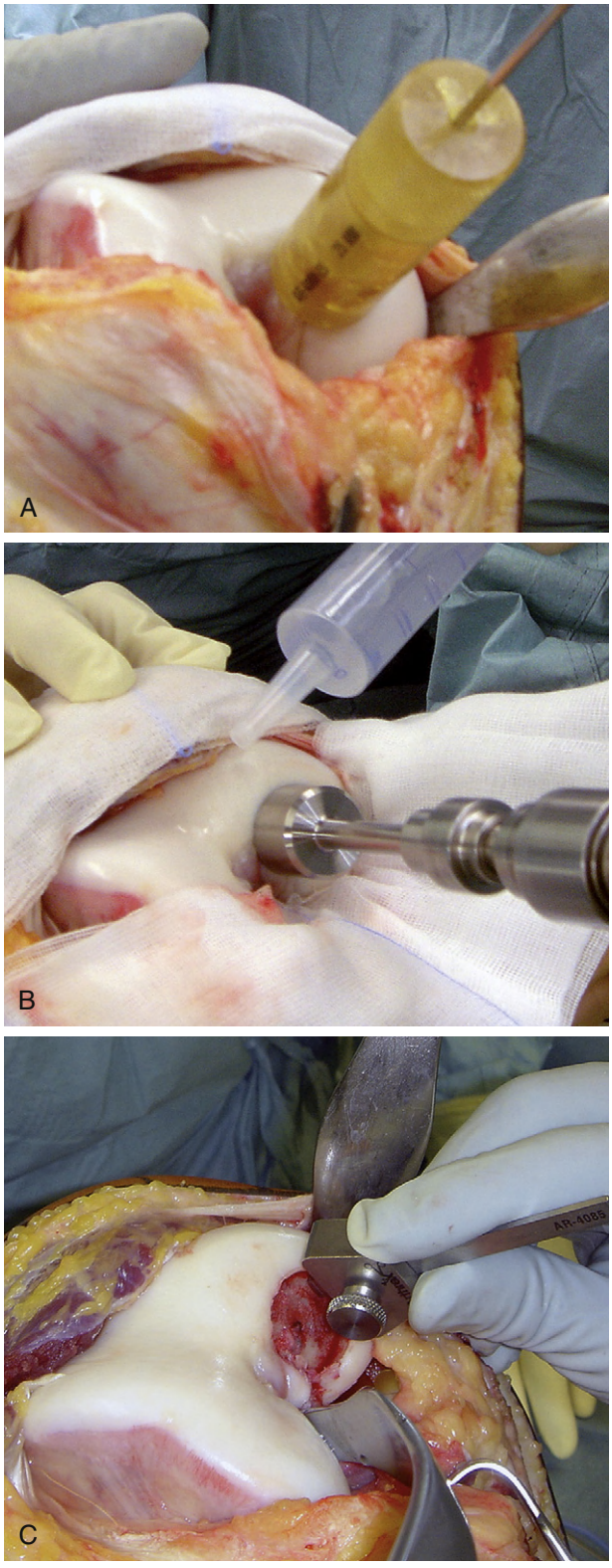
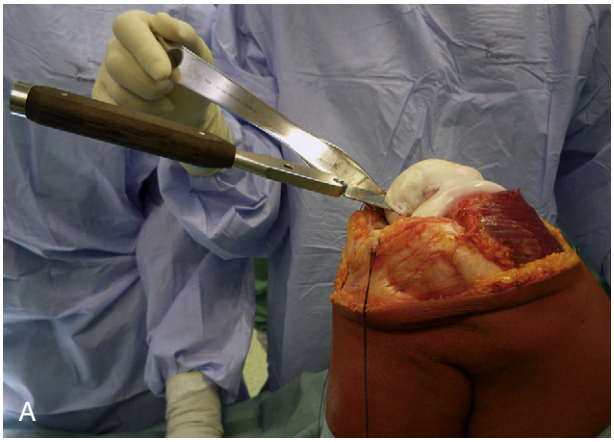
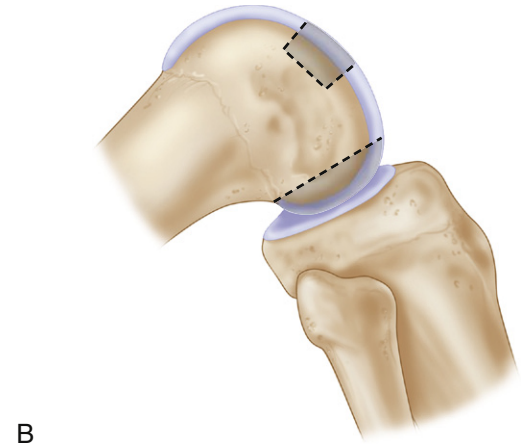


FIGURE 6-3 Preparation of the recipient socket. **A,** Measurement of the osteochondral size of the defect. **B,** Hollow drill for preparation of the defect bed. **C,** Measurement of the defect socket.





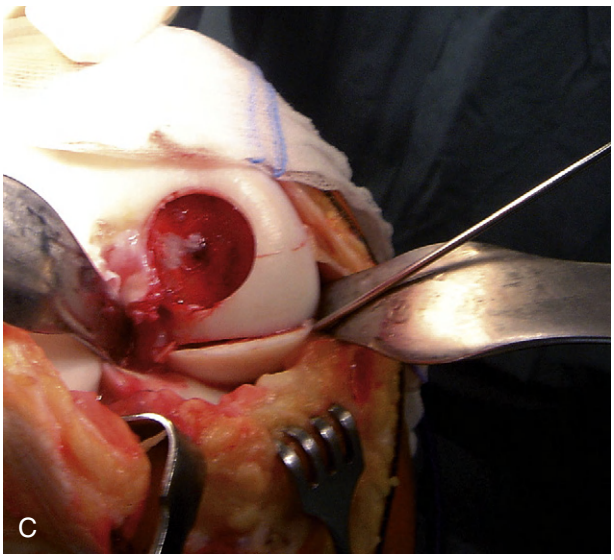


FIGURE 6-4 Osteotomy of the posterior femoral condyle. **A** and **B,** The osteotomy is performed parallel or in elongation of the cortex of the posterior femoral diaphysis. **C,** Temporary fixation of the incomplete posterior femoral condyle transplant using a K-wire during osteotomy for prevention of transplant slippage.

osteotomized posterior femoral condyle is fixed by screws at the workstation (Fig. 6-5, *A*).

For optimal harvest of the Mega-OATS cylinder, the guiding device of the workstation is adapted perpendicularly to the cartilage surface of the transplant (Fig. 6-5, *B*).

Then the Mega-OATS cylinder is cut out of the transplant using a core drill (Fig. 6-5, *C*). Usually, a diameter of the Mega-OATS cylinder between 20 to 35 mm can be achieved depending of the size of the osteochondral defect and the height of the patient.

The prepared Mega-OATS cylinder is finally implanted in the recipient socket following determination of the socket depth. Because the diameter of the Mega-OATS cylinder is 0.4 to 0.5 mm larger than the diameter of the defect socket, a press-fit technique is usually feasible (Fig. 6-6).

When an osteochondral skirt is less than 75% of the recipient socket circumference or when there are irregularities in the cavity, a temporary fixation of the Mega-OATS cylinder using a small fragment screw may be necessary. In these rare cases, the screws should be removed arthroscopically after 6 week before resumption of partial weight bearing.

For optimal congruency of the Mega-OATS cylinder to the adjacent cartilage curvature, the cylinder must be usually rotated about 90° to the longitudinal central axis of the cylinder to match the different surface curvatures of the posterior part of the femoral condyle and the weight-bearing zone of the femoral condyle.

An intraarticular drainage is placed before closure of the arthrotomy in a layer-by-layer fashion. Finally, sterile wound dressing and elastocompressive wrapping are applied.

COMORBIDITIES

Deviation of the axis of the leg (malalignment), ligamentous instability, meniscal lesions, or accompanying smaller osteochondral lesions are common comorbidities of large osteochondral defects in the weight-bearing zone of the knee joint. Usually, these comorbidities are treated simultaneously in a single-stage surgical intervention.

In cases of deviation of the axis and consecutive mechanical overload of the impaired compartment, a simultaneous correction of the axis is essential.

Ligamentous instability should also be addressed at the same time to avoid shear forces at the osteochondral transplant. Separate smaller osteochondral lesions may be treated with additional OATS plugs.

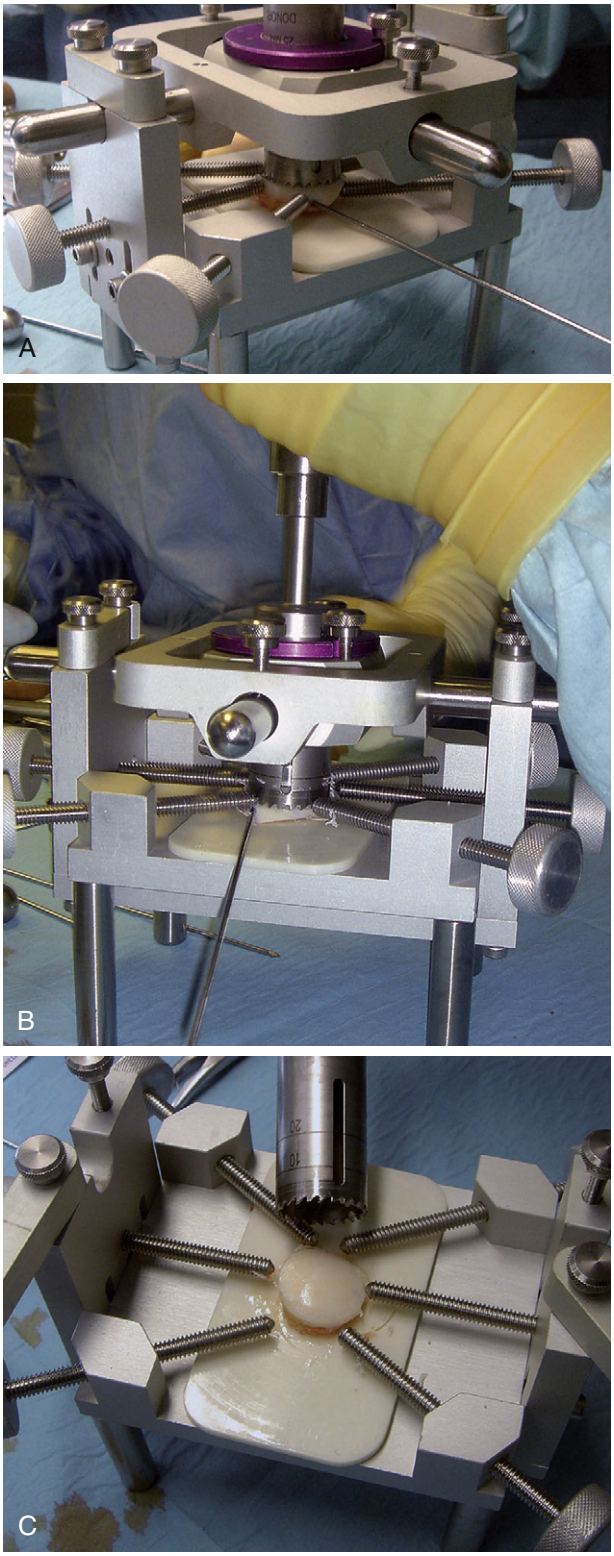


FIGURE 6-5 Mega-OATS cylinder harvest out of the osteotomized posterior femoral condyle. **A,** Fixation of the posterior femoral condyle within the Mega-OATS workstation. **B,** Perpendicular harvest of the Mega-OATS cylinder out of the fixed posterior femoral condyle. **C,** Final harvest of the Mega-OATS cylinder.

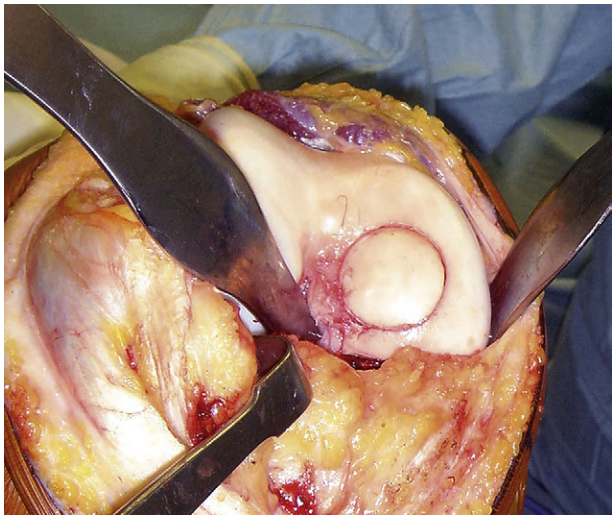


FIGURE 6-6 Positioning of the Mega-OATS cylinder into the recipient socket with adjustment of an optimal surface congruency to the adjacent cartilage.

POSTOPERATIVE MANAGEMENT

Unloading of the operated lower extremity for 6 weeks postoperatively is mandatory.

Within this period, active range of motion is limited to flexion/extension 90°-0°-0° and supported by usage of a 4-point hard frame knee brace for at least 6 weeks.

Continuous passive motion therapy and isometric muscle strengthening are concomitantly recommended.

Beginning at the 7th week postoperatively, progressive loading with 20 kg per week and free active range of motion are allowed as tolerated until full weight bearing of the extremity is achieved. Within the 3rd to 6th postoperative month, progressive muscle and proprioceptive training are performed.

A specific sports rehabilitation program is started at the 7th postoperative month. Sports at a recreational competition level in low- and mid-impact sports (with respect to the contraindication criteria) may be restarted at 10 to 12 months postoperatively; however, professional competition levels in mid- and high-impact sports are not recommended.

POSTOPERATIVE IMAGING

Postoperative standard radiography of the knee joint is performed after removal of the drain. A routine MRI postoperatively is not necessary but may be indicated in prolonged postoperative pain and swelling as well as for evaluation of osseous ingrowth, chondral congruency, and graft viability

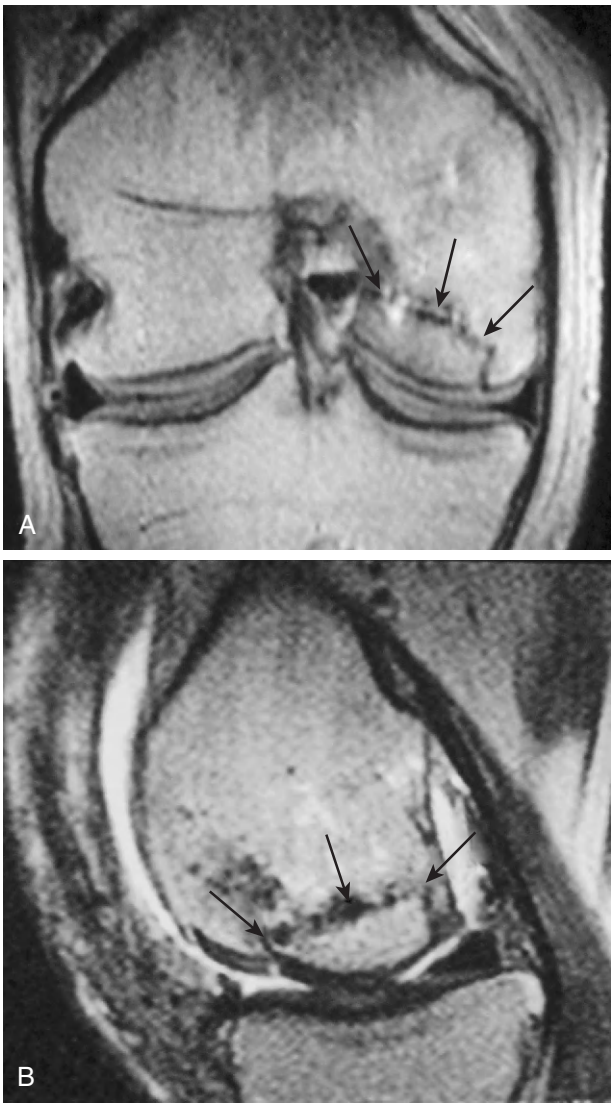


FIGURE 6-7 Postoperative MRI of the Mega-OATS transplant: **A,** coronal and, **B,** sagittal. The cylinder shows osseous integration, an adequate restoration of the condyle curvature, and a congruent chondral surface to the surrounding cartilage (*arrows*).

(Fig. 6-7, *A-B*). For special evaluation of graft viability, MRI may be enhanced using an intravenous fluid application.

CONCLUSION

The Mega-OATS procedure represents a reproducible technique that allows a restoration of pain-free or low-pain-level daily mobility and in many cases enables one to restart sporting activities on a recreational level.

However, this technique has to be considered as a salvage procedure for young individuals with large osteochondral defects in the weight-bearing

zone of the femoral condyle, who are considerably limited in performing normal daily and sporting activities. Addressing concomitant knee pathologies is essential for obtaining overall satisfactory results.

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CHAPTER 7

Osteochondral Allografts

William Bugbee

BACKGROUND AND RATIONALE

The fundamental concept governing fresh osteochondral allografting is the transplantation of architecturally mature hyaline cartilage, with living chondrocytes that survive transplantation and are thus capable of supporting the cartilage matrix.[1]

Hyaline cartilage possesses characteristics that make it attractive for transplantation. It is an avascular tissue and therefore does not require a blood supply, meeting its metabolic needs through diffusion from synovial fluid. Second, it is an aneural structure and does not require innervation for function. Third, articular cartilage is relatively immunoprivileged, as the chondrocytes are imbedded within a matrix and are relatively protected from host immune surveillance.

The second component of the osteochondral allograft is the osseous portion. This functions generally as a support for the articular cartilage, as well as a vehicle to allow attachment and fixation of the graft to the host. The osseous portion of the graft is quite different from the hyaline portion, as it is a vascularized tissue, and cells are not thought to survive transplantation; rather, the osseous structure functions as a scaffold for healing to the host by creeping substitution (similar to other types of bone graft).

Generally, the osseous portion of the graft is limited to a few millimeters. It is helpful to consider a fresh osteochondral allograft as a composite graft of both bone and cartilage, with a living mature hyaline cartilage portion and a nonliving subchondral bone portion. It is also helpful to understand the allografting procedure in the context of a tissue or organ transplantation, as the graft essentially is transplanted as an intact structural and functional unit replacing a diseased or absent component in the recipient joint.

The transplantation of mature hyaline cartilage obviates the need to rely on techniques that induce cells to form cartilage tissue, which are central to other restorative procedures

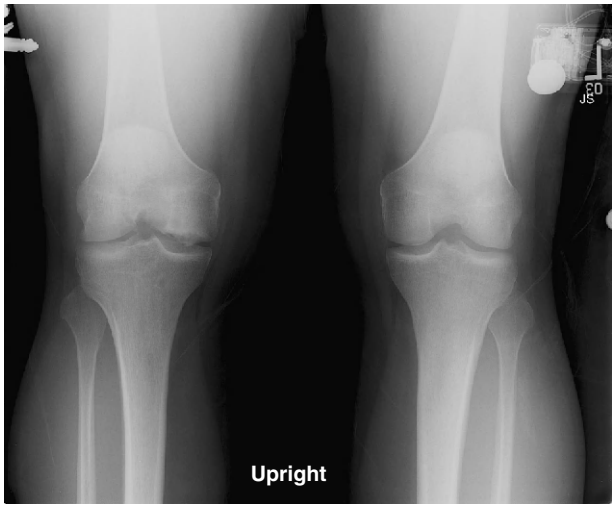

FIGURE 7-1 Preoperative anteroposterior radiograph demonstrating osteochondral lesion of the medial femoral condyle.

INDICATIONS

Fresh osteochondral allografts possess the ability to restore a wide spectrum of chondral and osteochondral pathology. As a result, the clinical indications cover a broad range of pathology. In addition to evaluating the particular lesion, the careful assessment of the entire joint and limb is important.

Many proposed treatment algorithms suggest the use of allografts for large lesions (>2 or 3 cm) or for salvage in difficult reconstructive situations. In our experience, allografts can be considered as a primary treatment option for osteochondral lesions >2 cm in diameter, as is typically seen in osteochondritis dissecans and osteonecrosis (Fig. 7-1).

Allografts are useful as a revision cartilage restoration procedure when other cartilage treatments, such as microfracture, osteochondral autologous transfer, or autologous chondrocyte implantation, have been unsuccessful. Allografts are also indicated for salvage reconstruction of posttraumatic defects of the tibial plateau, patella, or the femoral condyle.

In selected cases, allografts can be used to treat more severe disease situations such as unicompartmental arthrosis.

GRAFT SIZING

The surgical technique for fresh osteochondral allografting depends on the joint and surface to be grafted. Common to all fresh allografting procedures is matching the donor with recipient.[2,3]. This is done on the basis of size.

In the knee, an anteroposterior (AP) radiograph with a magnification marker is used, and a measurement of the medial-lateral dimension of the tibia is made

FIGURE 7-2 Instruments for preparing dowel-type grafts of various sizes.

and corrected for magnification. Some surgeons may prefer to use measurements based on magnetic resonance imaging (MRI) or computed tomography (CT) images, but we have not found this to be more useful than plain radiographs.

The tissue bank makes a direct measurement on the donor tibial plateau. Alternatively, a measurement of the affected femoral condyle can be performed. A match is considered acceptable at ±2 mm; however, it should be noted that there is a significant variability in anatomy, which is not reflected in size measurements. In particular, in treating osteochondritis dissecans, the pathological condyle typically is larger, wider, and flatter; therefore, a larger donor generally should be used.

DECISION MAKING FOR DOWEL OR SHELL TECHNIQUE

The two commonly used techniques for the preparation and implantation of osteochondral allografts include the press-fit plug technique and the shell graft technique. Each technique has advantages and disadvantages.

The press-fit plug technique is a similar in principle to autologous osteochondral transfer (OATS). A number of commercially available instruments are available (Fig. 7-2).

This technique is optimal for contained condylar lesions between 15 and 35 millimeters in diameter. Fixation is generally not required because of the stability achieved with the press-fit. Disadvantages include the fact that very posterior femoral condyle and tibial plateau lesions are not conducive to the use of a circular coring system and may be more amenable to shell allografts. Additionally, the more ovoid or elongated a lesion is in shape, the more normal cartilage needs to be sacrificed at the recipient site to accommodate the circular donor plug.

Shell grafts are technically more difficult to perform and typically require fixation. However, depending on the technique employed, less normal cartilage may need to be sacrificed.

SURGICAL APPROACH

The surgical approach for osteochondral allografting involves an arthrotomy of variable size (depending on the position and dimension of the lesion). Usually patients have been previously operated or are at least fully imaged and the size and location of the lesion(s) are known; otherwise, a diagnostic arthroscopy can be performed before the allografting procedure to confirm adequacy of the available graft or to treat coexisting pathology. It is the responsibility of the surgeon to inspect the graft and to confirm the adequacy of the size match and quality of the allograft tissue before surgery.

The patient is positioned supine with a proximal thigh tourniquet. A leg or foot holder is extremely helpful to position and maintain the knee in between 70° and 120° of flexion. For most femoral condyle lesions, eversion of the patella is not necessary.

A standard midline incision is made and elevated subcutaneously, depending on the location of the lesion (either medial or lateral) and the joint entered by incising the fat pad and retinaculum without disrupting the anterior horn of the meniscus or damaging the articular surface.

In some cases, where the lesion is posterior or very large, the meniscus must be detached and reflected; and generally, this can be done safely, leaving a small cuff of tissue adjacent to the anterior attachment of the meniscus.

Once the joint capsule and synovium have been incised and retractors carefully placed, the knee is brought to a degree of flexion that presents the lesion into the arthrotomy site.

Extending the arthrotomy proximal or distal may be necessary to mobilize the extensor mechanism.

Once the joint capsule and synovium have been incised and the joint has been entered, retractors are placed medially and laterally to expose the condyle. Care is taken for the positioning of the retractor within the notch to protect the cruciate ligaments and articular cartilage.

The knee is then flexed or extended until the proper degree of flexion is noted that presents the lesion into the arthrotomy site (Fig. 7-3).

LESION INSPECTION AND PREPARATION

The lesion is inspected and palpated with a probe to determine the extent, margins, and maximum size. The size of the proposed graft is then determined, utilizing sizing dowels (Fig. 7-4). If the lesion falls between two sizes it is generally preferred to start with the smaller size. At this point the surgeon should also determine if the allograft tissue is adequate in dimension

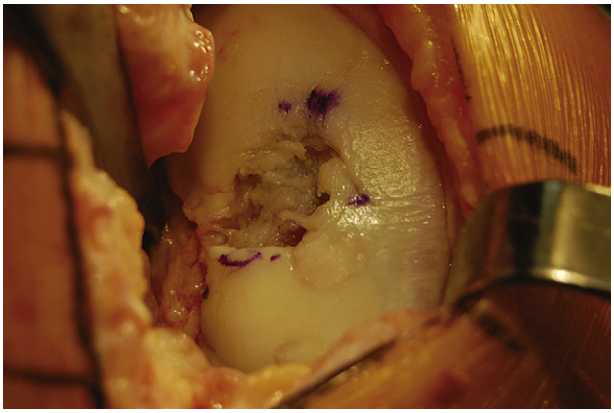

FIGURE 7-3 Intraoperative view of the exposed osteochondritis dissecans lesion. Note the patella retractor within the femoral notch.

FIGURE 7-4 Sizing of the lesion and determination of the location of guide pin placement.

(usually diameter) to harvest the proposed allograft plug (this becomes critical in grafts 25 mm or greater).

A guide wire is driven through the sizing dowel into the center of the lesion, perpendicular to the curvature of the articular surface (Fig. 7-5 *A-B*).

The cartilage surface is scored, and a special reamer is used to remove the remaining articular cartilage and 3 to 4 mm of subchondral bone (Fig. 7-6).

In deeper lesions, the pathological bone is removed until there is healthy, bleeding bone. Generally, the preparation depth does not exceed 5 to 8 mm. It is critical for the surgeon to take care not to inadvertently ream too deep, as the bone becomes much softer once the subchondral plate is removed and cancellous bone is encountered.

The reamings should be retained to be used as bone graft if needed. Bone grafting is performed to fill any deeper or more extensive osseous defects or to modify the fit of the graft if there is a depth mismatch between the recipient socket and allograft plug. At this point the guide pin can be removed and depth measurements are made and recorded in the four quadrants of the prepared recipient site (Fig. 7-7).

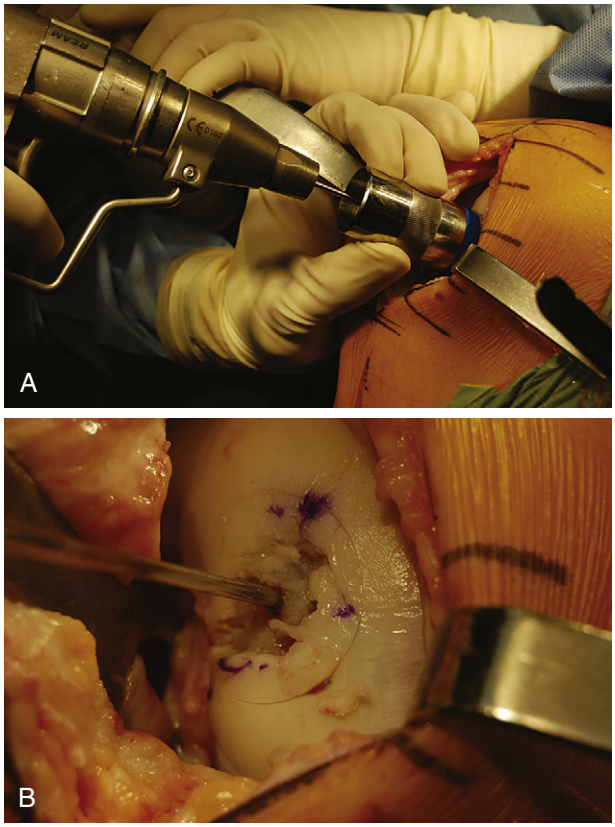

FIGURE 7-5 **A,** Placement of the guide pin in the center of the lesion utilizing perpendicular guide. **B,** Guide wire is centered in the lesion.

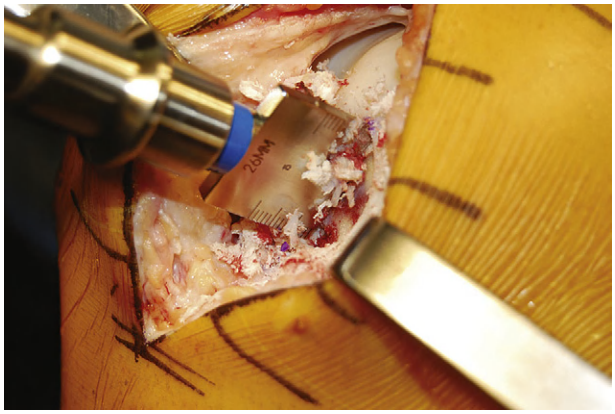

FIGURE 7-6 Reaming is performed carefully to the desired depth of 5 to 8 mm. Reaming speed is preferred over drilling for better control and less heat generation.

GRAFT PREPARATION

The corresponding anatomical location of the recipient site then is identified on the graft (Fig. 7-8). The graft is placed into a graft holder (or alternately, held with bone-holding forceps). A saw guide then is placed in the appropriate position, again perpendicular to the articular surface, exactly matching the orientation used to create the recipient site.

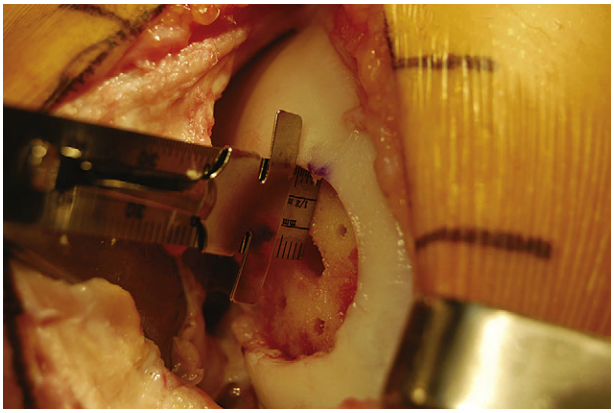

FIGURE 7-7 The guide wire is removed and depth measurements are made in the recipient socket.

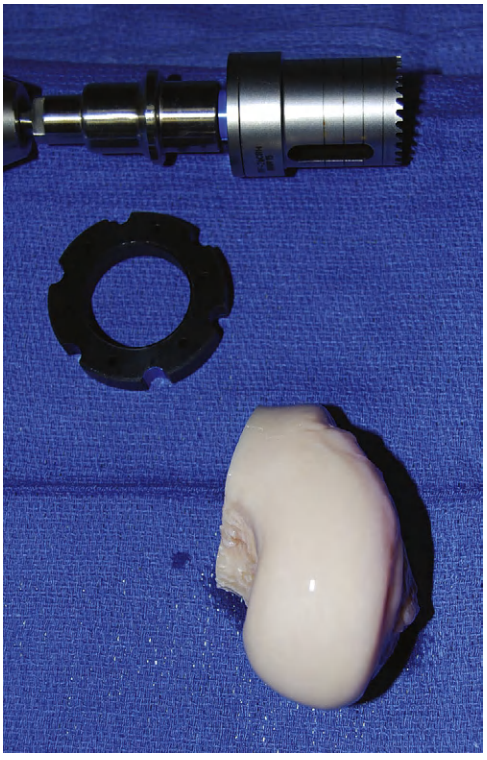

FIGURE 7-8 Donor coring saw, saw guide, and medial femoral condyle allograft.

The appropriate size matched coring saw is used to core out the graft (Fig. 7-9). The graft can be cut from the donor condyle and removed as a long plug. The allograft plug thickness now must be adjusted. Depth measurements, which were taken from the recipient, are transferred to the graft (Fig. 7-10).

The graft is mounted on the graft holder, which serves as a cutting guide and cut with an oscillating saw (Fig 7-11). Often, this must be done multiple times, to ensure precise thickness, matching the prepared defect in the patient (Fig. 7-12). It is also helpful at this time to bevel the edge of the osseous

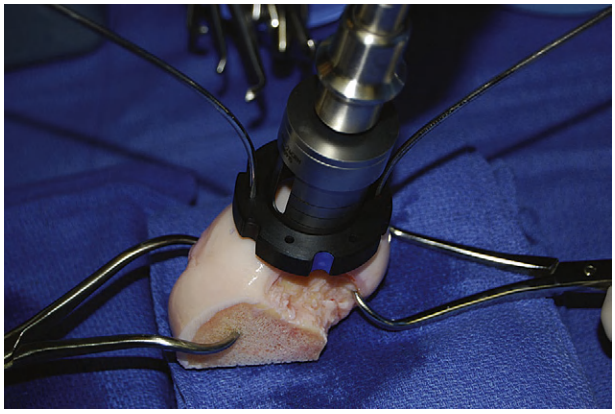

FIGURE 7-9 The saw guide is mounted on the allograft, perpendicular to the articular surface at the desired site of the graft harvest, and the coring saw is used to harvest the graft.

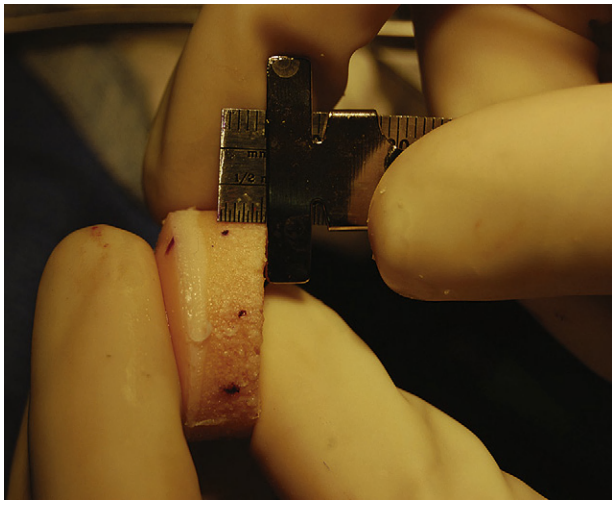

FIGURE 7-10 After the graft is removed from the hemicondyle with the oscillating saw, the recipient site measurements are transferred to the allograft plug.

portion of the graft with a small rongeur or rasp to facilitate initial fitting into the recipient socket. The graft should be irrigated copiously with a high-pressure lavage to remove all marrow elements (Fig. 7-13).

GRAFT INSERTION

The graft is then inserted by hand in the appropriate rotation and is gently pressed into place manually (Fig. 7-14). To fully seat the graft, the joint can be carefully brought through a range of motion, allowing the opposing articular surface to seat the graft (Fig. 7-15). Finally, gentle tamping can be performed to fully seat the graft. Excessive and forceful striking of the graft should be avoided, as this leads to chondrocyte necrosis.

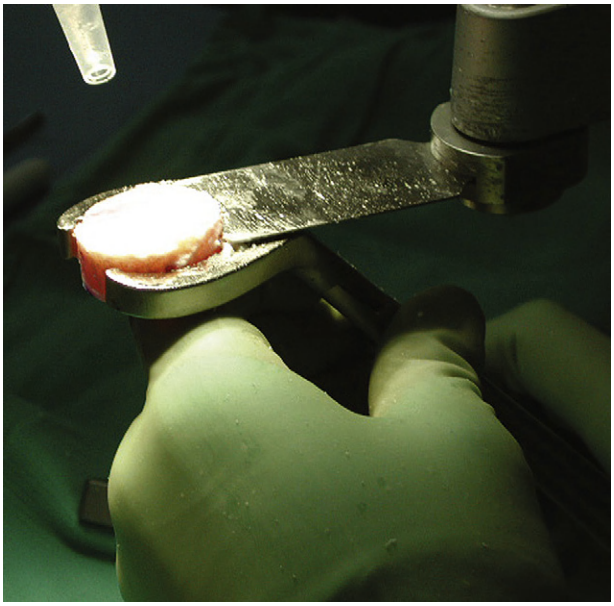

FIGURE 7-11 The graft is mounted on the graft holder and excess bone is removed with the oscillating saw.

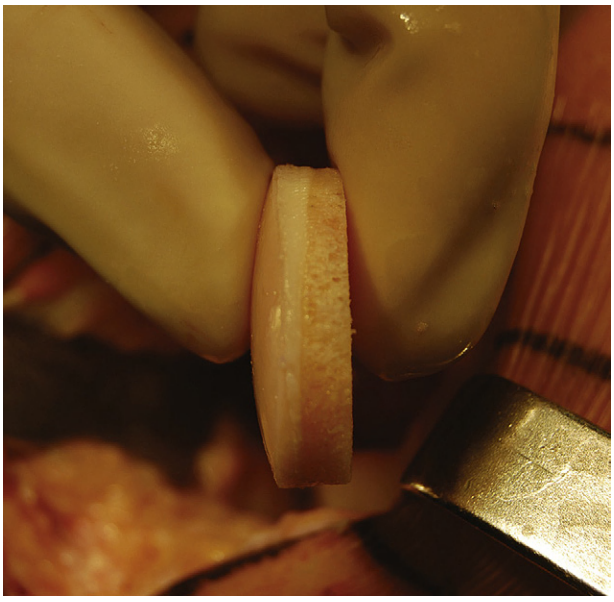

FIGURE 7-12 The graft dimensions should be rechecked. Bony edges can be trimmed or slightly rounded to facilitate insertion.

If the graft does not fit easily, the recipient site can be dilated or reamed again. The graft itself can be further trimmed or beveled. Occasionally, overhanging cartilage on the margins of the recipient socket or in the graft itself prevents seating, and this can be trimmed with a #15 scalpel blade.

Once the graft is seated, a determination is made whether additional fixation is required (Fig. 7-16). Typically, absorbable pins are utilized, particularly if the graft is large or has an exposed edge.

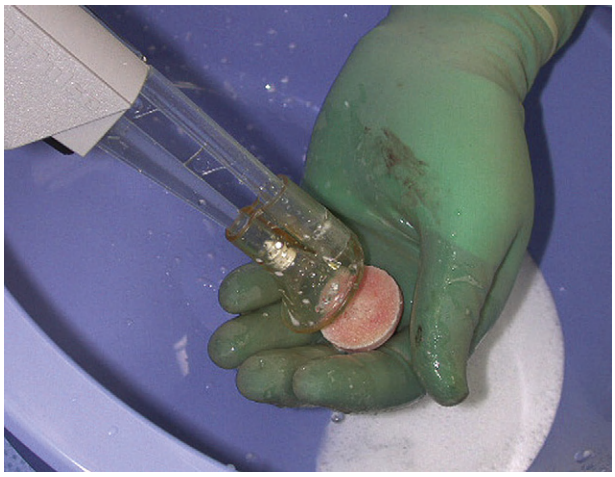

FIGURE 7-13 The graft should be washed with pulsatile lavage irrigation to remove debris and marrow elements.

FIGURE 7-14 The graft is oriented appropriately to the recipient site and inserted manually.

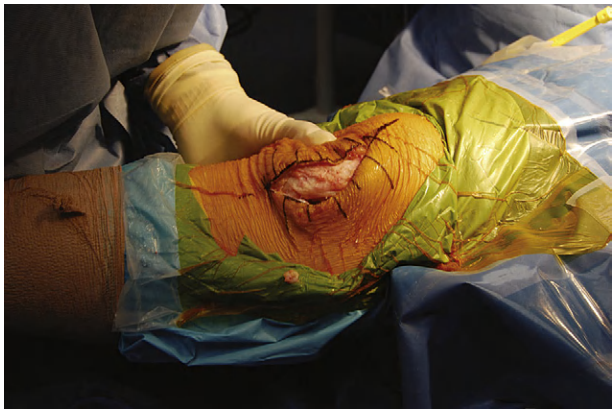

FIGURE 7-15 Joint compression and range of motion is used to initially seat the graft. Gentle tamping can be used for final seating.

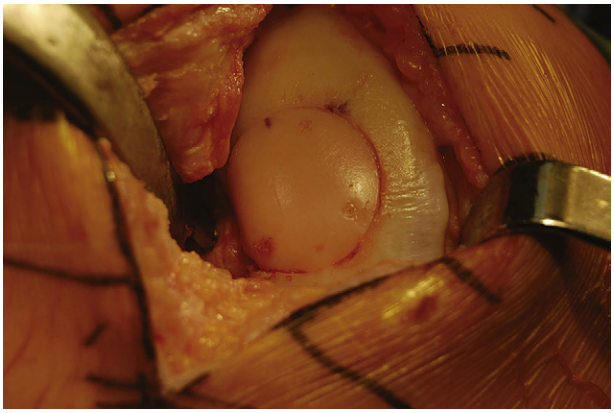

FIGURE 7-16 View of the osteochondral graft after insertion. Note placement of chondral darts for adjunctive fixation.

Often in cases of osteochondritis dissecans of the medial femoral condyle, the graft needs to be trimmed in the notch region, to prevent impingement. The knee is then brought through a complete range of motion to confirm that the graft is stable and that no catching or soft-tissue obstruction is noted.

SHELL ALLOGRAFT TECHNIQUE

Although the dowel or plug allograft method is generally preferred for most lesions, the surgeon should be prepared to perform a shell graft if the lesion size or location do not allow for proper placement of the dowel graft instruments.

For the shell graft technique, the defect is identified through the previously described arthrotomy, and the dimensions of the lesion are marked with a surgical pen.

Minimizing the sacrifice of normal cartilage, a geometric shape, such as a rectangle or trapezoid, is created that is amenable to hand crafting a shell graft. A #15 scalpel blade is used to demarcate the lesion, and sharp ring curettes are used to remove all tissue inside this mark. Using motorized burrs, sharp curettes, and osteotomies, the subchondral bone is removed down to a depth of 4 to 5 mm. The shape is transferred to the graft, using length, width and depth measurements or a foil template.

A saw is used to cut the basic graft shape from the donor condyle, initially slightly over sizing the graft by a few millimeters. Excess bone and cartilage are removed as necessary through multiple trial fittings.

The graft and host bed are then copiously irrigated, and the graft placed flush with the articular surface. The need for fixation is based on the degree of inherent stability.

Bioabsorbable pins are typically used when fixation is required, but countersunk compression screws may be used as an alternative.

After cycling the knee through a full range of motion to ensure graft stability, standard closure is performed.

POSTOPERATIVE MANAGEMENT

Initial postoperative management includes attention to control of pain, swelling, and restoration of limb control and range of motion. Patients generally are maintained on touch-down weight bearing for 4 to 6 weeks, depending on the size of the graft and stability of fixation. Patients with patellofemoral grafts are allowed weight bearing as tolerated in extension and generally are limited to 45° of flexion for the first four weeks, utilizing an immobilizer or range-of-motion brace.

Closed chain exercise such as cycling is introduced between weeks 2 and 4. Weight bearing is progressed slowly between the second and fourth month, with full weight bearing utilizing a cane or crutch. Full weight bearing and normal gait pattern are generally tolerated between the third and fourth month.

Recreation and sports are not reintroduced until joint rehabilitation is complete and radiographic healing has been demonstrated, which generally occurs no earlier than 6 months postoperatively.

RESULTS WITH OSTEOCHONDRAL ALLOGRAFTS

Garrett[4] first reported on 17 patients treated with fresh osteochondral allografts for OCD of the lateral femoral condyle utilizing a dowel technique. All patients had failed previous surgery, and in a 2-to-9-year follow-up period, 16 out of 17 patients were reported as asymptomatic.

Emmerson et al.[5] reported our experience in the treatment of osteochondritis dissecans of the medial and lateral femoral condyle. We evaluated 69 knees in 66 patients at a mean of 5.2 years postoperatively. All allografts were implanted within 5 days of procurement. In all, 49 males and 17 females, with a mean age of 28 years (range 15 to 54) underwent allografting using either the dowel or shell technique. Forty lesions involved the medial femoral condyle and 29 the lateral femoral condyle. An average of 1.6 surgeries had been performed on the knee before the allograft procedure. Allograft size was highly variable, with a range of 1 to 13 cm^2. The average allograft size was 7.4 cm^2. Overall, 53/67 (79%) knees were rated good or excellent, 10/67 (15%) were rated fair, and 6/67 (6%) were rated poor. Six patients had reoperations on the allograft: one was converted to total knee arthroplasty, and

five underwent revision allografting at 1, 2, 5, 7, and 8 years after the initial allograft. Forty-nine out of 66 patients completed questionnaires: 96% reported satisfaction with their treatment; 86% reported less pain. Subjective knee function improved from a mean of 3.5 to 7.9 on a 10-point scale.

Chu[6] reported on 55 consecutive knees undergoing osteochondral allografting. This group included patients with diagnoses such as traumatic chondral injury, avascular necrosis, osteochondritis dissecans, and patellofemoral disease. The mean age of this group was 35.6 years, with follow-up averaging 75 months (range 11 to 147 months). Of the 55 knees, 43 were unipolar replacements and 12 were bipolar resurfacing replacements. In this mixed patient population, 42/55 (76%) of these knees were rated good to excellent, and 3/55 were rated fair, for an overall success rate of 82%. It is important to note that 84% of the knees that underwent unipolar femoral grafts were rated good to excellent, and only 50% of the knees with bipolar grafts achieved good or excellent status.

Aubin[7] reported on the Toronto experience with fresh osteochondral allografts of the femoral condyle. Sixty knees were reviewed, with a mean follow-up of 10 years (range 58 to 259 months). The etiology of the osteochondral lesion was trauma in 36, osteochondritis in 17, osteonecrosis in 6, and arthrosis in 1. Realignment osteotomy was performed in 41 patients and meniscal transplantation in 17. Twelve knees required graft removal or conversion to total knee arthroplasty. The remaining 48 patients averaged a Hospital for Special Surgery Score of 83 points. The authors reported 85% graft survivorship at 10 years.

Williams[8] reported on the outcome of 19 fresh, hypothermically stored allografts, with a mean time to implantation from graft recovery of 30 days. At minimum 2-year follow-up, all patients showed functional improvement and magnetic resonance imaging demonstrated normal cartilage signal in 18 of 19 grafts and complete or partial osseous incorporation in 14 grafts.

McCulloch[9] reported on a series of 25 fresh, stored osteochondral allografts of the femoral condyle. Statistically significant improvements were seen in all outcome measures, and 22 of 25 were radiographically incorporated into host bone.

LaPrade[10] reported on 23 patients treated with osteochondral allografts for focal femoral condyle lesions. At a mean follow-up of 3 years, 22 of 23 grafts were stable and incorporated. Cincinnati and the International Knee Documentation Committee (IKDC) scores demonstrated significant improvement in this cohort.

SUMMARY

Osteochondral allografting is an extremely useful and versatile technique for managing difficult or complex chondral or osteochondral lesions. The surgical technique relies on common and straightforward principles. Great care should be taken in handling and preparation of the graft. The advantage of allografting lies in its ability to restore both osseous and chondral components of a defect. Reported clinical outcomes are favorable in the short and intermediate terms.

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2. Bonner KF, Bugbee WD. Osteochondral Allografting in the Knee. In: Cole B and Malek M. Textbook of Arthroscopy. Saunders, St. Louis, 2004, 611–623.
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CHAPTER

8

Fixation of Osteochondral Fragments

William Bugbee, Brice W. Blatz, Bert R. Mandelbaum

INTRODUCTION

Osteochondral fragments can occur in any synovial joint, but they are most commonly encountered in the knee. Typical etiologies include osteochondritis dissecans, trauma (such as the result of patellar dislocation), or nonunion of periarticular fracture.

Osteochondral fragments can also be created by the surgeon in the course of performing osteochondral autografts such as mosaicplasty and mega OATS (Chapters 5 and 6) or osteochondral allografting (Chapter 7).

This chapter reviews the most common methods of fragment fixation.

INDICATIONS FOR INTERNAL FIXATION

Few studies provide clear indications for surgical fixation of osteochondral fragments (Table 8-1). The underlying diagnosis has implications in the decision-making process, such as in the treatment of osteochondritis dissecans (OCD).

OCD lesions in situ are much more likely to heal in skeletally immature patients than in adults. Conversely, fragments with lucency on radiographs or fluid on MRI between the fragment and bone bed are less likely to heal and may do better with fixation.

Acute displaced traumatic fragments should be operated in a timely fashion, as there is obviously no opportunity for healing and the fragment risks degeneration as it moves in the joint.

In cartilage repair procedures, the osteochondral graft may require fixation depending on the inherent stability, size, and location of the graft.

To our knowledge, no quantitative measures of graft stability are available to assist the surgeon in deciding when to perform adjunctive fixation.

TABLE 8-1 Indications for Internal Fixation with Regard to Type of Osteochondral Fragment

Type of Osteochondral Fragment	Indication for Fixation
Osteochondral fracture	Fragment is nondeformed, reducible, viable
Chondral fracture	Lesions that are unstable, partially detached lesions, completely detached lesions that are nondisplaced and viable displaced lesions
Osteochondritis Dissecans (OCD)	

JUVENILE OSTEOCHONDRITIS DISSECANS

This diagnosis is classified as an OCD lesion in a patient with open physes demonstrated on radiographic imagery, specifically of the distal femur. The most common patients are athletic, active adolescents.

Surgical indication for juvenile osteochondritis dissecans (jOCD) includes failure of 6 to 9 months of nonoperative treatment of a stable lesion, an unstable or detached lesion, or a symptomatic patient with imminent physeal closure within 6 months to a year.[1]

ADULT OSTEOCHONDRITIS DISSECANS

Unlike jOCD, symptomatic adult OCD necessitates surgical intervention in most cases because of the progressive course, the inability of the fragment to heal on its own, and the fact that most adult lesions are unstable in nature.[2]

Arthroscopy is useful for determining size and stability of lesions. In situ lesions that are stable during arthroscopic probing can be treated with drilling or internal fixation. Flap lesions (unstable lesions) benefit most from internal fixation techniques.

Massive lesions, multiple fragmented lesions, and substantial craters often require procedures utilizing open bone grafting of the bed or osteochondral autografts and allografts when fixation is not possible or the fragment is not adequate for fixation.[3]

TRAUMATIC OSTEOCHONDRAL FRAGMENTS

The most important decision making in treatment of traumatic osteochondral fragments is whether the fragment has adequate remaining bone to allow both fixation and osseous healing.

In adults there is little evidence that purely chondral fragments have the ability to heal to bone. Nonetheless, surgeons may choose to attempt to repair very thin or small osteochondral fragments with the understanding that there is a significant risk of failure.[4,5]

TABLE 8-2 Internal Fixation Devices
Metal Pins and Wires
Smooth and threaded metal pins
K-wires
Cannulated and AO Metal Screws
Constant pitch
Variable pitch, headless (e.g., Herbert screw)
Bioabsorbable Implants
Biocompression screws
Chondral pins and darts (smooth and barbed)
Osteochondral Plugs
Autograft bone plug/Osteochondral core

One caveat of this approach (and, in fact, in treating any osteochondral fragment with internal fixation) is the avoidance iatrogenic injury to the joint by the fixation device should the fragment collapse or detach, leaving the fixation device proud or loose within the joint. Numerous case reports have documented articular cartilage injury and joint destruction by exposed or loose fixation devices.[3-7]

OVERVIEW OF INTERNAL FIXATION DEVICES

The goal of any chosen device should be rigid fixation and compression while establishing a position that is seated low enough as to not interfere with the surrounding articular cartilage (Table 8-2). The device should allow for early range of motion and should retain the ability to be removed, if necessary.[8]

Pins and Wires

The use of smooth metal pins for fixation was originally described by Smillie in 1957[9] but has since become more of a historical reference. Good results have been published using K-wires in combination with drilling and bone grafting,[8,10] especially when splitting of a smaller fragment is a concern. Other advantages of K-wires include availability, low cost, and ease of use. Disadvantages include lack of compression achieved and possibility of breakage, along with the need for removal.

Cannulated and Variable Pitch Screws

Several options exist with metal screws including cannulated screws and variable-pitch, headless screws. The most commonly referenced variable-pitch screw is the Herbert screw.[11-14] This type of screw allows for rigid fixation, as well as having an auto-compression effect. Another advantage to this screw is that the headless design allows it to be countersunk beneath the surface of the articular cartilage.

The disadvantage of the Herbert screw along with the other metal screws is that they may require an additional surgery for removal, and, if the fragment settles or breaks, the screw may become proud, leading to injury of the opposing articular surface. When possible, the surgeon attempts to place these devices in a manner that avoids the articular surface (Fig. 8-1).

Bioabsorbable Implants

Many available bioabsorbable implants are on the market in the form of screws, pins, darts, and nails. The first-generation implants were made from polyglycolic acid or PGA.

The rapid nature of degradation of this product led to reports of inflammatory foreign-body reactions. Because of this phenomenon, many devices are now made with poly-L-lactic acid (PLLA), which has a longer degradation time, or a combination of PGA and PLLA. These devices have a number of advantages over metallic devices.

They are bioabsorbable, which obviates the need for surgical removal, they are usually low-profile and can be countersunk below the articular cartilage surface and, unlike metallic implants, bioabsorbable implants produce no artifact on imaging studies, facilitating postoperative assessment of fragment healing.[15] Some of the complications that have been reported with bioabsorbable implants include the previously mentioned inflammatory reaction, screw loosening and back-out, synovitis, chronic effusions, and lack of adequate compression or fixation with some devices.[3,6,7]

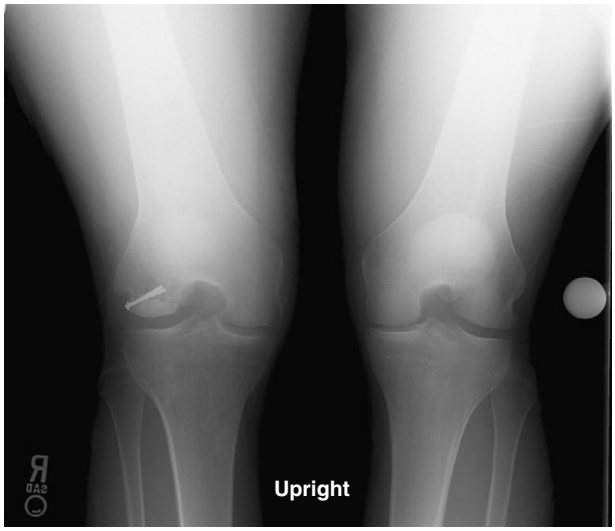

FIGURE 8-1 Fixation of a large osteochondral shell allograft of the lateral femoral condyle with two 3.0 cannulated screws. Note the screws have been placed lateral to the articular surface.

Osteochondral Plugs

Another innovative method of fixation of osteochondral fragments is the use of bone plugs or osteochondral cores. Miniaci has described a method of using a small osteochondral autograft plug to fix osteochondritis dissecans.[16] This technique has the obvious advantage of providing both fragment fixation and bone grafting with a single "device."

SURGICAL TECHNIQUE: CHONDRAL DART

Chondral darts or pins are best suited for providing resistance to shear of relatively stable fragments. They are not capable of providing significant fragment compression, if the surgeon deems this necessary. The low-profile nature is also suited to relatively small or thin fragments.

Darts can be inserted either arthroscopically or with an open procedure after bone grafting or placement of an allograft. The author's experience is primarily using chondral darts for adjunctive fixation of osteochondral allografts (Chapter 7).

The instruments include a cannulated guide, drill, and insertion tamp, which are designed to allow for 2 mm of countersinking of the dart (Fig. 8-2).

In this case a partial talus shell allograft is to be placed.

After fashioning of the graft (Fig. 8-3) and the recipient site of the medial talus (Fig. 8-4), the graft fragment is seated (Fig. 8-5). Note the relative stability of this fragment because of the conformity of the tibiotalar joint and lateral support of the host talus.

With the fragment in place, the cannulated guide is placed on the articular surface, and the drill is used to prepare the osseous channel for the dart (Fig. 8-6).

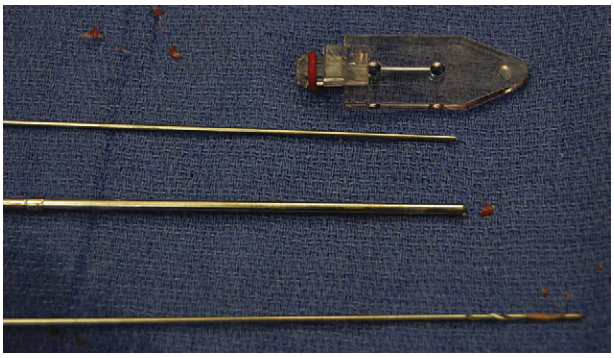

FIGURE 8-2 Instruments for insertion of chondral dart (Arthrex, Naples, Florida), including cannulated guide, drill, insertion tamp, and dart holder.

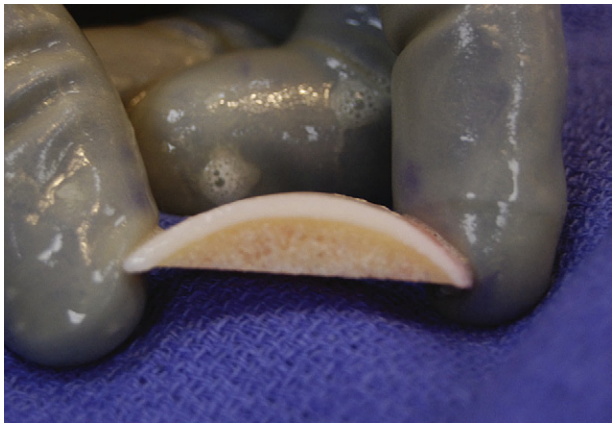

FIGURE 8-3 Osteochondral shell allograft of the medial talus preceding insertion.

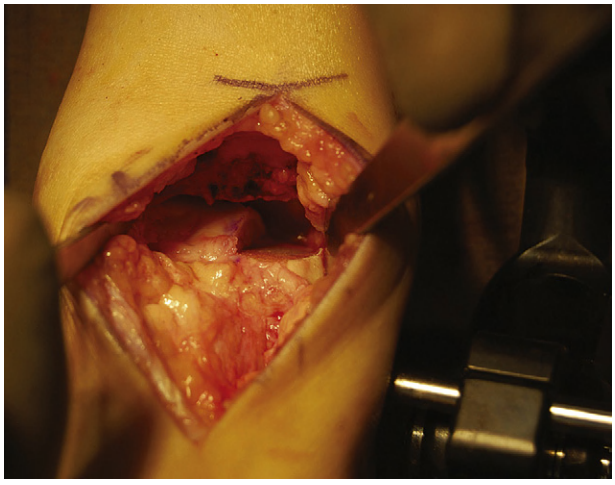

FIGURE 8-4 Intraoperative view of the ankle showing preparation of the medial talus for graft insertion. An external fixator is used to provide joint distraction.

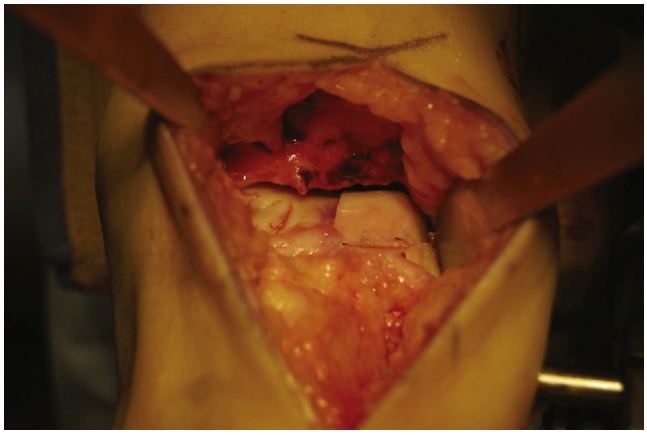

FIGURE 8-5 Shell allograft in place. Note conformity and congruency, which confers relative stability, allowing for pin rather than screw fixation.

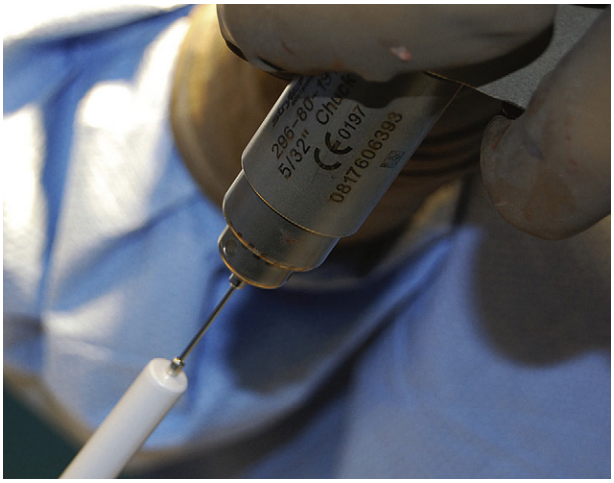

FIGURE 8-6 Drilling is performed through the cannulated guide. Depth is fixed at 20 mm.

While keeping the guide in place on the fragment, the chondral dart is loaded into the cannulated guide (Fig. 8-7) followed by the insertion tamp, which is gently impacted to seat the dart (Fig. 8-8). Care must be taken to maintain the cannulated guide at the same position and angle during both drilling and dart insertion.

The stability of the fixation can be evaluated, and additional darts can be inserted as necessary. One advantage of darts and pins is the relatively small insertion defect footprint on the articular cartilage (Fig. 8-9).

SURGICAL TECHNIQUE: BIOCOMPRESSION SCREW

Fixation devices that provide interfragmentary compression are ideal for fixation of osteochondritis dissecans fragments, when stability of fixation is critical or when there may be a mismatch between the fragment and the host bed requiring bone grafting.

Headed cannulated or variable pitch metal screws provide the best and most durable fixation, but absorbable compression screws may be adequate for many circumstances. For strength reasons, these absorbable screws are not cannulated, though the drill and tap may be.

Instruments include a tapered drill and tap (Fig. 8-10) and screwdriver for the implant insertion (Fig. 8-11). In this case example, the patient has an osteochondral lesion of the talus amenable to open grafting and fixation (Fig. 8-12).

The lesion is elevated to ensure there is adequate bone on the fragment for fixation and healing (Fig. 8-13), and the host bed is prepared by curettage, drilling, and bone grafting to improve the biological milieu (Fig. 8-14). Confirmation of the need for fixation with compression is made by determining

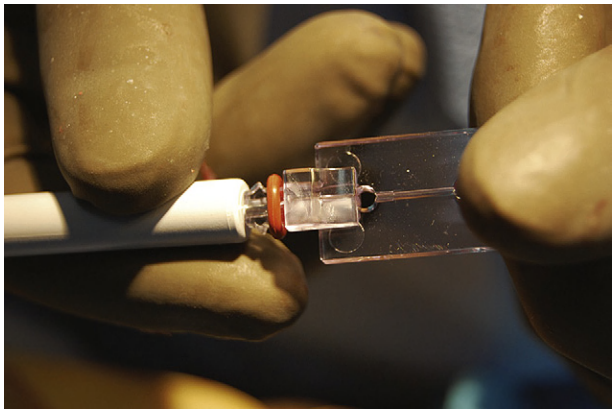

FIGURE 8-7 The chondral dart is inserted into the cannulated guide. Care is taken to not move the guide from the site of fragment drilling.

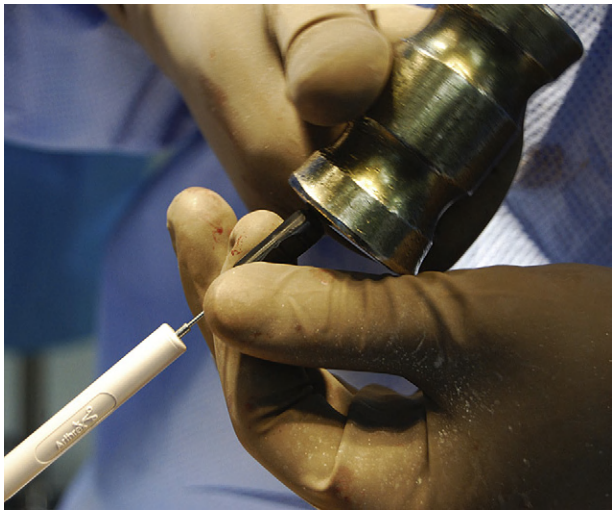

FIGURE 8-8 The chondral dart is gently tamped into place. The dart is 18 mm in length, providing 2 mm of countersinking into the articular cartilage surface.

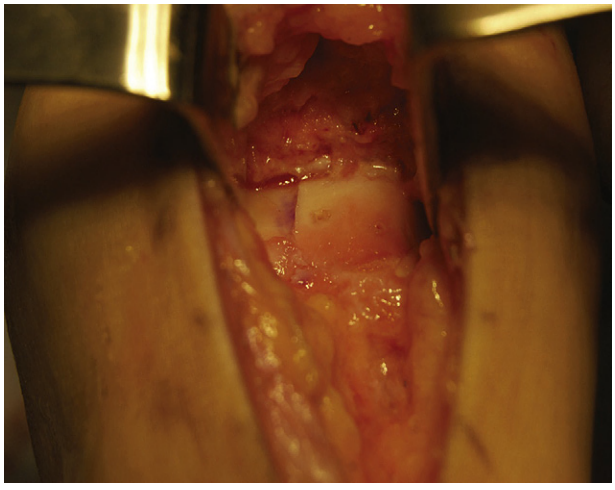

FIGURE 8-9 The allograft in place with two chondral darts inserted. Note the small footprint in the articular surface at the site of dart insertion.

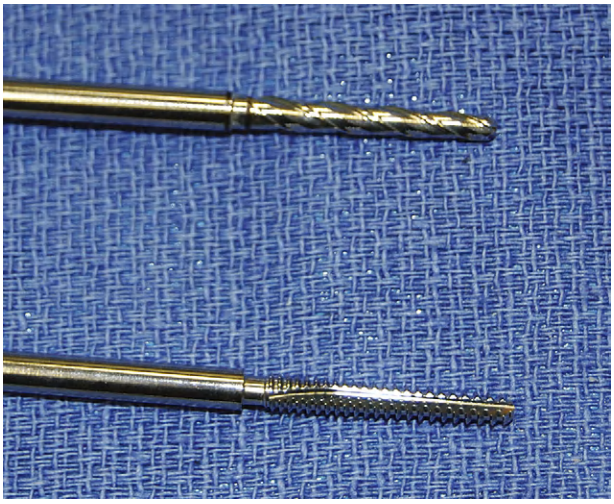

FIGURE 8-10 Cannulated drill and tap for insertion of biocompression screw (Arthrex, Naples, Florida).

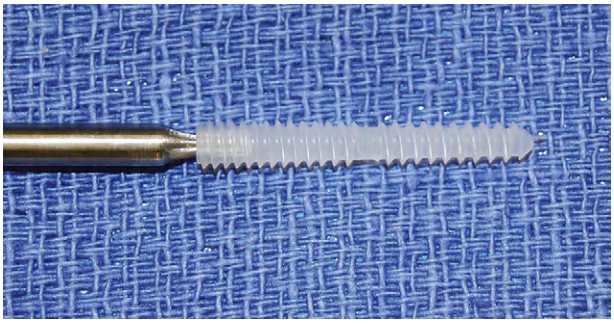

FIGURE 8-11 A 2.7-mm biocompression screw attached to a screwdriver. Note that the screw is tapered and the variable pitched.

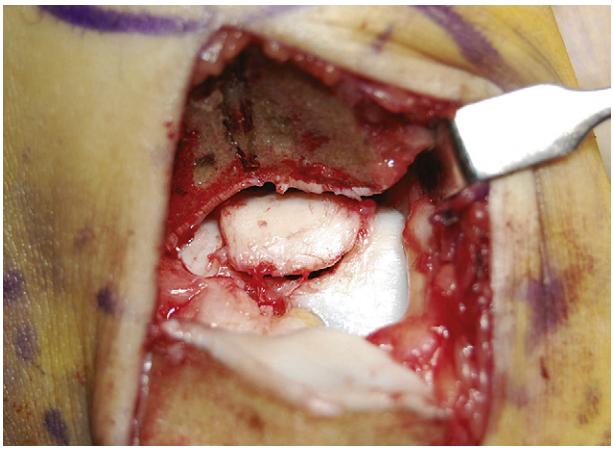

FIGURE 8-12 Osteochondral lesion of the medial talus exposed through medial malleolar osteotomy.

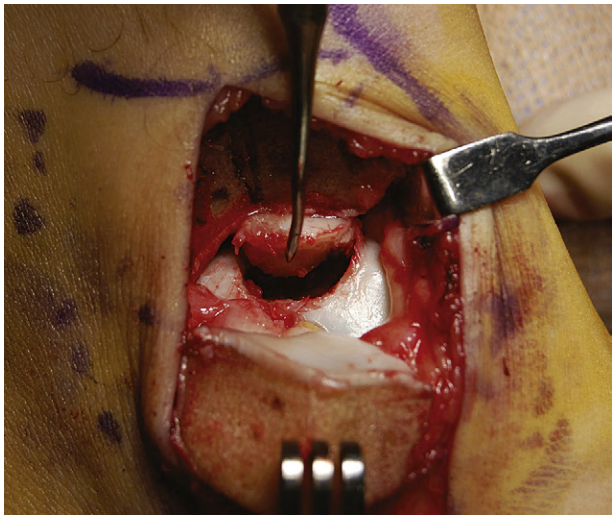

FIGURE 8-13 The lesion is elevated to inspect the osseous portion of the fragment and prepare the bone bed.

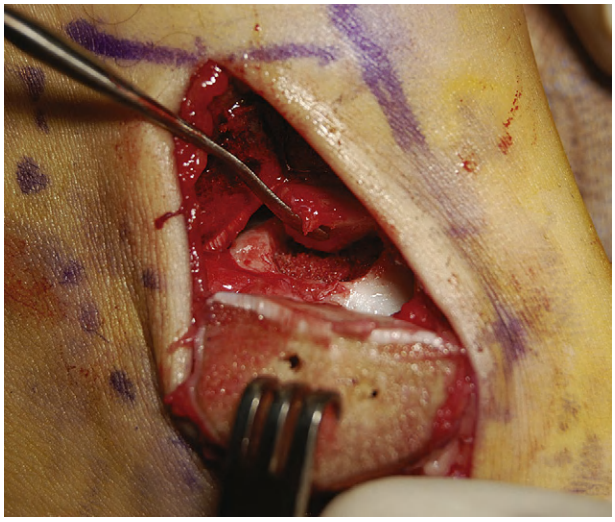

FIGURE 8-14 Cancellous bone grafting is performed to fill the lesion defect and improve potential for healing.

fragment stability. It is preferable that the fragment is slightly proud (by addition of bone graft) to accommodate the effect of compression and remodeling of the bone graft and fragment (Fig. 8-15).

Drilling and tapping through the fragment is performed, taking great care not to displace or damage the fragment with excessive torque (it may be worthwhile to place K-wires for temporary fixation while drilling, tapping, and inserting the compression screw).

The amount of countersinking can be adjusted by the depth of drilling and tapping. The biocompression screw is inserted carefully until the fragment is compressed and the screw is adequately countersunk (Figs. 8-16 and 8-17).

Headed screws require an additional step of removing cartilage and bone to allow countersinking of the screw head.

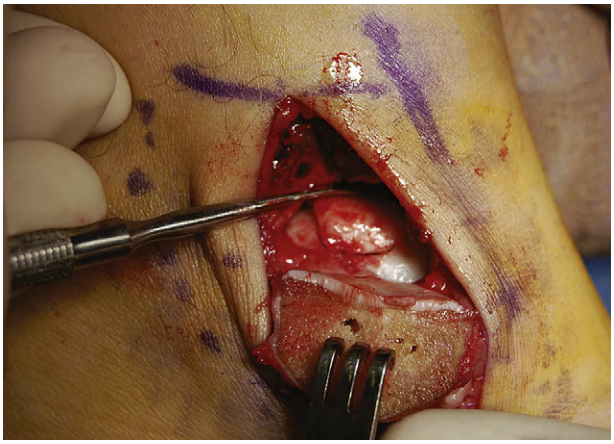

FIGURE 8-15 The osteochondral fragment is replaced and prepared for fixation.

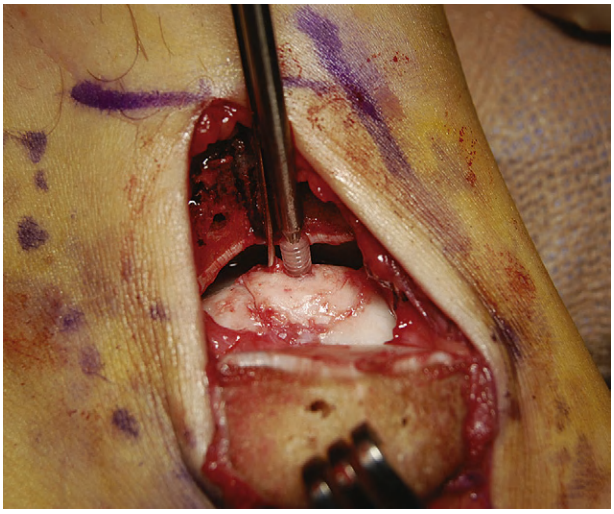

FIGURE 8-16 The biocompression screw is inserted after drilling and tapping. Note the additional K-wire placed for temporary fixation to prevent graft displacement during screw insertion.

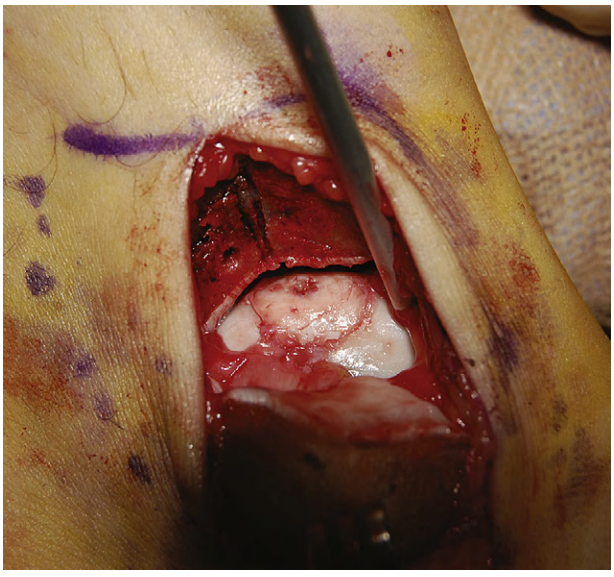

FIGURE 8-17 The biocompression screw is fully inserted and countersunk. Note that the osteochondral fragment is now compressed and flush with the surrounding articular surface.

SUMMARY

Numerous methods and devices are available for fixation of osteochondral fragments. Little objective data are available to guide the surgeon in decision making and choice of implant. Most common indications for fixation of osteochondral fragments include osteochondritis dissecans, acute traumatic injuries, and osteochondral graft fixation.

Principles of stable fixation should supersede the inherent desire to use minimal fixation in articular fragments, but surgeons should always be cognizant of the potential risk of loose or exposed fixation devices that can cause iatrogenic joint damage.

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CHAPTER

9A

Autologous Chondrocyte Implantation

Cartilage Biopsy Handling

Anders Lindahl, Sebastian Concaro

CARTILAGE BIOPSY AND HANDLING

The technology of autologous chondrocyte transplantation is based on the use of autologous cartilage for cell processing. The theoretical background to the autologous harvest and not other cell sources (e.g., bone marrow) is the fact that the joint and the articular cartilage have a unique developmental pathway in comparison to other cells with chondrogenic potential. The articular chondrocytes will have the capacity to form *de novo* cartilage that is halted before the hypertrophic differentiation and subsequent mineralization.

THEORETICAL BACKGROUND

The joint consists of different anatomical structures with different cell types (i.e., bone, ligament, synovium, fibrous capsule, and articular cartilage). The cartilage provides the initial mold of the skeleton in the embryo; in the adult, cartilage provides a mechanical and structural support for breathing, articulation, locomotion, and hearing.

FORMATION OF THE SYNOVIAL JOINT

The understanding of embryonic tissue formation will enable us to understand and control the processes of repair and regeneration in adult tissue. The first sign of joint formation in the embryo is the appearance of an interzone

where the cells gives rise to the articular layer of the future long bones. It has been unclear whether the interzone cells derive from transdifferentiation of local prechondrocytes into interzone cells or from migration of mesenchymal cells into the joint site, or a combination.[1] The prechondrocytes in the interzone differentiate to early chondroblasts, thereafter becoming and remaining articular chondrocytes. However, recently studies have shred new light of the role of this population of cells expressing GDF5 (growth and differentiation factor 5; also known as CDMP-1 [cartilage-derived morphogenic protein 1]), a member of the transforming growth factor-beta family. The role of GDF5 expressing cells was demonstrated in ROSA-LacZ-reporter mice where GDF5 reporter expressing cells from the interzone from E13.5 were followed postnatally and remain present in structures that appear to arise from the interzone, namely the articular cartilage, synovium, and other joint tissues.[2]

This strengthens the hypothesis that there are two populations of cells with distinct phenotypes: the transient chondrocytes forming the epiphysis and the GDF5 expressing cells forming the articular cartilage during interzone formation. These facts support the established method of autologous cartilage biopsy as a source for chondrocytes isolation and subsequent cartilage regeneration in treated patients.

THE ADULT ARTICULAR HYALINE CARTILAGE

Two questions are often asked: if full thickness biopsies or only superficial biopsies can be taken, and if osteoarthritic cartilage or free bodies can be used.

The articular cartilage tissue is an avascular, noninnervated, and alymphatic tissue where the nutrition of the chondrocytes comes from passive diffusion. The only cell type in cartilage is the chondrocyte, constituting about 2% to 5% of the tissue. The function of chondrocytes is to build, maintain, and remodel the extracellular matrix composed of collagens, proteoglycans, noncollagenous proteins, and water. The articular cartilage has specialized load-bearing properties and the ability to withstand compressive, tensile, and shear forces because of the composition and structural integrity of its extracellular matrix (ECM), which consists of fibrillar and nonfibrillar macromolecules. The principal fibrillar component is collagen type II, which accounts for 90% to 95% of the collagen in articular cartilage; it forms a three-dimensional cross-linked network (together with smaller amounts of other minor collagens such as collagen types IX and XI). The collagen fibrils on the surface are oriented tangentially to create maximal strength, whereas deeper in the cartilage the fibrils are more vertically oriented. Collagen type X is exclusively produced by prehypertrophic and hypertrophic chondrocytes in the calcified layer.

The main nonfibrillar component consists of sulphated aggrecan monomers attached to hyaluronic acid forming large polyanionic aggregates. The collagen network is constructed in a complex three-dimensional network that acts to resist the osmotic pressure induced by the hydrophilic aggrecan monomers. If the collagen network fails, the cartilage will swell and lose its resilient properties. The small proteoglycans include decorin, biglycan, and fibromodulin. They seem not to contribute directly to the mechanical behavior of the tissue. Instead they bind to other macromolecules and probably influence cell function.

Articular cartilage also consists of noncollagenous matrix proteins, which are important for the interaction and assembly of the various macromolecules. Cartilage oligomeric protein (COMP) is a glycoprotein belonging to the thrombospondin family, also named thrombospondin 5. COMP interacts with collagen types I, II and IX, and it has been used as a diagnostic marker in serum for the progress of matrix degradation.[3]

Depending on matrix composition and cellular appearance, the articular cartilage is divided into several zones with different functional roles: superficial, transitional, radial, and calcified zones. Facing the joint cavity is the tangential layer/superficial zone with small, flattened cells parallel to the surface and mainly collagen type I fibers arranged tangentially to the articular surface and small amounts of proteoglycans. The surface is covered with a thin sheet of fine fibrils and cells lubricated by a thin layer of synovial fluid, sometimes called the "lamina splendens." The production of the lubricin protein providing the frictionless surface of articular cartilage is a specific property for the cells at the surface of cartilage.[4] Below the superficial zone is the transitional zone with larger rounded chondrocytes arranged in groups and as single cells. The matrix is composed almost entirely of proteoglycan and aggrecan, and is rich in collagens. The collagen fibrils are more randomly arranged than in the superficial zone. This zone displays the typical morphological features of hyaline cartilage. The zone is followed by the radial zone of the articular cartilage, where the cell density is lowest and the large chondrocytes form radial columns and produce a matrix rich in proteoglycans, especially aggrecan. The content of collagen is low. The tidemark is the zone separating the cartilage from the underlying bone, and below the tidemark is the calcified cartilage layer, with chondrocytes demonstrating hypertrophic phenotype and a matrix rich in type X collagen but without proteoglycans.

The growth properties of chondrocytes from different layers are poorly studied. The superficial cells express markers of stem cells or progenitor cells (e.g., the notch receptor). Deeper layers are more differentiated but the cloning capacity of cells in the middle or deep layer is not negligible. Based on these uncertainties a full thickness cartilage biopsy is preferred. Several limiting factors are associated with the use of chondrocytes from osteoarthritis (OA) joints, including the number of cells that can be obtained from a diseased tissue, the capacity of cells to proliferate in vitro, and the

responsiveness to growth factors necessary to trigger redifferentiation process. Chondrocyte numbers are decreased by 38% in OA cartilage as assessed histomorphometrically and via the number of isolated cells. Whereas the proliferative capacity of chondrocytes in OA cartilage is increased in vitro and may account for chondrocyte clustering observed in vivo, results in vitro are still inconclusive given that both lower and higher proliferative rates have been reported. Despite all the identified differences, recent data indicate that OA chondrocytes retain their differentiation potential upon isolation and proliferation in vitro.[5] In the micromass pellet cultures, OA chondrocytes continued to proliferate for 14 days, thus increasing the pellet size in contrast to normal chondrocytes. The proteoglycan production was comparable to normal chondrocytes, and the collagen-rich matrix was present, although the total collagen was significantly lower. Additionally, in a 3D-scaffold based on hyaluronic acid, OA chondrocytes were also able to produce cartilage-specific matrix proteins. These results raise hope that despite their differences in comparison to normal chondrocytes, OA chondrocytes could be employed as a cell source for tissue engineering (TE) treatment providing that the disease can be controlled. Recent data using human chondrocytes from patients with the history of trauma demonstrated that cells exposed to a hyaluronan-based scaffold reduced apoptosis and decreased gene expression as well as secretion of degradation cytokines, namely, MMP-1, and MMP-13. At the same time, the expression of cartilage-specific genes SOX9, collagen type II, and aggrecan indicated differentiation toward chondrogenesis.[6]

In conclusion, osteoarthritic cartilage contains cells that differ significantly from normal cartilage especially when studying inflammatory response. However, in culture, especially in cultures with hyaluronan matrices, the difference between normal and OA cartilage is negligible. Theoretically, using hyaluronan scaffolds (e.g., Hyaff-11, Fidia Advanced Biopolymers, Abano Terme, Italy), cartilage harvests could be considered. In technologies using monolayer cultures only where treatment is based on singe-cell solutions OA cartilage specimens are not recommended.

TECHNICAL PROCEDURES

Instruments

- Standard arthroscopy set
- Periosteal elevator
- Ring curette
- Biopsy kit
    - Transport box
    - Plastic cylinder containing 40 ml of NaCl and antibiotics
    - Envelope with patient consent forms, address labels, and instructions

BIOPSY HARVESTING AND HANDLING

Before starting the arthroscopy, make sure that the cell culture laboratory is informed about the biopsy. A proper clinical evaluation prior to cartilage biopsy harvest is a prerequisite to determine if the patient is suitable for autologous cartilage implantation. The arthroscopic examination enables a proper diagnosis of the cause of clinical symptoms and will also enable the surgeons to provide first-line treatments if necessary (i.e., debridement of loose cartilage or microfracture).

Standard anterolateral and anteromedial portals are performed for the arthroscopy. Localize the cartilage defect, and measure it with an arthroscopic probe.

The grade of chondromalacia and inspection of opposing articulating joints are a part of the examination.

Register every variable in order to prepare for the upcoming surgical autologous chondrocyte implantatiton (ACI) procedure.

INSTRUCTIONS FOR CARTILAGE SAMPLING

Harvest the cartilage from low weight bearing areas such as the upper medial femoral condyle or the superior medial edge of the trochlea.

If required the intercondylar notch can be used.

Obtain a minimum amount of cartilage with a ring curette or a periosteal elevator.

The biopsy harvest should be performed with an instrument able to obtain full-thickness cartilage pieces. Approximately 200 to 400 mg of cartilage is appropriate (three strips, 10 mm in length and 5 mm in width).

The average weight recorded in our series (1235 biopsies) was 221 mg.

Use the periosteal elevator and go deep down to the cartilage-bone junction to obtain an appropriate strip.

Leave a thin attachment with the neighboring cartilage.

Then use a grasper forceps to remove the biopsy through the portal.

Place the strip aseptically in the plastic cylinder containing 40 ml of sterile transport media. Remember that the biopsy tube is *not* sterile on the outside. Attach a label with the patient's information.

Put the tube in the plastic cylinder.

Send the cartilage biopsy to the laboratory for isolation and expansion of chondrocytes.

The chondrocytes can be frozen to be used later (Fig. 9A-1).

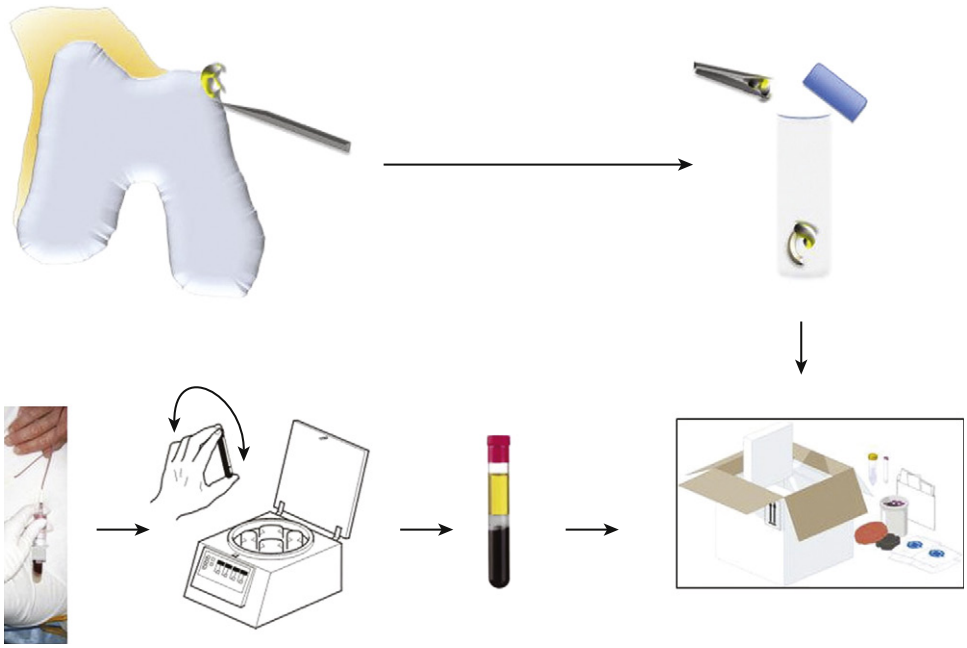

FIGURE 9A-1 The cartilage sampling procedure and the autologous blood sampling process.

AUTOLOGOUS BLOOD SAMPLING

Some laboratories use fetal calf serum as a standard for the expansion of chondrocytes. We use autologous human serum obtained as follows.

Use 15 9-ml Terumo tubes for autologous serum production (Venoject II Autosep: gel + activated clotting time [ACT] Terumo, Leuven, Belgium.) and one 9-ml tube for microbiology testing (Venosafe tube with no additives).

Instructions

Mark the tubes with the patient's name.

Perform vein puncture in the usual way, and fill the tubes with blood samples.

Turn the tubes upside down five times so that the coagulation activator is mixed with the blood.

Let the blood coagulate at room temperature for 30 minutes with the tubes in a vertical position.

Centrifuge the blood samples in a swing out centrifuge at 1000-1300 RCF for 15 minutes within 1 hour of sampling.

Remove the tubes from the centrifuge, and check the separation of the red blood cells from the serum.

Centrifuge one more time if needed.

Put the tubes in the plastic cylinder for transportation (Fig. 9A-1).

BIOPSY HANDLING IN THE CULTURE LABORATORY

The chondrocytes are isolated from the cartilage biopsies by mincing the tissue with a scalpel followed by enzymatic digestion with collagenase type II (0.8 mg/ml; Worthington Biochemical Corp, Lakewood, N.J., United States) in Ham's F12 (Invitrogen, Lidingö, Sweden) supplemented with ascorbic acid (0.025 mg/ml; Apotekets produktionsenhet, Umeå, Sweden), gentamicin sulphate (50 mg/ml; Invitrogen, Lidingö, Sweden), and amphotericin B (250 mg/ml; Invitrogen, Lidingö, Sweden).

The isolated cells are seeded in tissue flasks at 10^4 cells/cm^2 in tissue culture flasks and are culture expanded in DMEM/F12 media (Invitrogen) supplemented with 10% human autologous serum, ascorbic acid (0.025 mg/ml; Apotekets produktionsenhet, Umeå, Sweden), L-glutamine (2 mM; Invitrogen, Lidingö, Sweden), gentamicin sulphate (50 mg/ml; Invitrogen, Lidingö, Sweden), and amphotericin B (50 mg/ml; Invitrogen, Lidingö, Sweden)

After the expansion period, the cells are packed for delivery as a cell suspension or processed for a cell seeded scaffold.

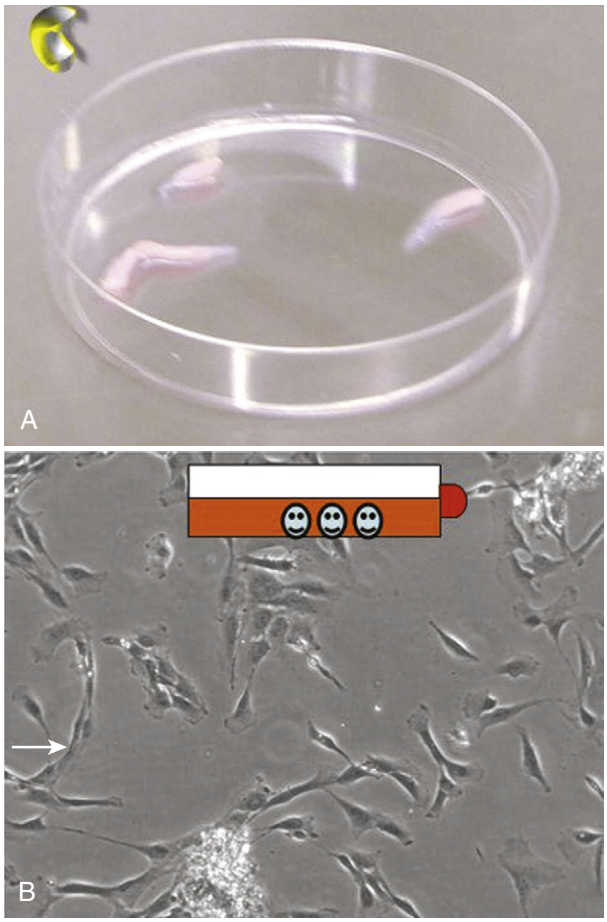

FIGURE 9A-2 The process to obtain cells from a cartilage biopsy. **A,** Biopsies after arrival. **B,** Cartilage samples after mincing.

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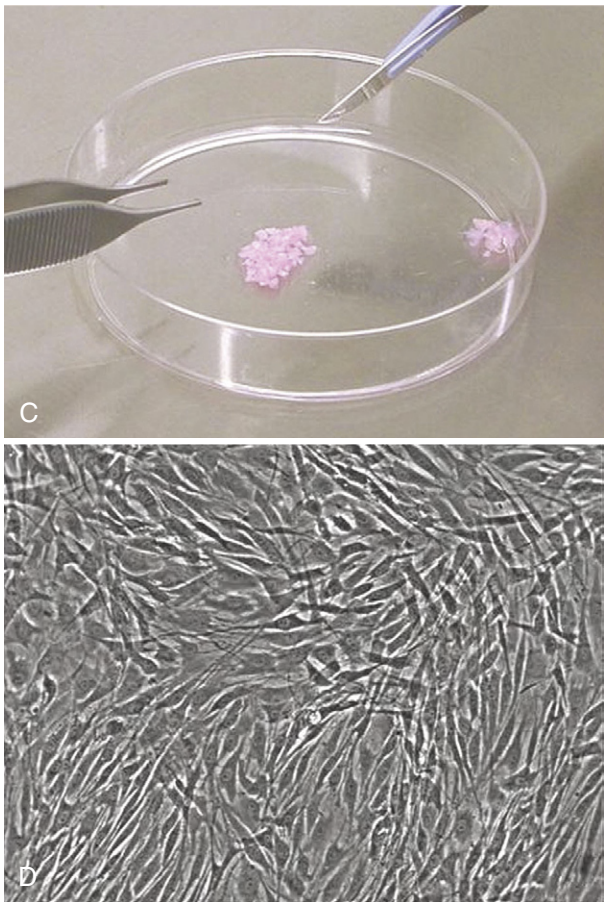


FIGURE 9A-2, Cont'd C, Early phase of expansion. D, Final phase of expansion.

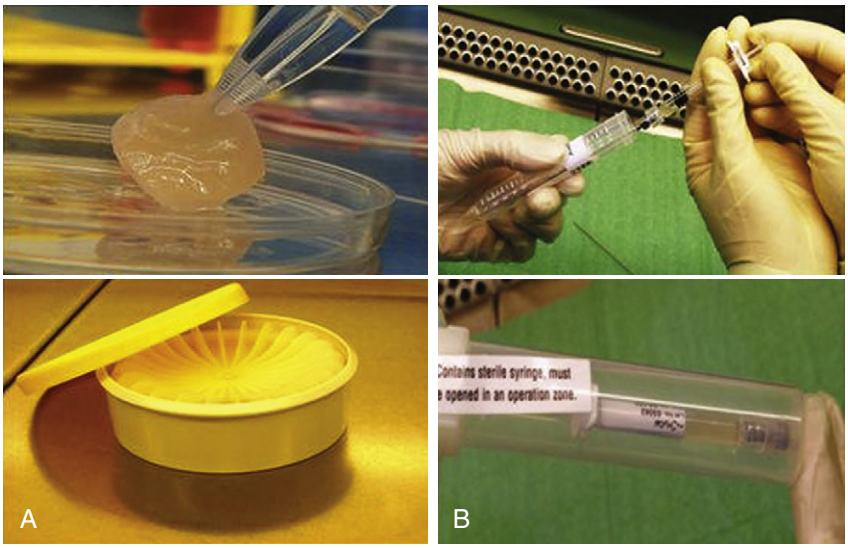
CELL SEEDED SCAFFOLD

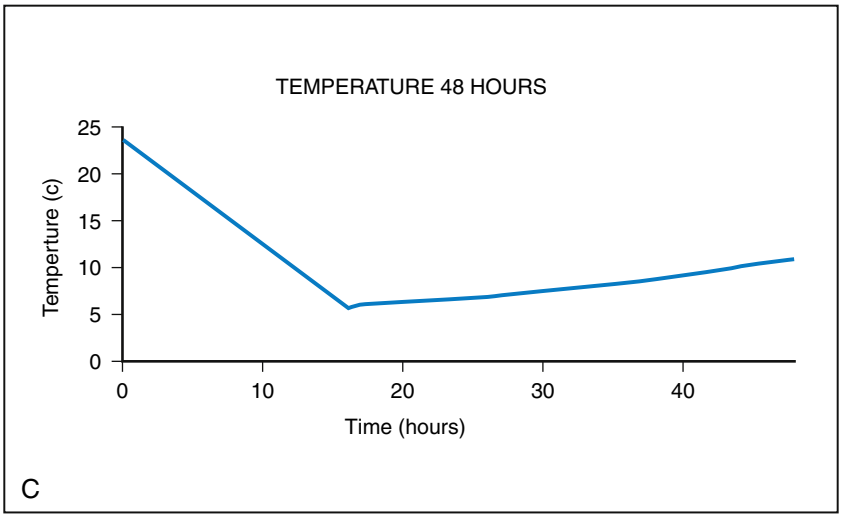
After expansion of the cells for two passages, the cells are seeded on human serum precoated Hyaff 11 scaffolds (thickness 2 and 4 mm;) using 2×10^6 cells per cm^2. After incubation overnight at 37°C in 7% CO_2/92% air, the scaffolds are cultured using chondrogenic media for 14 to 21 days (Fig. 9A-2, *A-D*).

The cartilage tissue engineered constructs are delivered in a two-container pack. Remember that the exterior of the outer container is nonsterile, whereas the inner container is sterile both inside and outside.

Let a nonsterile person open the outer container and drop the inner container onto the operating table.

It is important to keep the membrane wet before implantation. Use 0.9% NaCl if necessary (Fig. 9A-3, *A-D*).





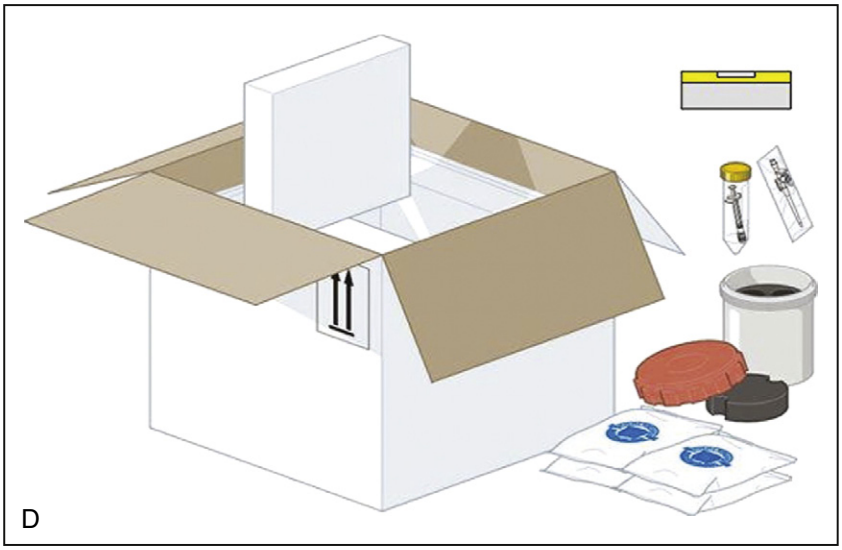


FIGURE 9A-3 The different delivery methods and the delivery package. **A**, A tissue-engineered construct and its delivery container. **B,** A syringe loading under sterile conditions and a final delivery container for cell suspension. **C,** Diagram showing the temperature validation of the delivery box. **D,** The delivery package for either cell suspension or tissue-engineered constructs.

CELL SUSPENSION DELIVERY

The chondrocyte doses for ACI treatment are in vials of 6, 12, and 18 million cells depending on defect size (1 million cells/cm^2 defect)

The autologous expanded chondrocytes are delivered in a two-container pack. Remember that the exterior of the outer container is nonsterile, whereas the syringe containing the cells is sterile both inside and outside.

Let a nonsterile person open the outer container and drop the syringe onto the operating table (Fig. 9A-3).

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CHAPTER

9B

Autologous Chondrocyte Implantation

Quality Assurance of Cells for Chondrogenic Implantation

Stephen J. Duguay

INTRODUCTION

High-quality chondrocytes are essential for successful autologous chondrocyte implantation (ACI) outcomes. Cell therapy manufacturers must comply with good manufacturing practices (GMPs), which are enforced by national authorities in most countries. The goal of GMPs is to ensure that products are safe, pure, and effective. The GMPs require that manufacturers establish quality systems for the design, manufacture, packaging, labeling, and storage of products commercially distributed for human use. In many countries, regulatory agencies have also issued guidance documents that pertain specifically to additional requirements for cellular therapeutics. It is the responsibility of the manufacturer to validate the manufacturing process and establish product release specifications. Products cannot be shipped unless all release specifications have been met. At a minimum, product release assays should assess cell number and viability, test for adventitious agents, and evaluate purity (i.e., endotoxin). Recently, the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMEA) have begun requiring that cell therapy manufacturers also develop identity and potency assays for their products. Each of these assays is defined in the following section. For detailed descriptions of quality control and quality assurance systems for cell therapy manufacturing, the reader is referred to Kielpinski et al.[1] and Mayhew et al.[2]

QUALITY ASSESSMENT OF CHONDROCYTES

Viability

Viability is defined as the percentage of live cells in the product. Viability is easily measured for cells in suspension using trypan blue or other well-established assays.

The measurement of viable cells in a matrix or on a membrane requires a customized approach. For example, Wang et al.[3] developed a novel assay to accurately and precisely measure viability in matrix-induced autologous chondrocyte implanation (MACI) implants because the collagen membrane caused interference in all conventional assay techniques that were tested.

Cell Number, Yield, or Density

Some indication of the number of cells in the product must be given. This may take the form of the actual number of cells delivered or the density of cells in relation to the volume or surface area delivered.

Sterility

Although living cells cannot be sterilized, manufacturers must ensure that all reagents used are sterile and that all manipulations are performed under aseptic conditions.

Sterility assays typically take 14 days to perform. Therefore, it is common to test prerelease samples of the product. A rapid microbial test, the BacT/Alert System (Genzyme Biosurgery, Cambridge, Mass.), has been validated for sterility testing of Carticel and MACI implants.[4] This system usually provides test results in a matter of hours. Regardless of the system used, product samples must be negative for microbial growth. The aseptic process must be validated using media fills.

Endotoxin

Endotoxins are lipopolysaccharides derived from the membrane of gram-negative bacteria. They are readily detected by standard laboratory testing, and levels must be at or below acceptable levels for product release.

Identity

The purpose of an identity assay is to confirm the identity of a culture as consisting of chondrocytes and to assess heterogeneity, if any. Historically this has been done by assessing cell morphology. Recently, two novel assays that can distinguish cultured chondrocytes from closely related synoviocytes on the basis of genetic markers have been described.[5,6] The assay developed by Rapko and colleagues has been validated as a chondrocyte identity assay and approved by the F&A as a Carticel lot release assay.[5] This is the first genetic marker-based chondrocyte identity assay approved for use in the United States.

Potency

Potency assays are meant to measure the functional potential of cultured chondrocytes. This is an active area of investigation, and several approaches have been described.[7,8,9] Although the potency assay requirement is relatively new, it is likely that potency assays will be used to evaluate chondrocytes produced for clinical use in the near future.

QUALITY VERIFICATION IN THE OPERATING THEATER

Verification of Contents

1. Open the envelope attached to the box and remove the certificate of analysis (C of A, also called the lot analysis)
2. Match patient name on the C of A with patient name on chart
3. Match patient ID number on the C of A with patient ID number on the labels located on the shipping box, secondary transport container (if any), and primary product container (Fig. 9B-1)

Certificate of Analysis

The results of product release testing are recorded on a certificate of analysis (C of A). Identifying information for the patient, and product expiration date and time are found at the header of the C of A. Testing requirements may

FIGURE 9B-1 Verification of shipping box contents.

differ from one country to another. The example in Figure 9B-2 is a C of A that conforms to U.S. FDA regulations.

Packaging Integrity

Inspect the shipping box for signs of damage to the exterior (Fig. 9B-3).

Open the box; it should contain insulating material and frozen or refrigerated gel packs to maintain the product at the appropriate temperature (Fig. 9B-4).

Inspect for leaking of the contents, such as gel packs or product shipping media.

Carticel® (autologous cultured chondrocytes)

The following provides the specific patient results for the patient lot number cited below.

PRECAUTION: Prior to implantation, verify the expiration date and time listed below. Dispose of expired cells in accordance with the hospital's biohazard waste policies.

Patient Name	John Doe	**Assembly Date**	01-Jan-09
Lot Number	CCXXXXX-XX	**Expiry Date**	04-Jan-09
Patient ID Number	XXXXX	**Expiry Time**	7:00 EST

Specifications	Results
Chondrocyte Viability The final chondrocyte sample meets or exceeds the viability acceptance criteria.	95% Viability
Chondrocyte Yield The final chondrocyte number falls within the product specifications.	1.20E+07 Cell Yield
Chondrocyte Density The final chondrocyte density is within the specifications of 20 to 30 million chondrocytes per mL.	3.00E+07 Cell Density per mL
Chondrocyte Morphology Chondrocytes are typical in appearance.	Acceptable Morphology
Sterility Pre-release showed no microbial growth.	None Microbial Growth
Endotoxin Meets acceptable criteria.	Acceptable Endotoxin

Quality Systems

FIGURE 9B-2 Reviewing the certificate of analysis.

FIGURE 9B-3 Exterior of a shipping box.

FIGURE 9B-4 Interior of a shipping box. Note that the foam insulation and gel packs surround the secondary transport container.

Remove the secondary transport container. This could be a hard container or a bag. Inspect for damage and leaking (Fig. 9B-5).

Remove the primary product container.

Cell suspensions are typically packaged in vials (Fig. 9B-6), whereas membrane-based products are packaged in dishes (Fig. 9B-7).

Shipping media should be clear, not cloudy.

Ensure that the container seal has not been compromised.

If there are any questions regarding packaging integrity, contact the manufacturer immediately.

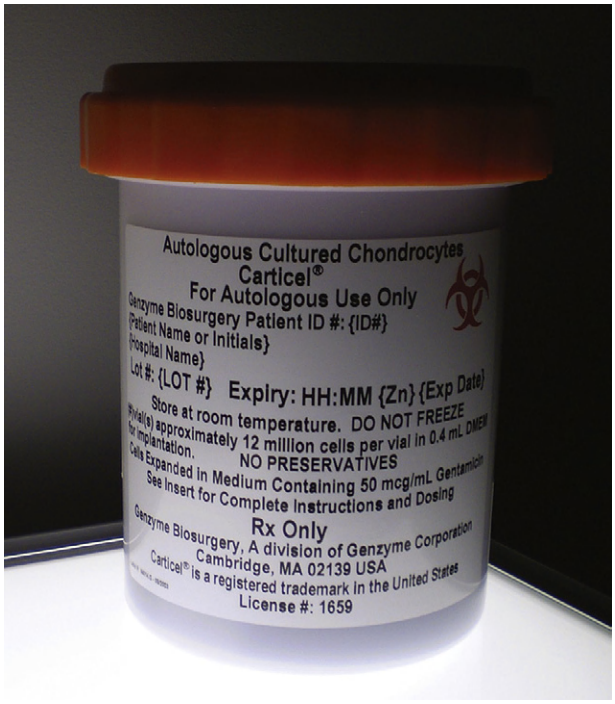

FIGURE 9B-5 Photograph of a secondary transport container showing appropriate product labeling.

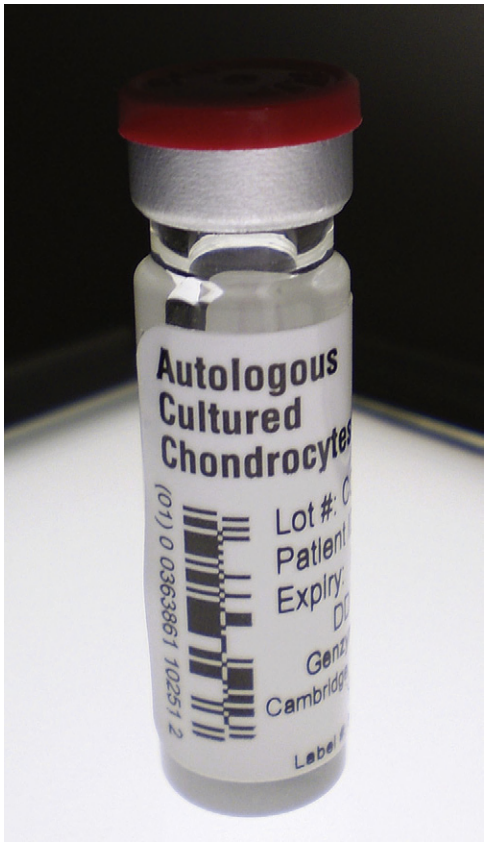

FIGURE 9B-6 Vial containing a cell suspension of chondrocytes. The rubber stopper and crimp seal must be intact.

FIGURE 9B-7 Dish designed to secure a membrane seeded with chondrocytes during shipment.

SUMMARY

Cell therapy products are among the most complex and challenging biologics to manufacture. A comprehensive quality system is essential for production of a consistent product.

As our understanding of chondrocyte biology increases and new technologies evolve, ever more sophisticated and accurate analytical assays will be developed for testing product quality attributes such as identity and potency. These advances will further strengthen existing quality systems and ensure that the highest quality product is delivered to the patient.

ACKNOWLEDGMENTS

The author would like to thank Marianne Pongratz, Grace Kielpinski, and Gary du Moulin, Ph.D., for helpful comments on the manuscript. The author would also like to thank Cynthia Provencher for photography of the shipping box and containers.

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CHAPTER

9C

Autologous Chondrocyte Implantation

ACI First and Second Generation

Mats Brittberg

INTRODUCTION

Autologous chondrocyte implantation (ACI) is another means of repairing damaged cartilage.[1] It is based on harvest of 200 to 300 mg of cartilage from a less loaded area in the knee. The cartilage is sent to a lab for processing. The cartilage is digested; the isolated chondrocytes are expanded in vitro during 2 to 3 weeks. The expanded final amount of cells is re-sent to the doctor as a suspension. The cells are to be injected into the defect covered with a membrane, periosteum (**first generation**), or collagen membrane (**second generation**).

TECHNICAL OVERVIEW

First-Stage Operation

The knee joint is examined by normal arthroscopy. A cartilage lesion is detected, and a decision is made to treat the defect by ACI. Often such a decision is made based on an earlier treatment that failed.[1,2,3]

ACI could subsequently be regarded as a second line of treatment option. All types of joints can be treated, but the most treated joints have been the knee joint and the ankle joint. The technique is the same regardless of the joint treated. However, in this chapter the description is for the knee joint.

Cartilage Harvest

The cartilage is harvested from a less loaded weight-bearing area such as the upper medial femoral condylar area or similar on the lateral upper femoral trochlear area. Also the notch area is easy to use for harvest (Fig. 9C-1).

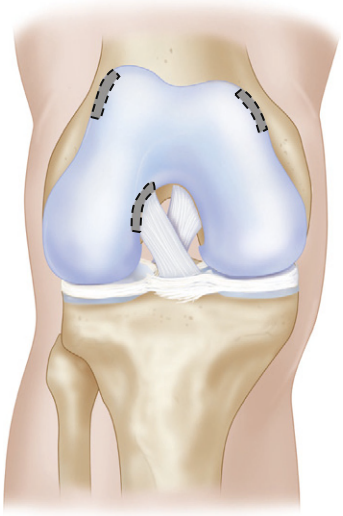

FIGURE 9C-1 The suggested locations for harvest of cartilage for cell culture.

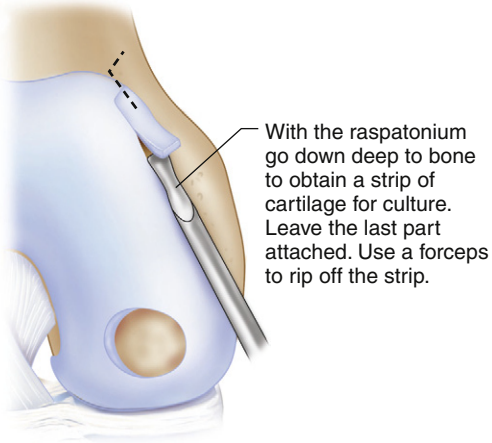

FIGURE 9C-2 With the raspatorium, go down deep to bone to obtain a strip of cartilage for cell culture. Leave the last part of the strip still attached. Use a grasping forceps to rip off the strip and pull out from the knee portal.

By long-time experience, the amount that has been suggested for cartilage harvest is 200 to 300 mg. Such an amount is about a strip with 10 mm in length and 5 mm in width.

Use a ring curette or sharp gouge like a Wiberg raspatorium. Go deep down to cartilage-bone junction and leave a thin attachment of the strip. This strip may then be grasped with a forceps and ripped off with a gentle movement and taken through the portal to be put into a tube with saline. You may need two to three similar strips (Figs. 9C-2 and 9C-3).

For the cell culture, the staff needs to take 10 6-ml test tubes with blood to be processed into serum for the subsequent cell culture.

Blood test tubes and harvested cartilage are sent to the cell laboratory that the hospital has a contract with.

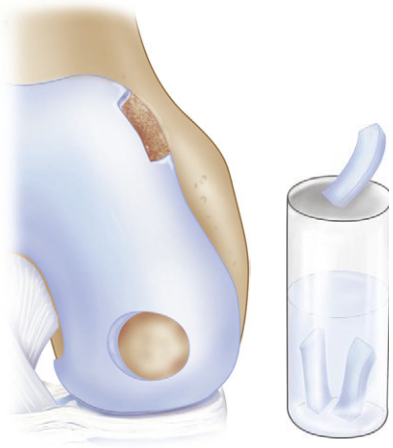

FIGURE 9C-3 About two to three strips are harvested and put into a transport medium.

Second-Stage Operation

The knee joint is opened by a miniarthrotomy. The cartilage defect is debrided (see Chapter 3). The debridement should result in a well-delineated defect, slightly oval.

Lesion Measurement

The size of the defect is measured using a sterile packaging of the sutures as a template. If any bleeding is observed in the bottom of the defect, hemostasis with cotton pads soaked with epinephrine (1:100 epinephrine in 20-ml sterile saline) may be used.

Harvest of the Periosteum

For the first generation of ACI, periost is to be harvested. The periosteum is harvested through a separate incision from the proximal medial tibia, just distal to pes anserinus (Fig. 9C-4).

With the template in place, the periosteum could be sized and cut with a scalpel and harvested sharply with a periosteal elevator and carefully released from the bone.

It is very important that a thin periosteum without remaining fibrous tissue is harvested.

Positioning and Suturing of the Periosteum

The received periosteum is positioned over the defect with the part that has been attached to the bone, the cambium layer facing the cartilage defect.

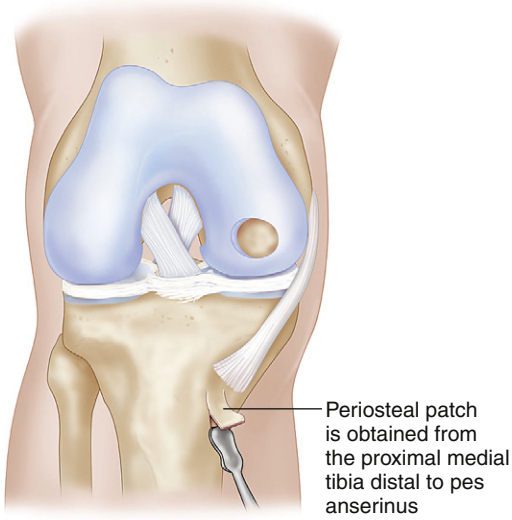

FIGURE 9C-4 The periosteal patch is obtained from the upper medial tibia, distal to the insertion of the pes anserinus.

The periosteum is sutured to the defect with interrupted sutures (Vicryl Ethicon, Inc., Somerville, N.J. or Dexon. [Coviden, Mansfield, MA]) 5-0 or 6-0 sutures (Figs. 9C-5 and 9C-6). The sutures should be immersed in sterile glycerin or drawn through the patients' fatty tissues.

Interruptured sutures are used with an interval of approximately 3 to 4 mm.

Start with one suture in each corner of the defect except for the trochlear region where sutures are placed directly after each other. Angle the suture needle toward the periosteal membrane approximately 2 mm from its edge, and pass the through the membrane into the adjacent cartilage wall, following the curvature of the used needle. It is advisable to enter the cartilage about 2 mm below the surface and with a 3 to 4 mm bite (Fig. 9C-5).

Use fibrin glue to seal the suture line in order to minimize leakage of cells. One may also fill the bottom of the defect with fibrin glue to get an even distribution of the cells when implanting the cells under the membrane.

Implantation of Cultured Cells in Suspension

The cultured chondrocytes are finally implanted into the defect under the membrane. A final suture is put at the implantation entrance after implantation and some extra fibrin glue (Figs. 9C-7 and 9C-8). The aim is to implant 30 million cells/ml or at least 2 million cells/cm^2 (Fig. 9C-9).

Wound Closure

Close wounds as one would for a normal arthrotomy. No drainage is used intraarticularly. If wanted, the drainage can be placed extra capsular.

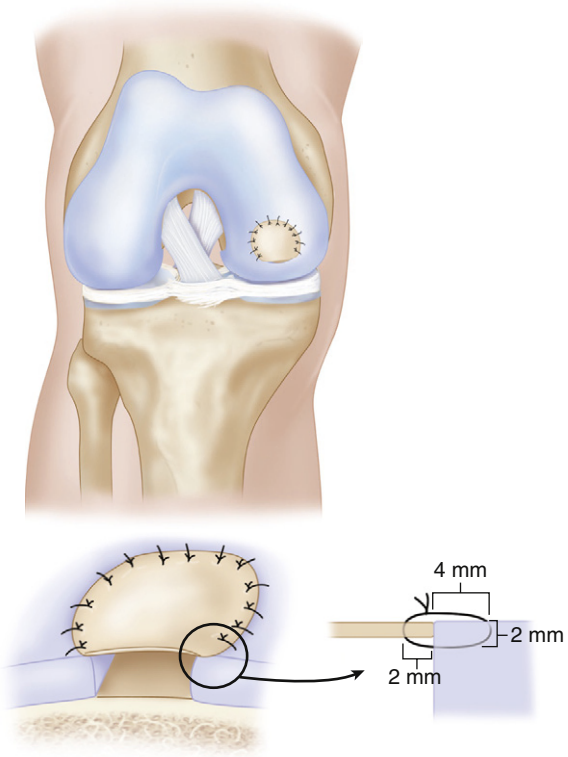

FIGURE 9C-5 The periosteum is sutured to the defect with inter-ruptured sutures with an interval of approximately 3 to 4 mm. Angle the suture needle toward the periosteal membrane approximately 2 mm from its edge and pass through the membrane into the adjacent cartilage wall following the curvature of the used needle. Enter the cartilage about 2 mm below the surface with a 3- to 4-mm bite.

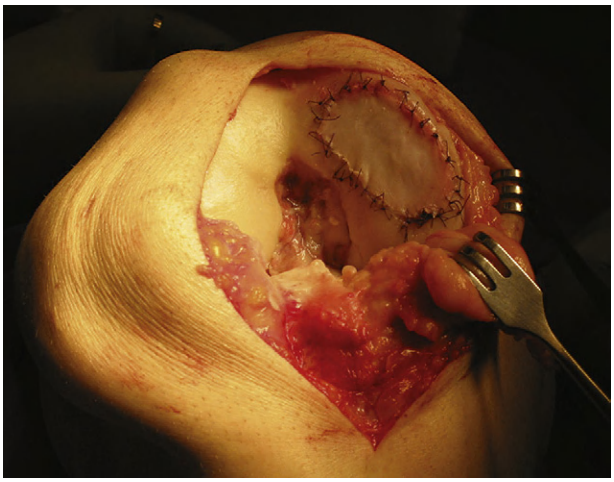

FIGURE 9C-6 Example of a large femoral condylar defect covered with a periosteum.

Noncontained Lesions

If the defect is not well contained, the membrane can be sutured to the synovial lining if near the notch. At other regions, suture anchors may be needed. If the uncontained lesion has thick walls, mosaicplasty plugs can

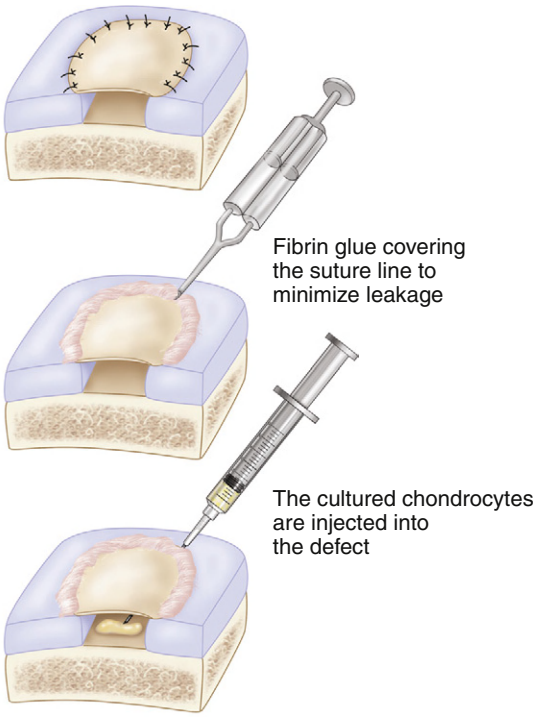

FIGURE 9C-7 The defect has been covered by a periosteal or collagen membrane. The suture line is filled with fibrin glue to minimize the leakage of cells. The cell suspension is finally injected into the water-tight sealed defect.

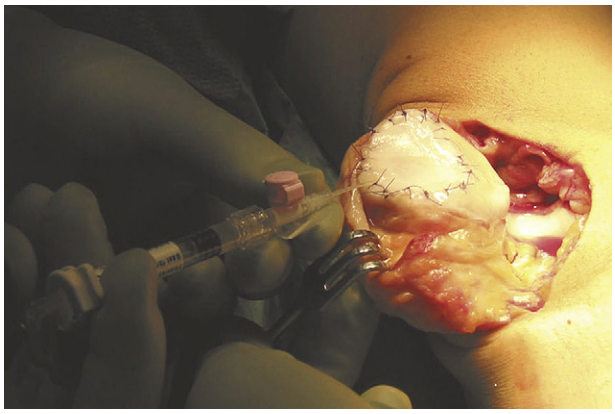

FIGURE 9C-8 A patella defect covered by a sutured collagen membrane. Cells are injected into the defect, under the membrane.

be used to build up the missing wall, making the defect into a contained reconstructed defect.

Large Defects and Defects with Concomitant Malalignment

Consider doing a concomitant unloading osteotomy (see Chapter 13). Prepare the defect as described previously until cell implantation. (See first page of this chapter "Technical Overview.") Do the osteotomy operation, and finish with implantation of the cells (Fig. 9C-10).

FIGURE 9C-9 A syringe with chondrocytes in suspension. The aim is to implant 30 million cells/ml or at least 2 million cells/cm^2.

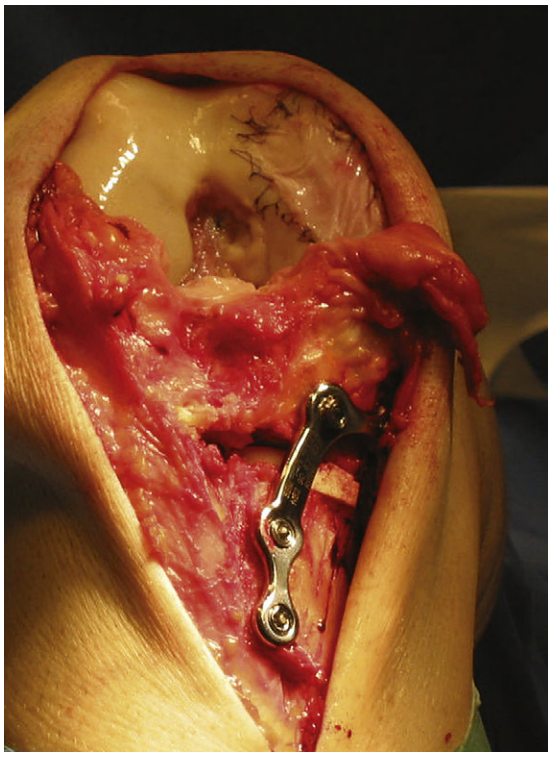

FIGURE 9C-10 An ACI chondral defect treated at the same time with an unloading opening wedge osteotomy.

Second-Generation ACI

The second-generation ACI is an exchange of the periosteal membrane to instead use a collagen membrane[4] such as the Chondro-Gide membrane (Chondro-Gide Geistlich Surgery, Wolhusen, Switzerland). The membrane has to be cut in the exact size because, in comparison to the periosteum, it does not stretch much. Otherwise, the same technique used for the periosteum can be used for membranes.

Postoperative Management

There exists no consensus for the postoperative rehab (see also Chapter 16). The rehabilitation guidelines have changed during the years since the first ACI was done in 1987.

The short description that follows is my personal recommendation for ACI and similar repair techniques. For more specific information and discussion about the rehabilitation, look also at the Postoperative Cartilage Repair Rehabilitation chapter (Chapter 16).

The extremity is immobilized in a brace and locked in extension for 2 weeks. Full weight bearing is allowed in the brace as pain allows. After 2 weeks, the brace is used outdoors, unlocked, for another 4 weeks.

A very large defect may be protected by an unloader brace for a longer period. One may even consider performing a concomitant permanent unloading with osteotomy (Fig. 9C-10).

Open chained knee strengthening should occur from approximately 8 weeks. Running is not advised until 9 to 10 months postsurgery.

High-level activities should not be performed until 12 to 14 months postoperatively.

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CHAPTER

9D

Autologous Chondrocyte Implantation

Transarthroscopic Implantation of Hyalograft (Hyaff 11) with Autologous Chondrocytes

Mats Brittberg, Sebastian Concaro

INTRODUCTION

To facilitate the implantation of cultured chondrocytes and make it possible to perform an autologous chondrocyte implantation (ACI) procedure transarthroscopically, different porous scaffolds have been developed. One such material is based on the benzylic ester of hyaluronic acid (Hyaff 11, Fidia Advanced Biopolymers, Abano Terme, Italy) and consists of a network of 20-μm-thick fibers with interstices of variable sizes.

It has been demonstrated to be an optimal physical support to allow cell-cell contacts, cluster formation, and extracellular matrix deposition and to deliver differentiated chondrocytes.[1,2]

The cells harvested from the patient are expanded and then seeded onto the scaffold where the cells are able to redifferentiate and retain a chondrocytic phenotype even after a long period of in vitro expansion in monolayer culture[1,2] (Fig. 9D-1). The Hyalograft with cultured chondrocytes may be implanted by press fitting directly into the lesion as described by Kon et al.[3] The scaffold has self-adhesive properties, but most often additional fibrin glue is needed for a secure positioning. In this chapter, the authors describe a modified implantation technique: the "folded blanket" technique for the knee and for the ankle.

INDICATIONS

See the indication for ACI described in Chapter 9C.

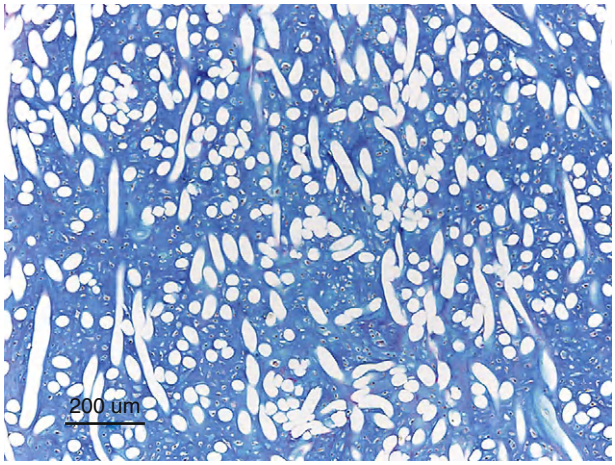


FIGURE 9D-1 A Hyalograft with cultured chondrocytes has been implanted subcutaneously into a Severe combined immunodeficiency syndrome (SCID) mouse after 4 weeks of in vitro culture. This section is demonstrating the cartilage tissue produced after 8 weeks in vivo.

TECHNICAL OVERVIEW

Cartilage is harvested as described in Chapter 9C. The cell culture takes a longer time to grow compared to when cells are transplanted as suspension. After 4 to 5 weeks, the scaffold is delivered as 2 × 2 cm large patches (Fig. 9D-2). Depending on the quality of the cultured cells, the seeded scaffolds have different strength.

OPERATIVE TECHNIQUE FOR THE KNEE

A high anteromedial or anterolateral portal is created, and a standard arthroscopy is performed in supine position.

The arthroscopic Hyalograft-chondrocyte technique is applicable for defects at the medial and lateral femoral condyle, trochlea, tibial plateau, and in some rare cases when reachable also for the patella.

For a defect at the medial femoral condyle, a medial suprameniscal portal is created. This portal is needed to introduce the matrix into the joint.

A half pipe introducer may be used to introduce the scaffold into the joint.

The defect has already been debrided as described in Chapter 3. The central part of the defect is treated by a microfracture awl to get a fixation point (mushroom fixation) (Fig. 9D-3).

The chondrocyte-seeded matrix is then cut with a scissor or scalpel to the approximate size of the defect (Fig. 9D-4).

The scaffold is covered with a thin fibrin glue layer (Fig. 9D-5), grasped with an arthroscopic grasp instrument with plain surfaces (Fig. 9D-6), and

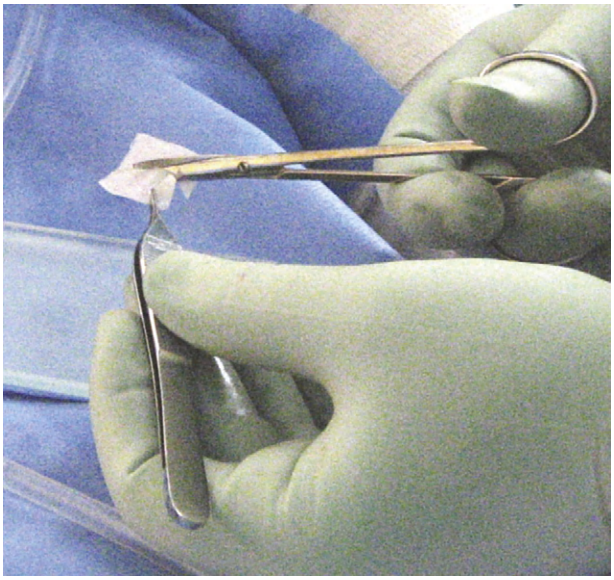


FIGURE 9D-2 The scaffold is delivered as a 2 × 2 cm large patch.

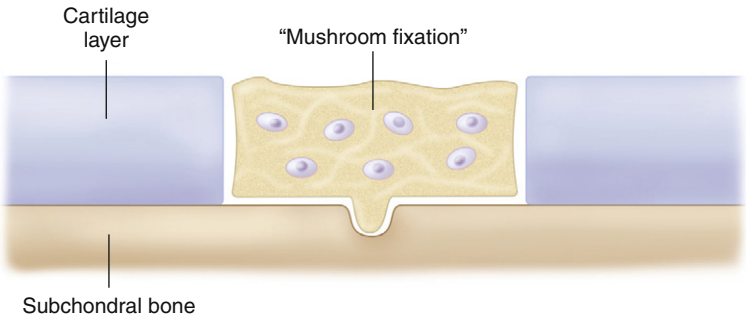


FIGURE 9D-3 The central part of the cartilage defect is treated by a microfracture awl to get a fixation point (mushroom fixation). The central part of the graft is pushed into the hole to get a secure position and fixation.

introduced into the joint along the half pipe intruder to reach the defect (Fig. 9D-7).

The pressure controlled pump may be stopped intermittently during the procedure. (The operation may also be done in CO_2.)

The scaffold is released from the grasper and with a smooth arthroscopy obturator caught and moved into the defect. The central part of the scaffold is pressed gently into the fixation point.

Some extra fibrin glue is injected over the implanted scaffold, and the scaffold is compressed toward the defect bottom with a curved smooth tonsil elevator. If the scaffold is oversized, the edges may be folded like a blanket into the defect to fill it up entirely (Fig. 9D-8).

If too small, additional pieces of the scaffold are implanted to fill the defect like a patchwork quilt. Several layers of Hyalograft may be needed to fill the defect up to surrounding cartilage (mille feuille technique) (Fig. 9D-9).

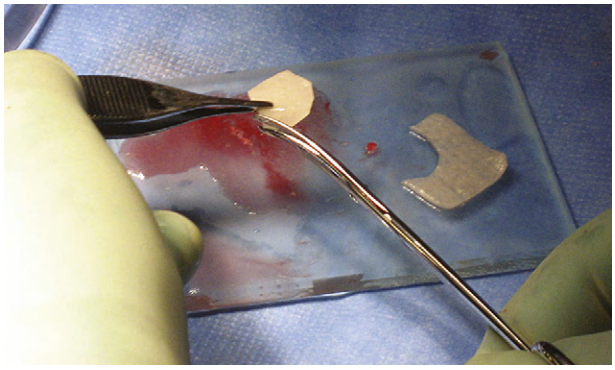


FIGURE 9D-4 The chondrocyte-seeded matrix is cut with a scissor or scalpel to the approximate size of the defect.

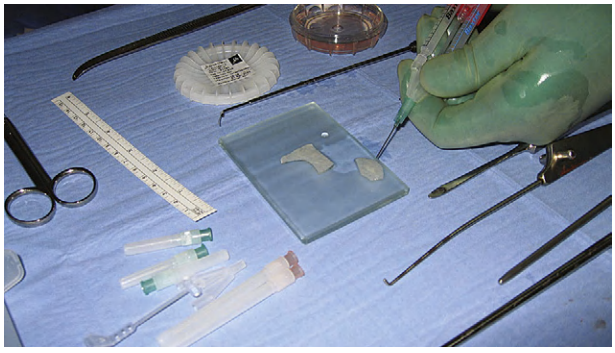


FIGURE 9D-5 The scaffold is covered with a thin layer of fibrin glue and becomes saturated and easier to handle.

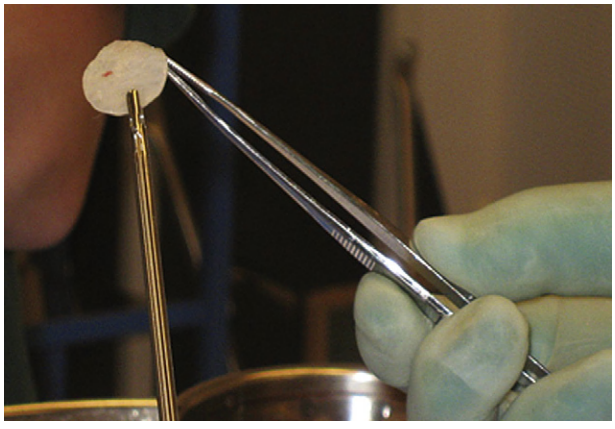


FIGURE 9D-6 The sized graft is grasped with an arthroscopic grasp instrument with plain surfaces.

Excess glue is taken away with a gentle move of the shaver. Care should be taken not to catch the implant with the shaver.

Graft adherence and integration are controlled by moving the knee joint with flexion and extension movements. The scaffold should either be in level with surrounding cartilage or slightly below (Fig. 9D-10).

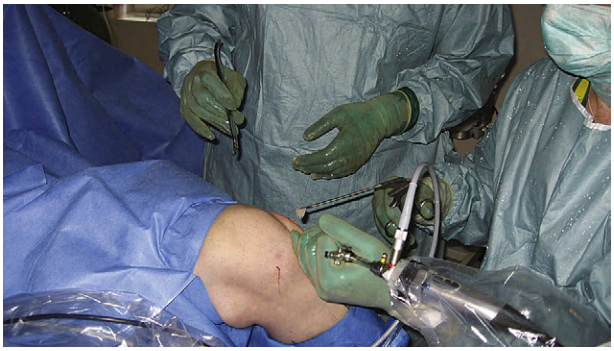


FIGURE 9D-7 The graft is introduced into the joint along a half pipe intruder to reach the defect area in the knee joint.

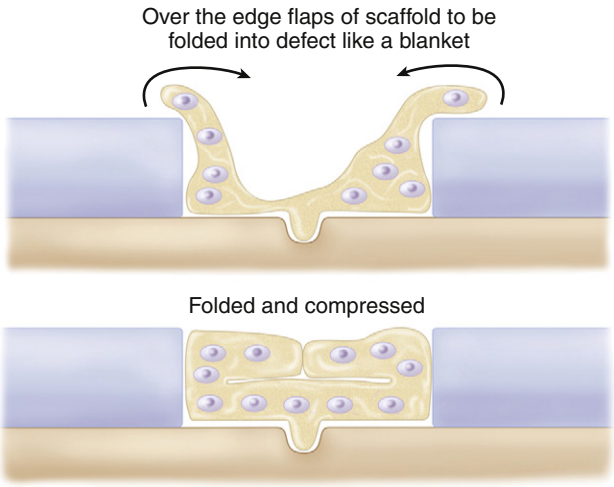


FIGURE 9D-8 If the scaffold is oversized, the edges may be folded like a blanket into the defect to fill it up entirely.

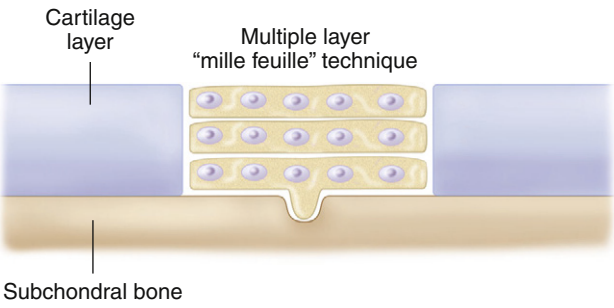


FIGURE 9D-9 Several layers of Hyalograft may be needed to fill the defect up to the surrounding cartilage (mille feuille technique).

THE TIBIAL PLATEAU

In a defect that is situated on the tibial plateau and often depressed, the repair can be done in a retrograde direction. With a vector guide, a channel is drilled from the proximal tibia to the defect area (Fig. 9D-11). A Hyalograft scaffold is pushed through the channel to the cartilage defect surface followed by a bone graft filling of the channel (Fig. 9D-12). From the inside, a pusher or a

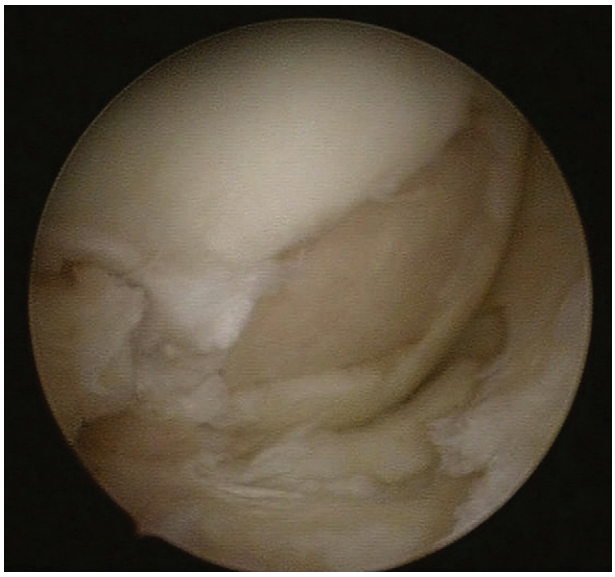


FIGURE 9D-10 The scaffold after implantation.

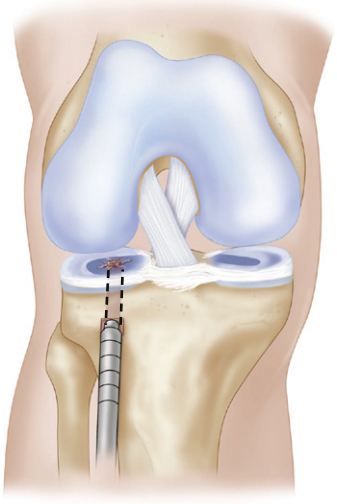


FIGURE 9D-11 Retrograde drilling of a tibia plateau defect. With a vector guide, a channel is drilled from the proximal tibia to the defect area.

curved tonsil elevator keeps the implant in place, while from the channel the bone paste is compressed against the implant with counter press (Fig. 9D-12).

HYALOGRAFT WITH SEEDED CHONDROCYTES AND BONE GRAFTING FOR OSTEOCHONDRAL DEFECTS

When a bone grafting is needed for deep and large osteochondral defects such as osteonecrosis and osteochondritis dissecans (OCD), the seeded scaffold may be used directly in conjunction with bone grafts. The bone grafts may be harvested from the crista iliaca anterior superior region or from the proximal tibia (Fig. 9D-13).

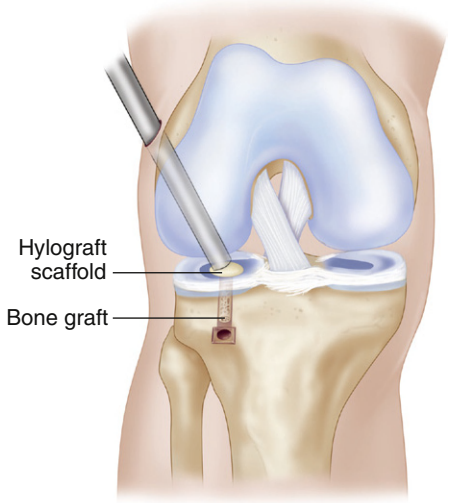


FIGURE 9D-12 A Hyalograft scaffold is pushed through the channel to the cartilage defect surface followed by a bone graft filling of the channel. An instrument that gives counter pressure on the Hyalograft is needed to get a compression on the bone grafts.

FIGURE 9D-13 Bone grafts may be harvested from the crista iliaca anterior superior region or from the proximal tibia to be used in deep osteochondral defects.

The bone grafts are mixed with fibrin glue to a putty-like consistency, forming bone paste (Fig. 9D-14). The bone grafts are put into a 2-ml syringe where the top of syringe has been cut off leaving a round opening (Fig. 9D-15). The bone grafts may be mixed with an artificial bone substitute if needed.

The bony defect has been prepared by excision and subchondral drilling to stimulate the sclerotic bone region.

Finally, the bone paste is implanted via the syringe into the osteochondral defect (Fig. 9D-16). The bone paste is compressed to fill the osseous part of the defect (Figs. 9D-17 and 9D-18).

The cell seeded scaffold is implanted and put over the top of the bone grafts, saturated with fibrin glue (Fig. 9D-19). Extension-flexion motions are used to test the stability of the dual graft (Fig. 9D-20).

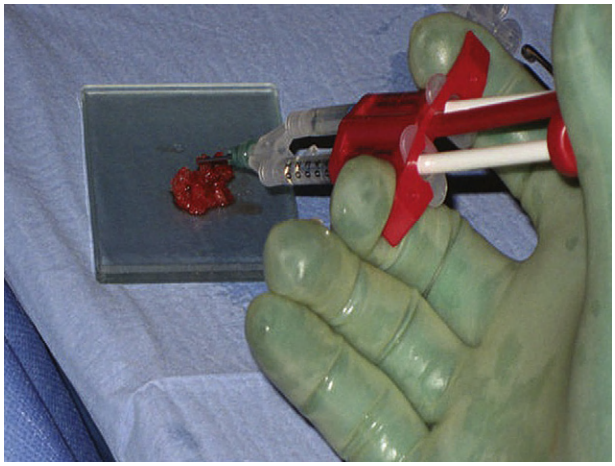


FIGURE 9D-14 The bone grafts are mixed with fibrin glue to form a putty-like consistency, a bone paste.

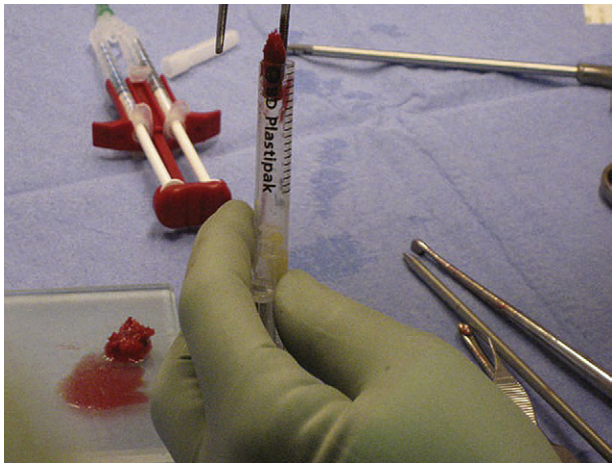


FIGURE 9D-15 The bone grafts are put into the 2-ml syringe where the top of syringe has been cut off leaving a round opening.

POSTOPERATIVE REHABILITATION FOR AN IMPLANTED KNEE JOINT

The extremity is immobilized in a brace locked in extension for 2 weeks (Fig. 9D-21). Full weight bearing is allowed in the brace up to a level that pain allows. After 2 weeks, the brace is used outdoors, unlocked, for another 4 weeks.

A large defect may be protected by an unloader brace for a longer period. Or one may even consider performing a concomitant permanent unloading with osteotomy (see also Chapter 12).

The osteotomy can be performed as an arthroscopy plus an osteotomy. The defect is debrided first, followed by the osteotomy, and finally the Hyalograft is implanted transarthroscopically. Rehabilitation is the same as it is without an osteotomy.

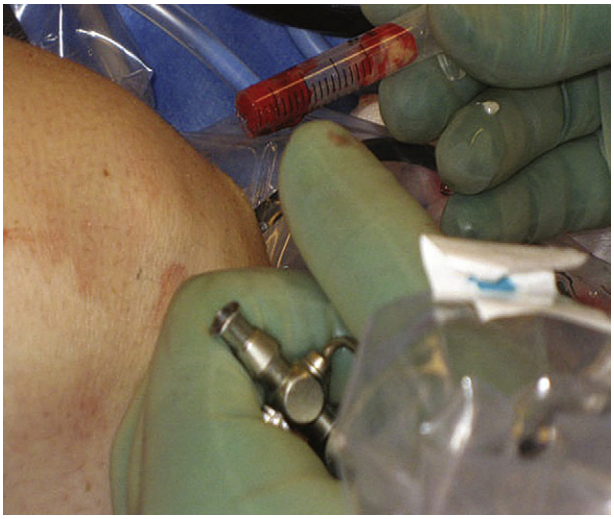


FIGURE 9D-16 The bone paste is implanted via the syringe into the osteochondral defect.

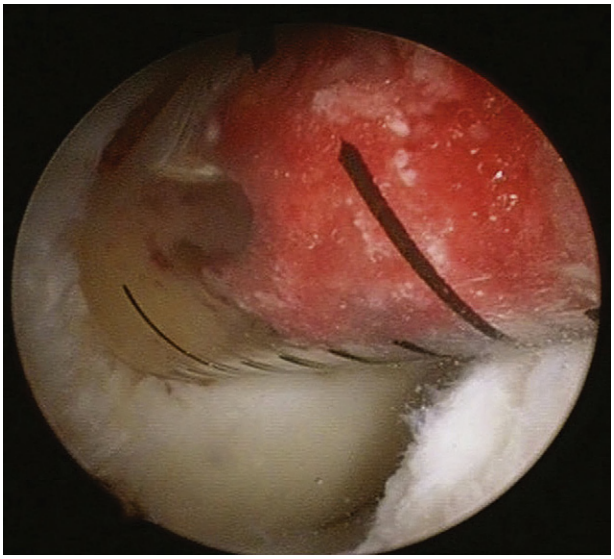


FIGURE 9D-17 The bone paste is pushed into the defect to fill up the osseous part to the level of the surrounding cartilage layer.

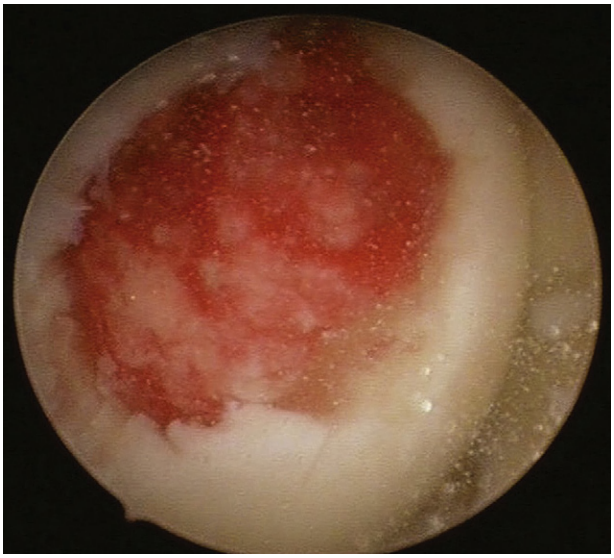


FIGURE 9D-18 The bone paste in place and compressed.

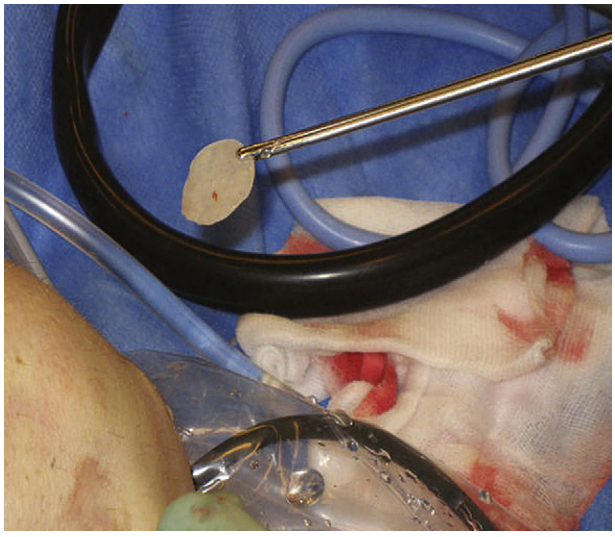


FIGURE 9D-19 The cell seeded scaffold is implanted and put over the top of the bone grafts plus additional fibrin glue for a firm adhesion.

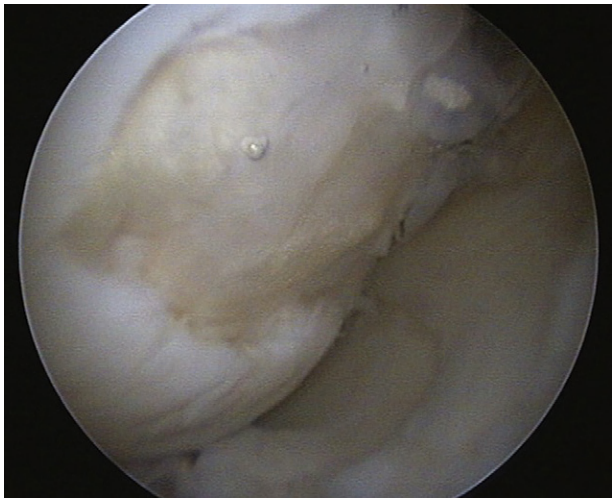


FIGURE 9D-20 Hyalograft in place in the defect.

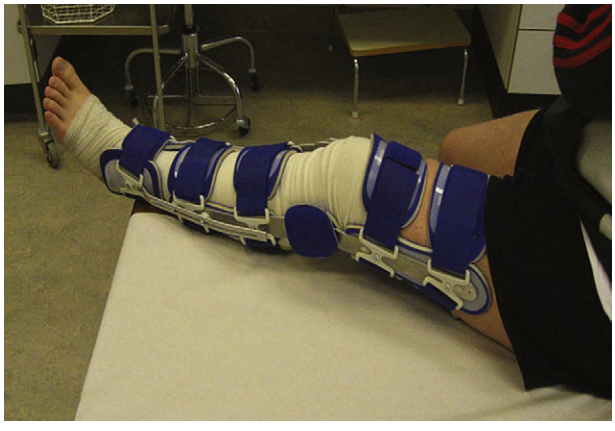


FIGURE 9D-21 The extremity is immobilized in a brace locked in extension for 2 weeks.

Open-chained knee strengthening is advised at approximately 8 weeks postoperatively. Running is not advised until 9 to 10 months postsurgery. High-level activities are not advised before 12 to 14 months.

Preoperative antibiotics such as cloxacillin 1g × 3 times during 24 hours postoperatively are recommended. Antithrombotic treatment with low-fragment heparin once per day is recommended for 2 weeks.

HYALOGRAFT-C TREATMENT FOR TALAR LESIONS OF THE ANKLE

Using a vector guide and an arthroscopic examination through lateral and medial portals, the lesion is reached and debrided. With the vector guide positioned in the lesion, a 3.2-mm drill is used to drill a channel through the malleolus to reach the lesion area (Figs. 9D-22 and 9D-23). The sized graft is pushed through the channel like a handkerchief through a hole, the pusher in the center of the graft and the surrounding parts folded against the channel walls (Fig. 9D-24). When the graft has reached the lesion area, a curved tonsil elevator is inserted via a portal and used to spread out the graft in the lesion (Figs. 9D-25 and 9D-26). If needed, bone grafts can be used to fill a deep osteochondral defect before implantation of the cell graft.

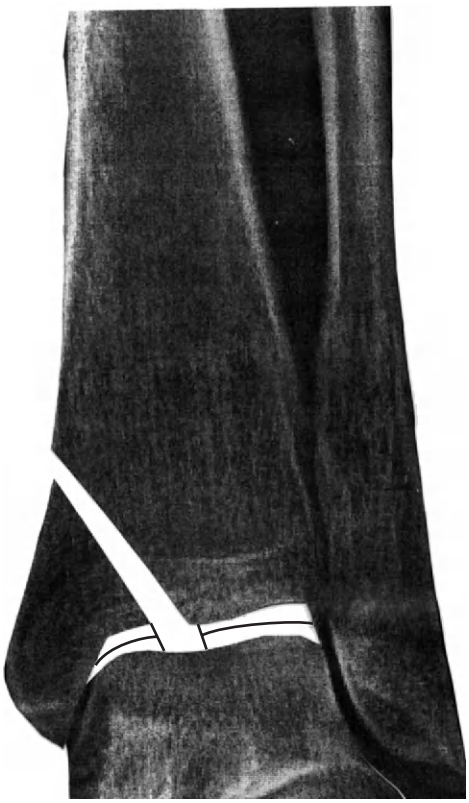


FIGURE 9D-22 A talar defect is treated transarthroscopically by drilling to the defect through the malleolus using a vector guide. Frontal view, 3.2 mm.

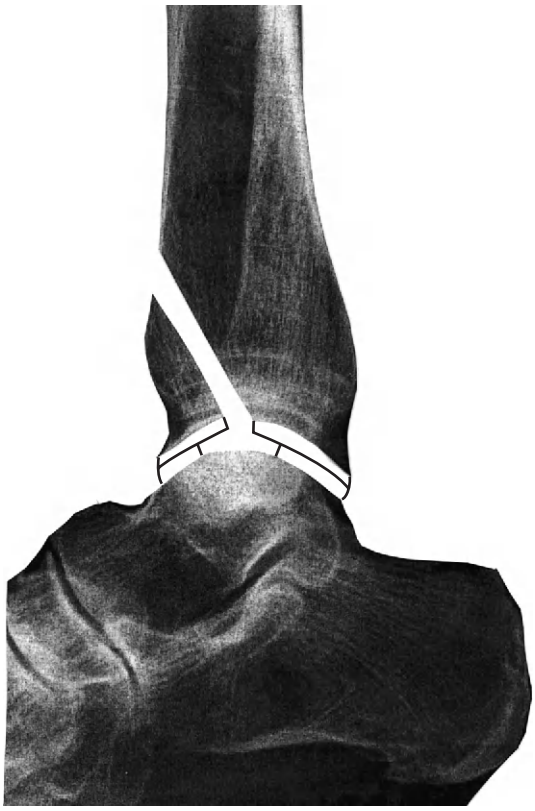


FIGURE 9D-23 Lateral view of defect and drilled channel before implantation.

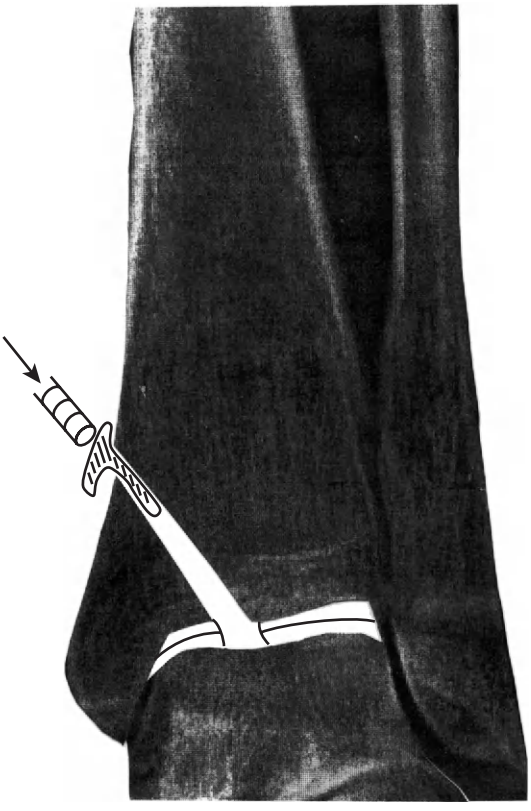


FIGURE 9D-24 The sized graft is pushed through the channel like a handkerchief through a hole; the pusher is in the center of the graft, and the surrounding parts are folded against the channel walls.

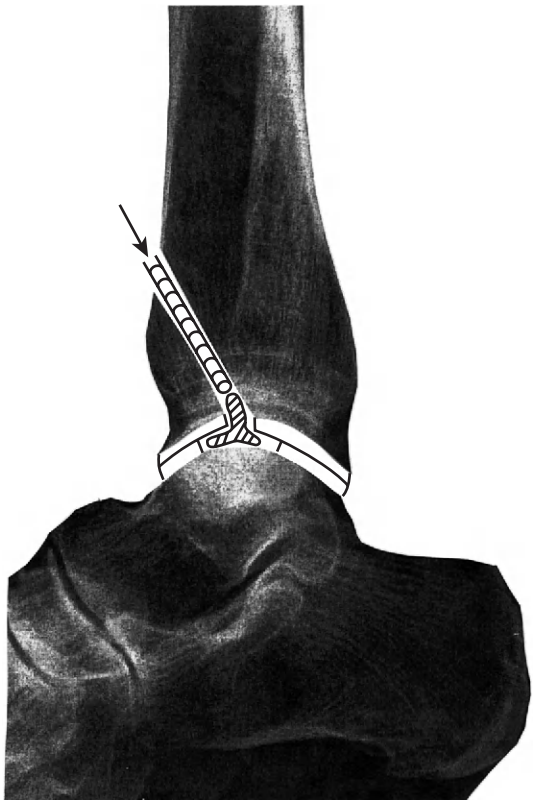


FIGURE 9D-25 When the graft has reached the lesion area, a curved tonsil elevator is inserted via a portal and is used to spread out the graft in the lesion.

FIGURE 9D-26 The graft is in place, in level with surrounding cartilage or slightly below.

POSTOPERATIVE REHABILITATION

The ankle is put in a brace locked in 90 degrees for 2 weeks. Weight bearing is allowed with the brace. After 2 weeks, successive increased motions of the ankle are encouraged.

REFERENCES

1. Kon E, Gobbi A, Filardo G, Delcogliano M, Zaffagnini S, Marcacci M. Arthroscopic second-generation autologous chondrocyte implantation compared with microfracture for chondral lesions of the knee: prospective non randomised study at 5 years. *Am J Sports Med*. 2009 Jan;37(1):33-41. Epub 2008 Dec 4.
2. Nehrer S, Chiari C, Domayer S, Barkay H, Yayon A. Results of chondrocyte implantation with a fibrin-hyaluronan matrix: a preliminary study. *Clin Orthop Relat Res*. 2008 Aug;466(8):1849-1855.
3. Kon E, Gobbi A, Filardo G, Delcogliano M, Zaffagnini S, Marcacci M. Arthroscopic second-generation autologous chondrocyte implantation compared with microfracture for chondral lesions of the knee: prospective nonrandomized study at 5 years. *Am J Sports Med*. 2009 Jan;37(1):33-41.

CHAPTER

9E

Autologous Chondrocyte Implantation

Matrix-Induced Autologous Chondrocyte Implantation (MACI)

David Wood, Gregory C. Janes

INTRODUCTION

Matrix-induced autologous chondrocyte implantation (MACI) is a method of cartilage regeneration that combines autologous cells with a type1/111 porcine membrane.[1-6] MACI was developed from collagen-covered autologous chondrocyte implantation (CACI), but cells are seeded onto the membrane 3 days before implantation. The graft is implanted "cells down" and secured in the cartilage defect with fibrin glue.

INDICATIONS AND CONTRAINDICATIONS

Surgical indications and contraindications are similar to those described by the International Cartilage Research Society for other autologous chondrocyte implantation (ACI) techniques (see also Chapters 9C and 9D):

Size of defect. Symptomatic defects more than 1.5 cm in diameter are suitable for MACI, but areas from 1 to 12 cm^2 have been successfully grafted.
Meniscectomy. Not a contraindication to MACI, but the consequent overloading exposes the graft to wear.
Obesity. Is a contraindication to MACI; patients should be within 10% of their ideal BMI at surgery, and this should be maintained postoperatively.
Malalignment or instability. Should be corrected at the time of surgery.
Age. Patients from 15 to 55 years of age are acceptable but most surgeons will have some patients outside this age range.
Comment on age. A large defect in a younger adolescent or an isolated defect in someone older than 55, who is physiologically young, can be justified.

Osteoarthritis. A contraindication to MACI.

In a pilot study on 20 arthritic patients, we achieved poor in-fill compared with unipolar cartilage defects.

Planning

We support the "open meeting" principle of surgical planning a week before the event. The clinical picture, functional score, MRI or CT arthrogram are considered with the arthroscopy report from cartilage biopsy.

Some Key Questions Are Addressed

1. Do the symptoms and knee injury and osteoarthritis outcome score (KOOS) justify invasive surgery?
2. Is the patient compliant and physically fit for surgery?
3. Is the defect suitable for MACI?
4. Is the defect best treated arthroscopically or by an open procedure?
5. Has enough graft been ordered?
6. Are ancillary procedures required?
7. How do the preceding decisions influence rehabilitation?

CARTILAGE BIOPSY

Instruments

Notchplasty gouge, pituitary rongeurs, and ring curettes are useful additions to the standard arthroscopy set (see also Chapters 9C and 9D).

Surgical Technique

This is an arthroscopic procedure performed under general anesthesia with a thigh tourniquet. First, a thorough examination under anesthetic is performed. The whole knee joint is inspected arthroscopically and the defect evaluated.

Meniscal tears, loose bodies, or internal derangement amenable to arthroscopic treatment is dealt with.

The biopsy for MACI is similar to other ACI techniques and may be taken from the median ridge at the level of the sulcus terminalis, the distal trochlea in the intercondylar region, or the surface of a fresh osteochondral fragment (see also Chapters 9C and 9D).

Using the small notchplasty gouge, a suitable-sized volume of cartilage is "scored" as deep as the subchondral plate. Using the gouge or ring curette, the biopsy is partially levered away from the subchondral plate of bone and finally grasped with pituitary rongeurs, immediately placed in culture medium (Fig. 9E-1), and transported to the laboratory for cell multiplication preparation.

We favor using a notchplasty gouge to partly dissect a biopsy from the median ridge as deep as the subchondral plate and as peripheral as possible from an area of normal cartilage. The biopsy should include the deep proliferative layer of cells.

Tension in the lateral retinaculum makes lateral ridge harvest more difficult and probably best done with pituitary forceps.

Briggs et al.[7] have demonstrated that surface cartilage of osteochondral fragments produces chondrocytes of good quality.

MACI IMPLANTATION

For open MACI implantation, the patient is positioned supine with a midthigh tourniquet and foot braces to position the knee in 90 and 120 degrees of flexion, respectively. A side support helps to control the leg in flexion.

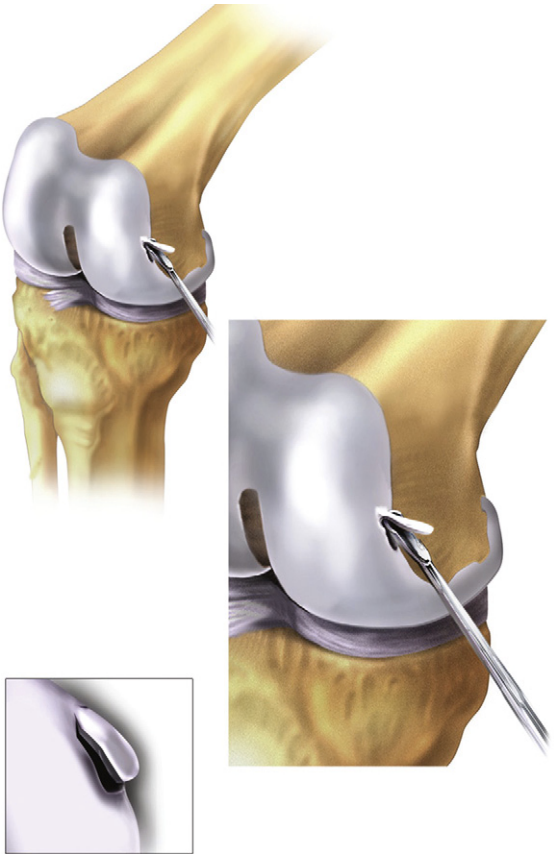


FIGURE 9E-1 Using a gouge or a ring curette, a cartilage biopsy is partially levered away from the subchondral plate from the upper medial femoral condyle and grasped with pituitary rongeurs, immediately placed in culture medium, and transported to the laboratory for cell isolation and culture expansion.

Incisions

The medial parapatellar incision is the most frequently used approach to the knee, as most cartilage defects occur on the medial femoral condyle (MFC).

A 5-cm incision is usually enough for isolated MFC defects, but this approach can be extended to gain access to the patellofemoral joint and lateral compartment. The standard incision starts just distal and medial to the proximal pole of the patella and runs distally to the tibial joint line parallel and medial to the patellar tendon.

The capsule is incised in line with the skin incision, and some of Hoffa's fat pad may be removed if required.

Jackson-Burrows condyle-shaped retractors are useful, but adequate access to the defects is most commonly achieved with a simple West's self-retaining retractor.

The incision is extensile proximally between rectus femoris and vastus medialis, with a medial bias. Femoral nerve branches to these muscles arise proximally and are not normally at risk.

Observe

The infrapatellar branch of the saphenous nerve can be damaged by distal extension, and this can occasionally lead to dysesthesia.

Although proximal extension and lateral displacement of the patella can be used to repair lateral femoral condylar damage in a patient with multiple defects, isolated lateral defects are best approached through a lateral parapatellar approach.

An incision from midpatella passing distally and further lateral in an oblique direction facilitates access to posterior femoral condylar and tibial lesions. The posterior tibial lesions are more readily dealt with arthroscopically.

A more vertical lateral parapatellar incision can be combined with a lateral release proximally and a tibial tubercle transfer distally. The deep dissection involves lateral retinaculum and joint capsule with no significant structures at risk. The capsule and retinaculum may be dissected separately and form a single repair following lateral release.

Recipient Bed Preparation

The defect is cleaned down to the subchondral plate and peripherally until stable vertical walls of normal cartilage surround the recipient site, removing all areas of damaged tissue and fibrocartilage. This is achieved with sharp curettes, a scalpel, and bone nibblers.

Eburnated bone and internal osteophytes should be removed with a small burr.

Very deep defects of 1 cm or more may be grafted with autogenous bone, milled allograft bone, or bone substitute. We prefer autogenous bone, which may be harvested from the distal femur or proximal tibia.

Hemostasis is achieved by pressure with epinephrine-soaked compresses or by the double fibrin glue technique. A thin layer of fibrin glue is used to seal off the area of hemorrhage, which when set forms a foundation for the definitive graft.

Templating the Defect

Templates or free hand membrane preparation are both acceptable and which method is used is determined by the skills and preference of the surgeon (Fig. 9E-2).

Matched "cookie cutter" instruments are available to make oval defects and a matched membrane. Templates have been created using aluminum foil and other inelastic materials. The graft itself is more mobile and stretches during implantation. If a template is made, it can be used to mark a pattern

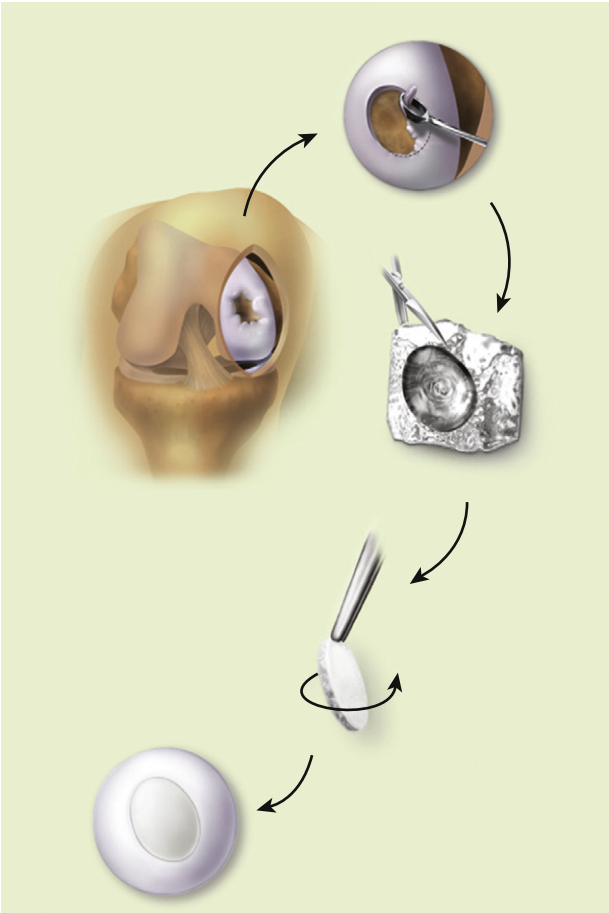


FIGURE 9E-2 Templates are created using aluminum foil and other inelastic materials. Templates or free hand membrane preparation are both acceptable, and which method is used is determined by the skills and preference of the surgeon.

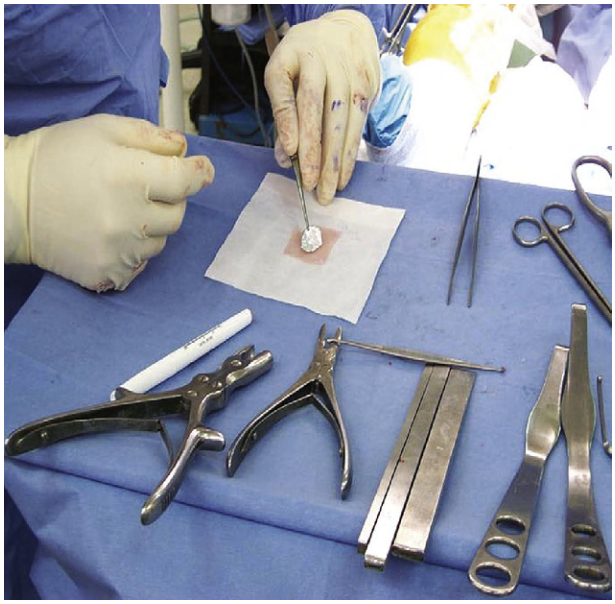


FIGURE 9E-3 The graft is oriented; there is a rough side and a smooth side. The rough side is where the cells are growing. This cell-seeded side should face the bone during implantation.

or as a definitive guide. I have not found templates useful, and they are impractical in arthroscopic MACI.

The recipient bed is dried, and a trial fit of the membrane is done before implantation.

Implantation

The graft is oriented; there is a rough side and a smooth side (Fig. 9E-3). The cells are seeded on the rough side.

The recipient bed is completely covered with a very thin layer of fibrin glue. The membrane is inserted into the bed and pressurized with a transparent Silastic catheter; this provides even pressure throughout the bed.

Ideally, the rough (seeded) surface of the membrane should cover the whole of the recipient bed and at the periphery face out toward the vertical walls of normal cartilage to enable integration with adjacent cartilage.

The MACI graft is kept under mild pressure for 30 seconds and then allowed to cure for 2 minutes (Fig. 9E-4, *A-B*). The knee is then put through a full range of movement to check that the membrane is stable before the wound is closed. If the membrane is unstable, then strategic stitches and repeat application of fibrin glue is required. The wound should not be closed until you are sure that the membrane is perfectly stable. This is a critical step, and to ignore it would invite delamination of the membrane.

Ancillary sutures are more frequently needed in larger defects. Internal osteophytes should be removed with nibblers or a small burr. Eburnated bone may be "freshened up" with a burr.

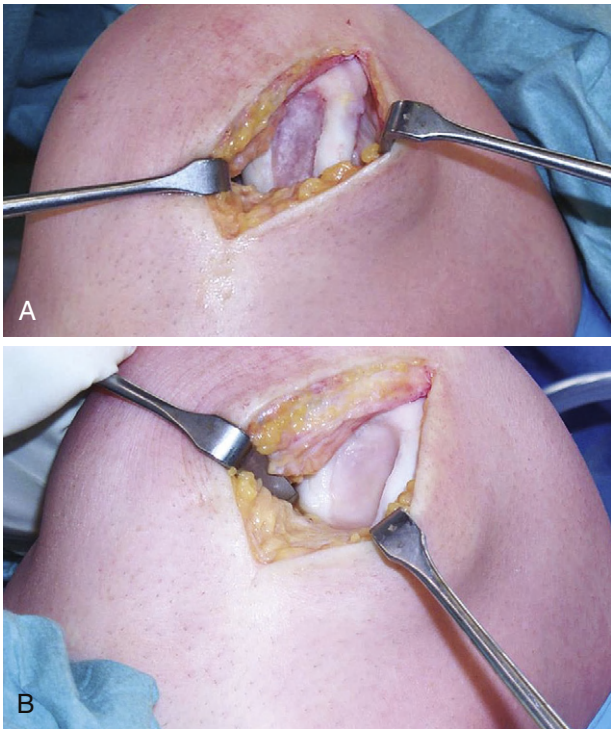


FIGURE 9E-4 A, The cell-seeded membrane has been implanted. The rough (seeded) surface of the membrane should cover the whole of the recipient bed and at the periphery face out toward the vertical walls of normal cartilage to enable integration with adjacent cartilage. B, The MACI graft is kept under mild pressure for 30 seconds and then allowed to cure for 2 minutes.

Stitches are useful when there is an intact vertical wall to the perimeter of the defect, but when the defect is uncontained, it may be necessary to use resorbable Vicryl pins if sutures cannot be anchored in host cartilage or where access is too difficult. Pins should be strategically placed to hide the pinheads and prevent impingement on the articulating surface. We have tried to graft two opposing surfaces by this technique without success, as one membrane will displace the other.

The wounds are closed in layers, taking care to accurately close the synovial layer separately with a fine (2.0) Vicryl suture to prevent the friction of an uneven surface over the graft.

ARTHROSCOPIC MACI

Indications

Simple single defects of the femoral condyles and tibial plateau can be treated arthroscopically, but the trochlear groove and patella are less accessible and best treated with a traditional open procedure.

Instruments

The arthroscopy set (Fig. 9E-5) should include atraumatic grasping forceps, ring- and standard curettes, a shaver, epinephrine-soaked compresses, transparent urinary catheters, a valveless arthroscopic cannula (Fig. 9E-6), neuro sucker, fibrin glue, and spinal needles. Ringer's lactate irrigation fluid is preferred, although definitive implantation is done dry.

The patient is placed prepared in a low thigh tourniquet with a brace.

Anteromedial and anterolateral portals are used initially to prepare the defect as the knee is irrigated with Ringer's lactate fluid.

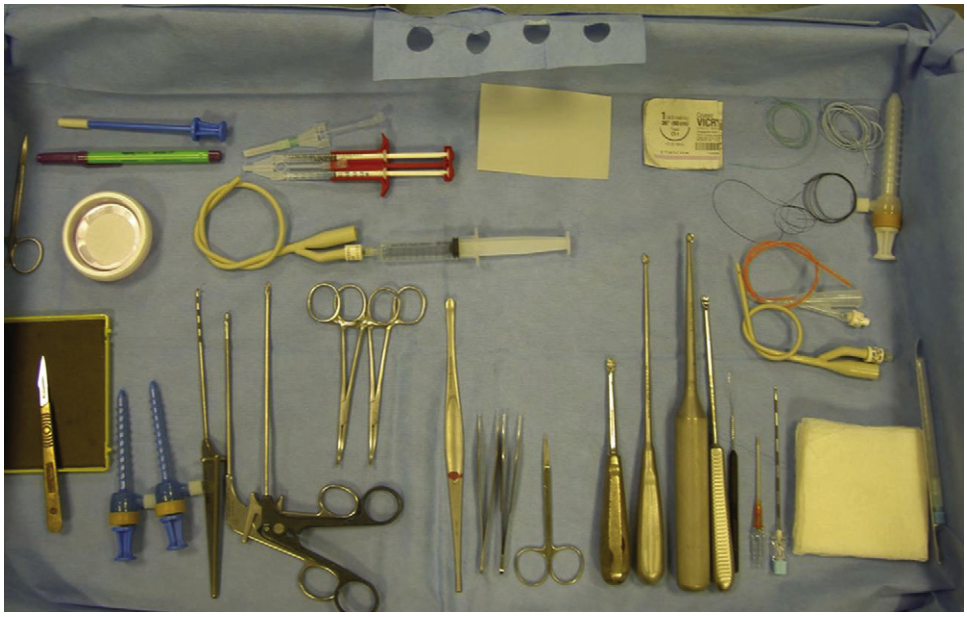


FIGURE 9E-5 The set for arthroscopic MACI implantation including different atraumatic grasping forceps, ring- and standard curettes, shaver, epinephrine-soaked compresses, transparent urinary catheters, neuro sucker, fibrin glue, and spinal needles.

FIGURE 9E-6 A valveless arthroscopic cannula used for the introduction of the MACI implant into the articular joint.

First, the cartilage defect is prepared to accept the MACI graft. The edges of the defect must be debrided to ensure a well-defined, contained defect. All areas of fibro-cartilage and loose hyaline cartilage are removed with the aid of a curette and power shaver.

A stable shoulder of hyaline cartilage with a base of subchondral bone is achieved (Figs. 9E-7 and 9E-8). The resultant defect is then measured with the end of an arthroscopy probe in several planes (Figs. 9E-7 and 9E-8). These measurements are then used to shape the membrane of the MACI graft.

Dots are placed onto the edges of the graft with a sterile colored marker to assist with orientation once the graft is inside the knee. Once the graft has been prepared, all irrigation fluid is drained from the knee converting to dry arthroscopy to facilitate implantation of the graft.

An arthroscopic sucker is used to fully dry the bed of the defect. An epinephrine-soaked compress is pressed onto the bed to further dry it and to try and prevent bleeding from the base. In the occurrence of any bleeding from the graft bed, fibrin glue can be used in a thin layer and allowed to set before proceeding with graft implantation.

The prepared graft is introduced into the knee (Fig. 9E-9, *A*) via a large bore valveless arthroscopic cannula (ConMed Linvatec, Largo, Florida). The graft is positioned in the defect using a probe; care must be taken to ensure the membrane is the right way up and correctly oriented (Fig. 9E-9, *B*).

Graft size is then re-assessed to ensure it fits the defect exactly without overlap onto the surrounding healthy cartilage. The graft may need further trimming out of the knee at this point. The large cannula facilitates multiple atraumatic passes into and out of the knee for fine-tuning the shape of the graft.

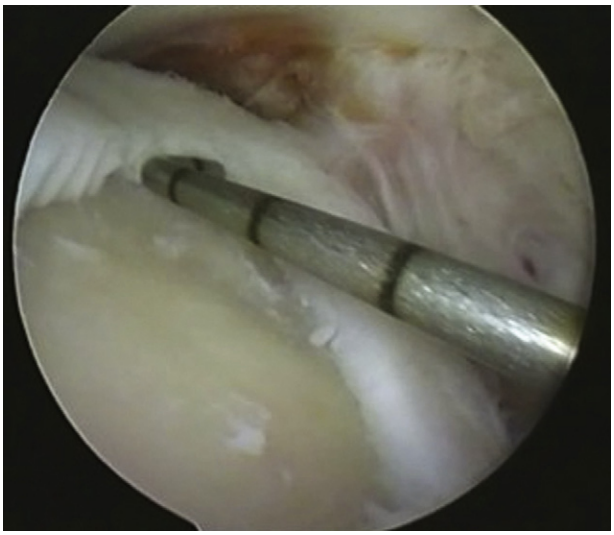


FIGURE 9E-7 A stable shoulder of hyaline cartilage with a base of subchondral bone has been achieved, and the cartilage defect is then measured with the end of an arthroscopy probe in several planes.

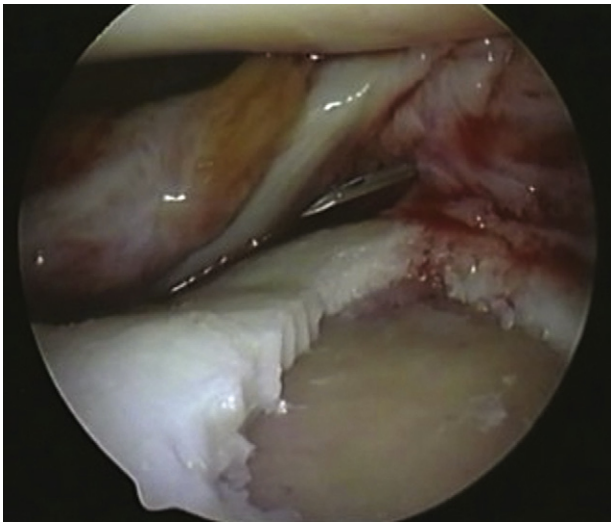
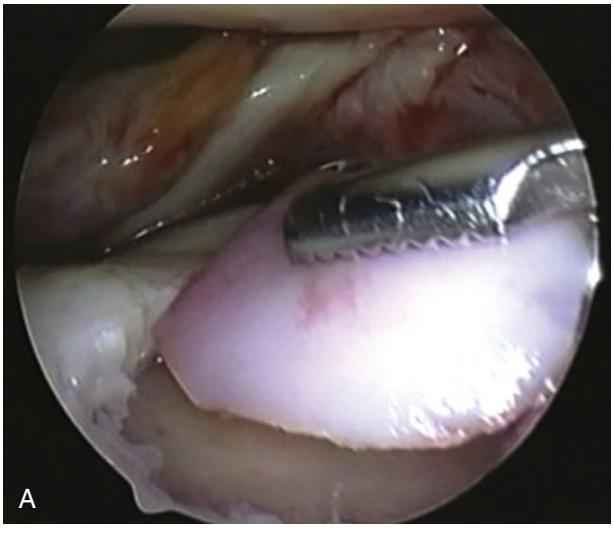


FIGURE 9E-8 Note the vertical walls that have been achieved during debridement plus a clean, bare subchondral bone surface.



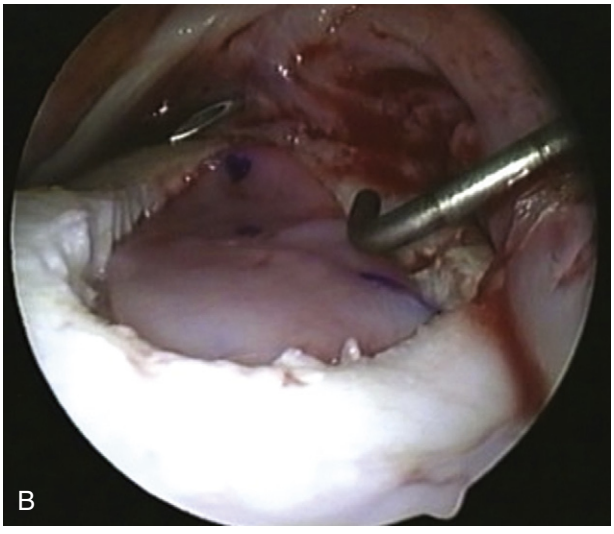


FIGURE 9E-9 **A,** The MACI membrane is introduced with a grasper into the joint through the valveless arthroscopic cannula to be implanted into the defect. **B,** The graft is positioned in the defect using a probe. The MACI membrane has been marked with ink to ensure the membrane is the right way up and correctly oriented.

The graft is then folded away from the defect to allow fibrin glue to be introduced to fix the graft (Fig. 9E-10a). A small amount of fibrin glue is introduced into the defect via a 19-gauge needle via the anteromedial portal (Fig. 9E-10, *A*). Even spread of the glue is achieved using the end of a probe (Fig. 9E-10, *B*).

The graft is then replaced over the glue and smoothed into place again with the probe (Fig. 9E-10, *B*).

Even pressure is applied to the graft for 30 seconds with the balloon end of a transparent Silastic urinary catheter (Fig. 9E-11). The catheter balloon is nonstick, and graft position can be checked as the glue sets.

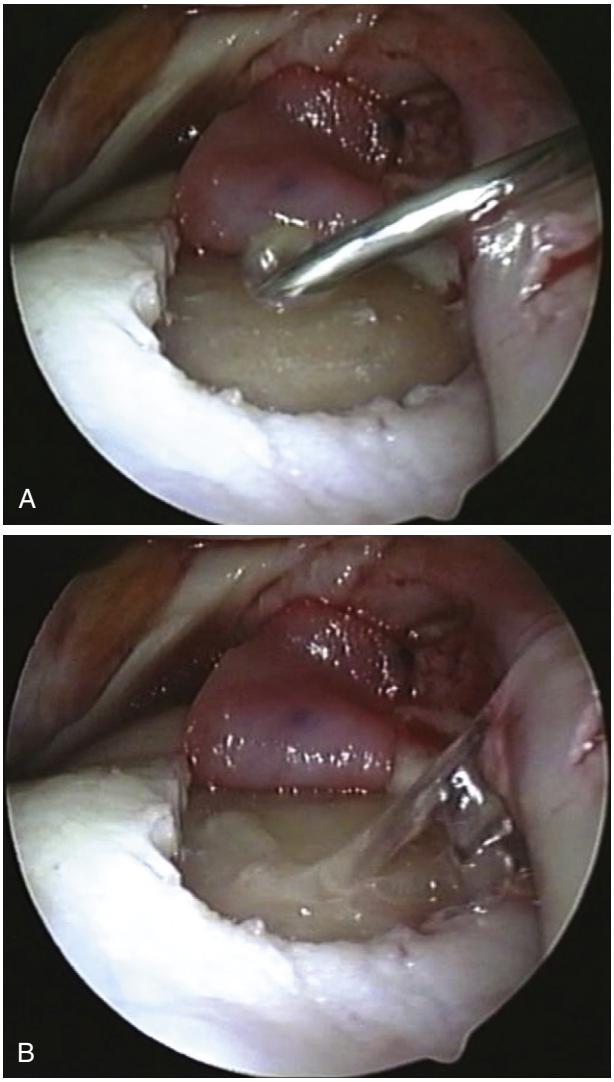


FIGURE 9E-10 **A,** The graft is partly lifted up from the defect to allow fibrin glue to be injected on the bony surface to fix the graft. **B,** Fibrin glue is introduced into the defect via a 19-gauge needle via an anteromedial portal. The graft is folded over the glue and smoothed into place again with the probe.

The redundant tip of the catheter is trimmed. The tip of the catheter is passed through the medial portal beyond the graft to orient the balloon over the defect and graft.

The balloon is then inflated with saline instilled into the end of the catheter outside of the knee (Fig. 9E-11). Even pressure is achieved over the graft as the balloon tamponades against the defect and the other surfaces of the knee. After 30 seconds the balloon is deflated and the catheter is removed (Fig. 9E-12).

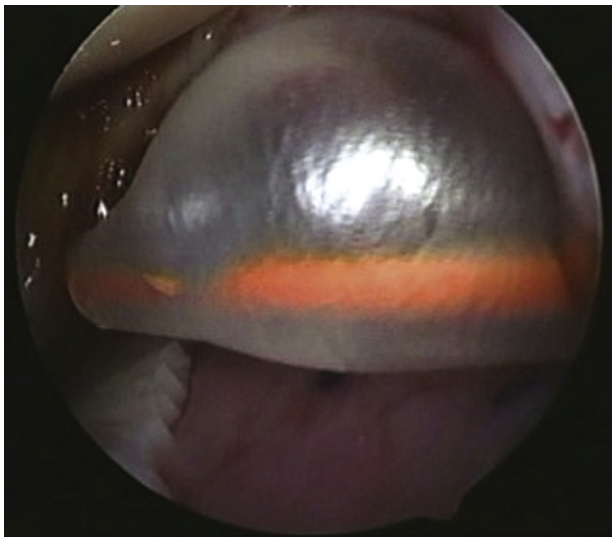


FIGURE 9E-11 Even pressure is applied to the graft for 30 seconds with a balloon end of a transparent Silastic urinary catheter.

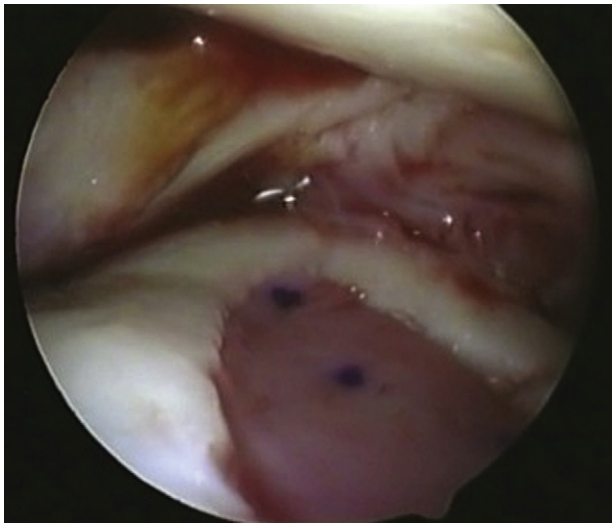


FIGURE 9E-12 The MACI graft is now securely fixated with glue combined with 2 minutes of pressure from the applied balloon. The knee is put through a range of movement for several cycles to ensure the graft remains fixed.

A further 2 minutes is allowed for the glue to cure, then the knee is put through a range of movement for several cycles to ensure the graft remains fixed. The arthroscopy portals are then closed in standard fashion without drainage.

No local anesthetic is instilled into the knee.

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CHAPTER

10

Allograft Particulate Cartilage Transplantation: *DeNovo Natural Tissue (NT) Graft*

Jack Farr

INTRODUCTION: DENOVO NT GRAFT

The *DeNovo* Natural Tissue (NT) Graft is derived from articular cartilage allograft.[1,2] The allograft articular cartilage is mechanically particulated into pieces of tissue and stored in a proprietary storage medium developed by ISTO Technologies, Inc. (St. Louis, Mo., United States).

The tissue is procured from donors 13 years old or younger (no fetal tissue), as more robust collagen type II and proteoglycan production occurs in cartilage from donors in this age group than in adult cartilage tissue.

As an allograft tissue, *DeNovo* NT is not required to be preapproved for clinical use by the Food and Drug Administration (FDA) but complies with the FDA regulations for human tissue products and the American Association of Tissue Banks (AATB) standards. The packages of *DeNovo* NT graft are shipped in controlled temperature containers (distributed by Zimmer, Inc.).

As tissue comprising the *DeNovo* NT graft is analyzed in the same manner as fresh stored osteochondral allograft, per AATB standards and FDA regulations, it is released for use only after all viral screening and sterility tests are completed. Similar to other fresh allograft tissues such as fresh osteochondral allografts,[3-6] the tissue has a limited shelf life.

The aseptically prepared *DeNovo* NT graft is placed in an inner sterile package filled with the storage medium. The sterile inner package is then sealed within a protective outer plastic package that is sterile inside.

Preoperatively, the lesion sizes are documented. The lesion areas are calculated and used to order the separate packets of *DeNovo* NT graft. Each package contains particulated cartilage pieces to cover an area of up to 2.5 cm^2.

The *DeNovo* NT graft has been implanted to repair cartilage defects in the knee, ankle, hip, shoulder, elbow, and great toe, with the earliest surgery performed in May 2007.

TECHNIQUE OVERVIEW

Step 1. Prepare the contained chondral lesions as standard for cell therapy techniques such as autologous chondrocyte implantation (ACI): vertical walls, with a clear base (Figs. 10-1 and 10-2).
Step 2. Achieve hemostasis with tourniquet deflated.
Step 3. Mold a sterile foil template into defect, and place template on sterile gauze (Fig. 10-3).
Step 4. Apply *DeNovo* NT graft pieces onto the foil mold base uniformly (Fig. 10-4).
Step 5. Use a needle to perforate the base of the foil mold to drain the storage medium transferred with the tissue pieces (dry field of *DeNovo* NT graft pieces) (Figs. 10-5 and 10-6).
Step 6. Apply a layer of fibrin glue to cover all pieces of cartilage (Fig. 10-7).
Step 7. Allow the fibrin glue to fully cure (Fig. 10-8).
Step 8. Gently elevate the fibrin glue/*DeNovo* NT graft construct from the floor of the mold.
Step 9. Dry the base of the chondral defect, and apply a thin layer of fibrin glue on this base.
Step 10. Remove the fibrin glue/*DeNovo* NT graft construct from the foil mold and place it in the cartilage defect, ensuring full contact with the fresh fibrin.
Step 11. Assure that the fibrin glue/*DeNovo* NT graft construct is below the shoulders of the lesion and will *not* see stress/shear from the opposing joint surface when motion is initiated (Fig. 10-9).

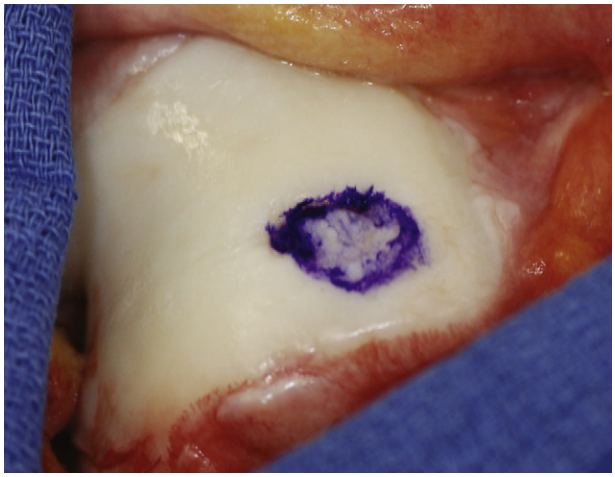

FIGURE10-1 A trochlear-contained defect with Grade 3a chondrosis.

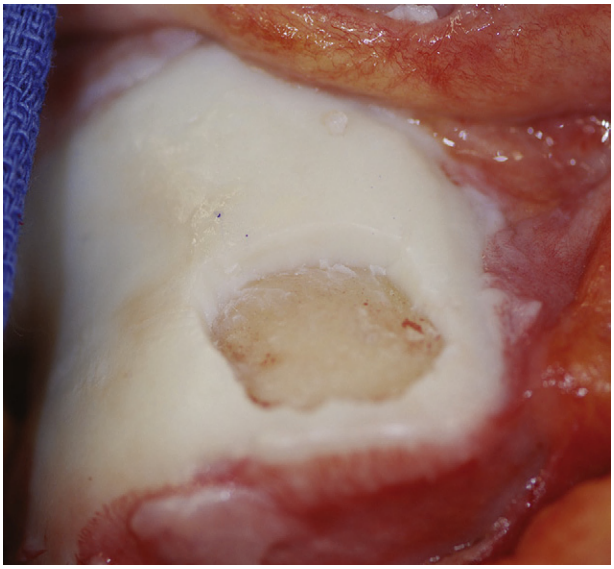

FIGURE 10-2 The defect base is cleared of debris, walls are vertical, and hemostasis is achieved.

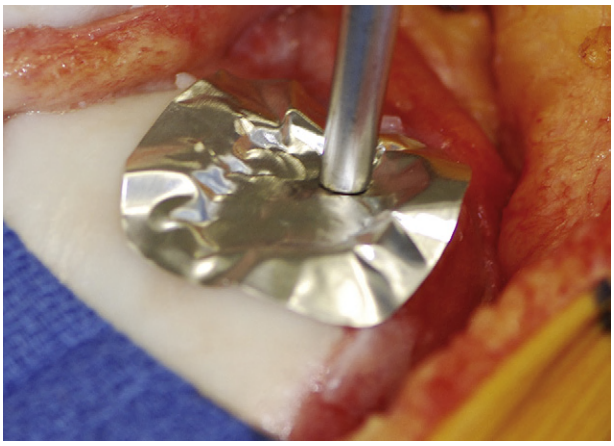

FIGURE 10-3 The sterile foil template is molded to fit the defect.

FIGURE 10-4 The *DeNovo* NT graft packet is removed from the protective sterile inside of the packaging.

Step 12. Allow the fibrin glue to fully cure.
Step 13. Check the stability of the implant with a controlled gentle trial of range of motion.

PEARLS AND PITFALLS

1. Normal cartilage vertical walls and clear base are as important as they are for all cell and implant cartilage surgery—do not compromise.
2. Containment is important for the current application.
3. The foil mold may require further sculpturing to mimic the defect.
4. Particulated cartilage is easiest to work with when a few drops of medium are still present—too much medium and the particulated cartilage flows; too little medium and it sticks to the dispersing tool.
5. All fibrin glues cure at a different rate; be patient for the construct to be fully cured and to allow ease of transfer.
6. Once in the defect, the fibrin glue/particulated cartilage construct can be plastically molded to optimally fill the defect.
7. Assure stability through range of motion trials.

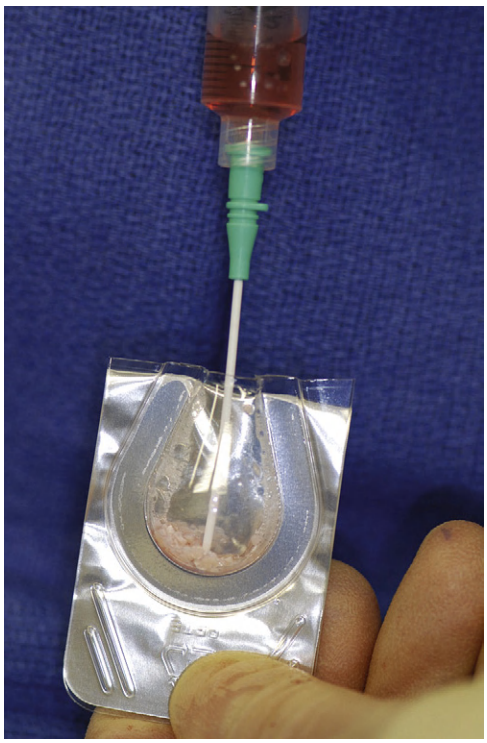

FIGURE 10-5 The storage medium is aspirated, leaving a few drops that improve handling of the *DeNovo* NT graft pieces.

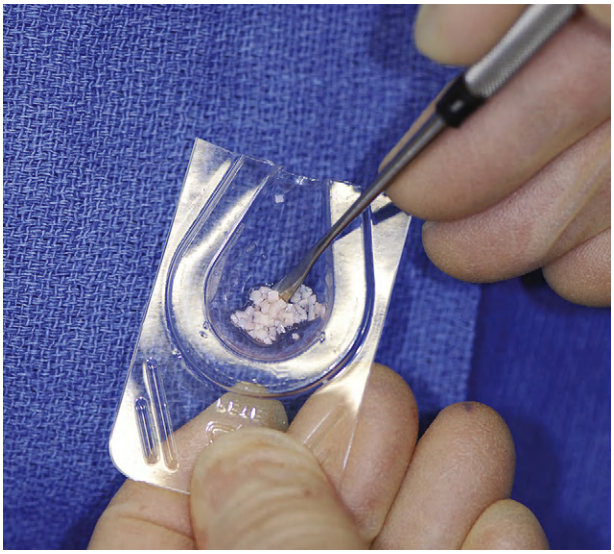

FIGURE 10-6 The *DeNovo* NT graft ready for transfer to the mold.

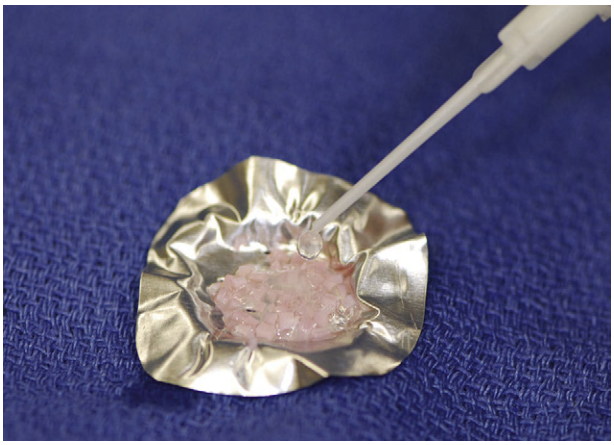

FIGURE 10-7 A thin layer of fibrin glue is applied to the *DeNovo* NT graft in the mold.

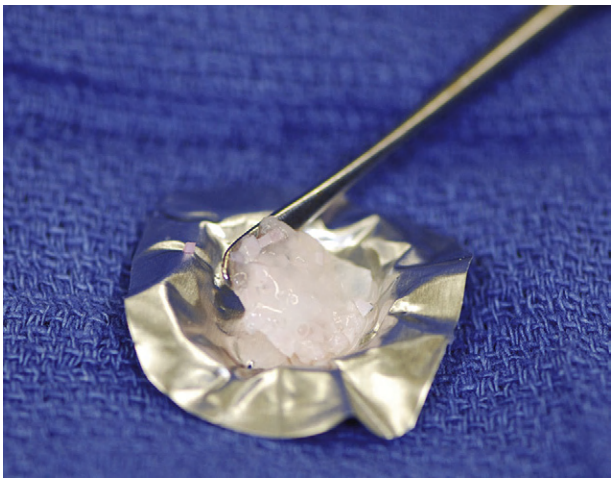

FIGURE 10-8 After the fibrin glue has cured, a freer elevator is used to carefully detach the fibrin glue/*DeNovo* NT graft construct from the foil mold.

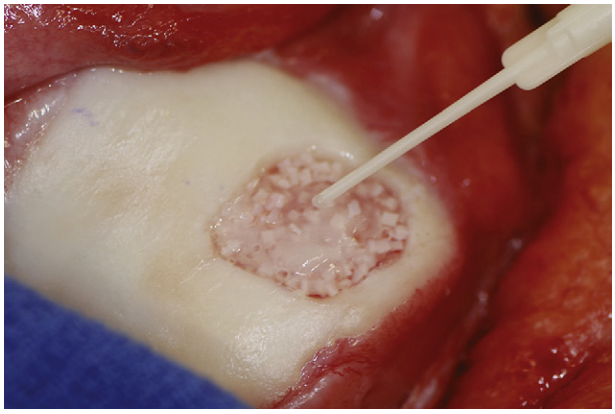

FIGURE 10-9 The fibrin glue/*DeNovo* NT graft construct is fixed into the defect with additional fibrin glue. The construct remains recessed from the defect shoulders.

POSTOPERATIVE MANAGEMENT AND REHABILITATION

Postoperative management and rehabilitation follow the same guidelines as with other cell-based therapies. It is important to document that the lesion is not subjected to disruptive forces during range of motion. If there is concern, motion may be limited to avoid loading of the implant region in the early phases of recovery. As for other cell-based treatments, protocols are modified according to the specifics of the patellofemoral or tibiofemoral compartment loading.

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CHAPTER

11

Cartilage Fragment Implantation

Mats Brittberg

INTRODUCTION

The Cartilage Autograft Implantation System (CAIS) is a kit that utilizes morselized autologous hyaline cartilage harvested arthroscopically, affixed onto a synthetic, resorbable scaffold using a fibrin sealant and implanted in a single surgical procedure.

Similar to autologous chondrocyte implantation (ACI) techniques, CAIS results in chondrocyte-based tissue repair but does not require ex vivo isolation and culture expansion of the cartilage tissue biopsy. Rather, donor cartilage is morselized in situ into small fragments using a customized harvesting device. The resulting increase in surface area of the cartilage fragments promotes cell outgrowth and expansion of the chondrocytes incarcerated within the dense cartilaginous matrix. Fragments are then incorporated on a chondro-conductive scaffold and affixed in the lesion site using bioresorbable staples in a single-stage procedure.[1,2]

TECHNICAL OVERVIEW (KNEE JOINT)

The CAIS procedure requires the utilization of two single-use items (a CAIS harvester and a disperser) and two implantable devices (a CAIS scaffold implant and staples) (Fig. 11-1, *A-H*).

CAIS HARVESTER

The CAIS harvester is a single-use device with a battery-operated motor. The harvester tip, with the aid of surgical vacuum, directs the morselized cartilage mixed with irrigation fluids into a tissue collector.

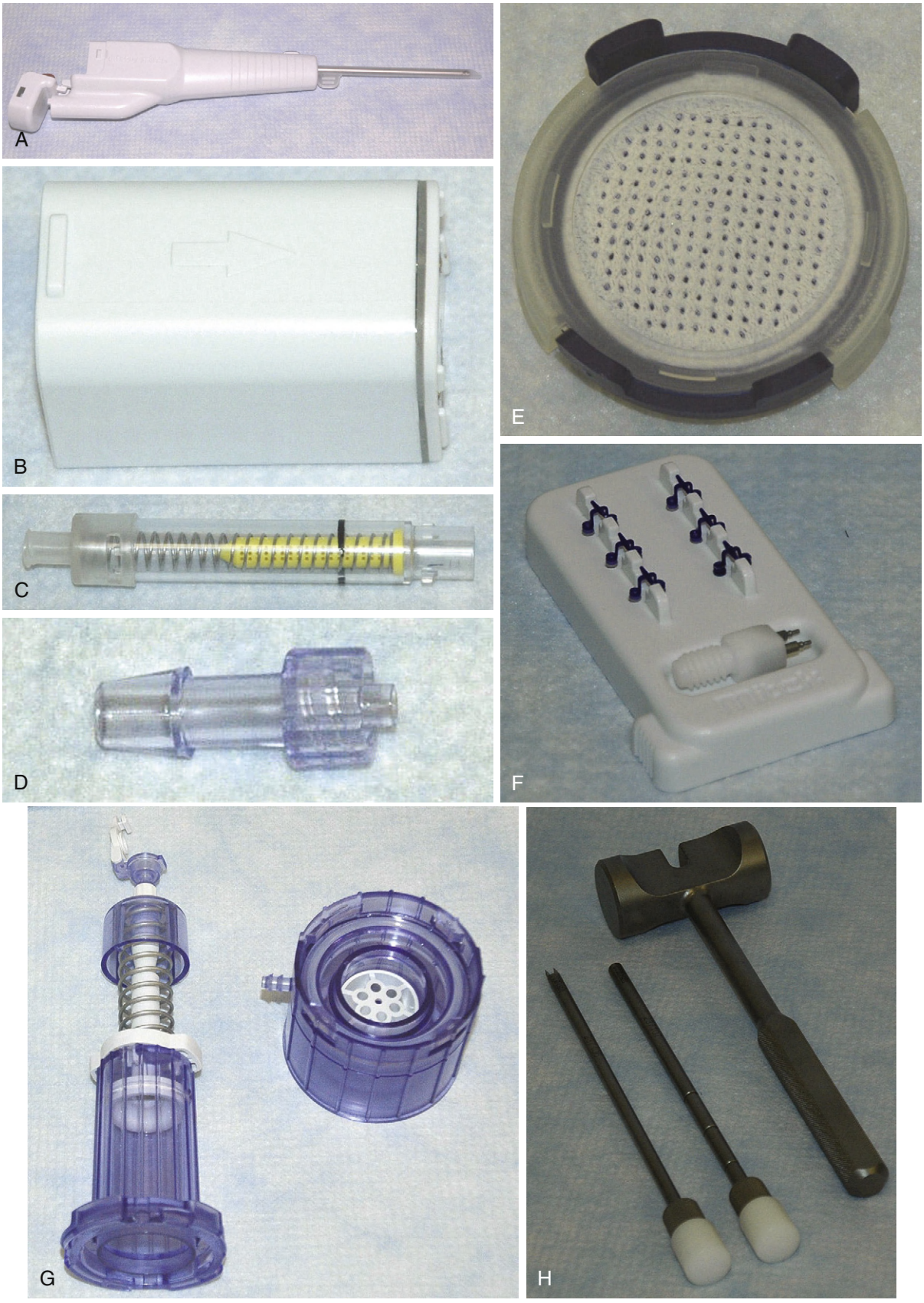

FIGURE 11-1 A to H Devices used for the CAIS procedure include the harvester with collector, disperser, scaffold, staples, and staple instruments (mallet, punch, and inserter).

CAIS DISPERSER

The CAIS disperser allows for even dispersion of the collected tissue onto the scaffold located in a bottom compartment of the disperser.

CAIS SCAFFOLD

The CAIS scaffold is a 10 cm^2 resorbable copolymer foam of polycaprolactone (PCL) and polyglycolic acid (PGA) that is reinforced with a polydioxanone (PDS) mesh. The scaffold is fixated within the prepared lesion site using CAIS staples (a resorbable PDS U-shaped strap).

SURGICAL TECHNIQUE

Standard arthroscopic portals are used to assess the joint and the lesions. Cartilage is to be harvested for the fragmentation preparation.

HARVEST AND COLLECTION OF CARTILAGE FRAGMENTS

Cartilage can be harvested arthroscopically from healthy, low-weight-bearing areas (the lateral femoral trochlea, medial femoral trochlea, sulcus terminalis, or intercondylar notch). A minimum of 200 mg of tissue is required.

The CAIS disperser is prepared by placing the CAIS scaffold into the bottom of the disperser with the clear side of the cartridge ring facing up and the blue side facing down. The top tube is then assembled to the disperser base using alignment arrows and rotating clockwise to a hard stop. The disperser spring is then compressed by depressing the disperser cap until an audible click is heard (Fig. 11-2, *A-E*).

The CAIS harvester is prepared by loading the battery pack into the device. The fragment collector tube is inserted into the harvester and rotated clockwise to a hard stop (Fig. 11-3, *A-E*). Following attachment of surgical vacuum, the harvester is then inserted through the portal and placed with its tip near the cartilage harvest site (Fig. 11-4).

The outer sheath that covers the tip during portal insertion is removed, and the harvester blade tip is placed against the cartilage and the motor is started.

Full thickness cartilage is harvested down to the calcified layer. Cartilage is harvested until the flange of the yellow basket in the collector aligns with the black demarcation line on the tube, indicating a minimum harvest quantity of 200 mg has been collected.

FIGURE 11-2 A to E Technique to assemble the scaffold into the disperser.

The collector is then disconnected from the harvester by rotating it counterclockwise and pulling outward. The collector is placed into the disperser with its Luer fitting facing up. Fragments are dislodged from collector and transferred to the disperser using two saline flushes (60 cc each) and a small, blunt Kirschner wire.

The collector is then removed and the disperser connection is closed. The disperser is activated by compressing the plunger retaining ring. The cap

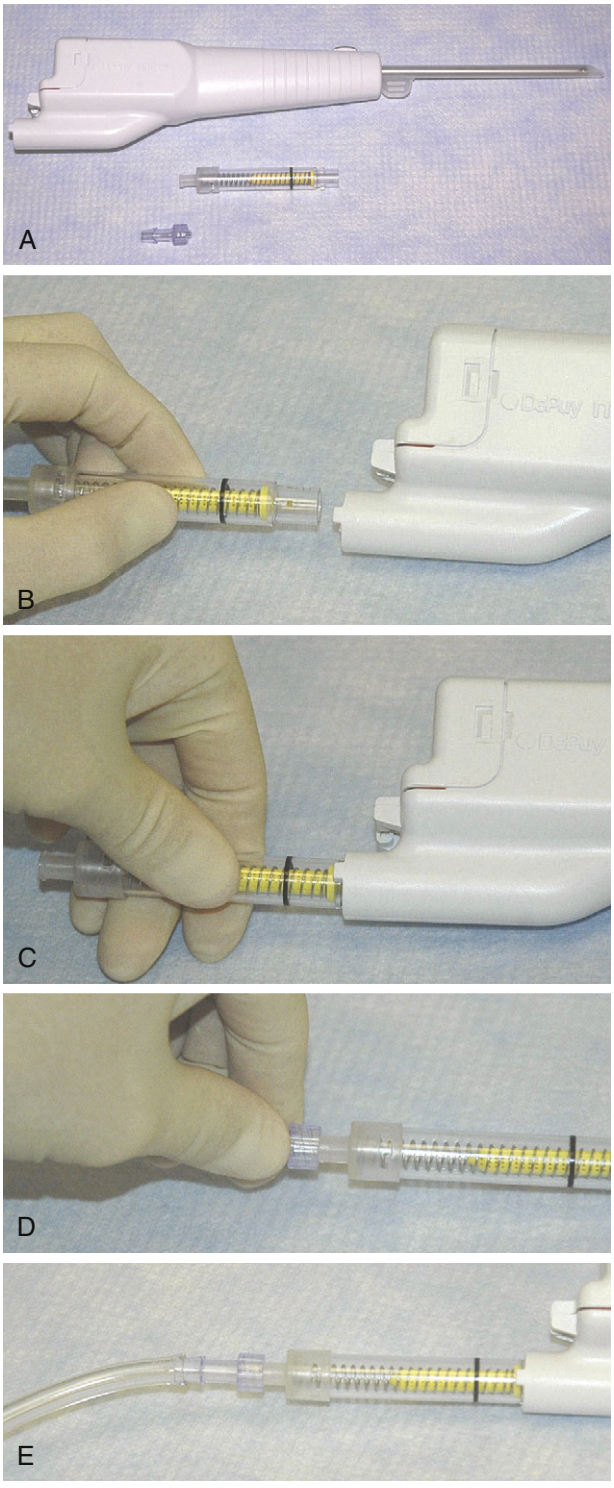

FIGURE 11-3 A to E Technique to prepare the harvester for collection of cartilage fragments.

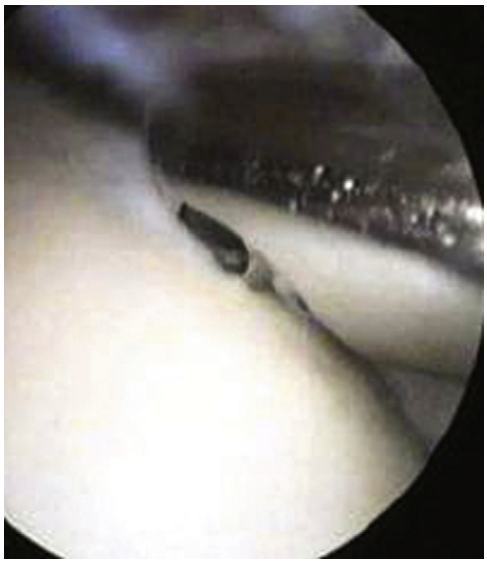

FIGURE 11-4 The tip of the harvester is placed on the cartilage surface at the harvest location.

springs upward to suspend the cartilage fragments in the saline solution. The fragments then settle because of gravity and disperse uniformly across the surface of the scaffold. The dispersion step is performed two times.

The scaffold is examined to confirm a uniform tissue fragment dispersion (Fig. 11-5, *A-E,* and Fig. 11-6). Provided the distribution of fragments is acceptable, the scaffold is removed from base of the disperser.

Fibrin sealant is applied over the fragments to hold them in place during preparation and implantation. The cartridge rings are then unsnapped, and the scaffold is placed in a safe location or specimen cup until templating is performed.

DEFECT PREPARATION

The joint is accessed through a miniarthrotomy. The lesion is debrided to healthy, orthogonal margins and templated as described in Chapter 3.

The template is used to trim the scaffold to the appropriate size and shape (Fig. 11-7). The implant should be slightly oversized to ensure it will completely cover the defect once staples have been placed. Finally, the implant is placed onto the debrided lesion with the fragment side facing the subchondral bone. The implant is held in a stable position using forceps, and pilot holes for the staples are made using the CAIS punch and mallet (Fig. 11-8a-e). With constant pressure on the scaffold, the punch is carefully removed.

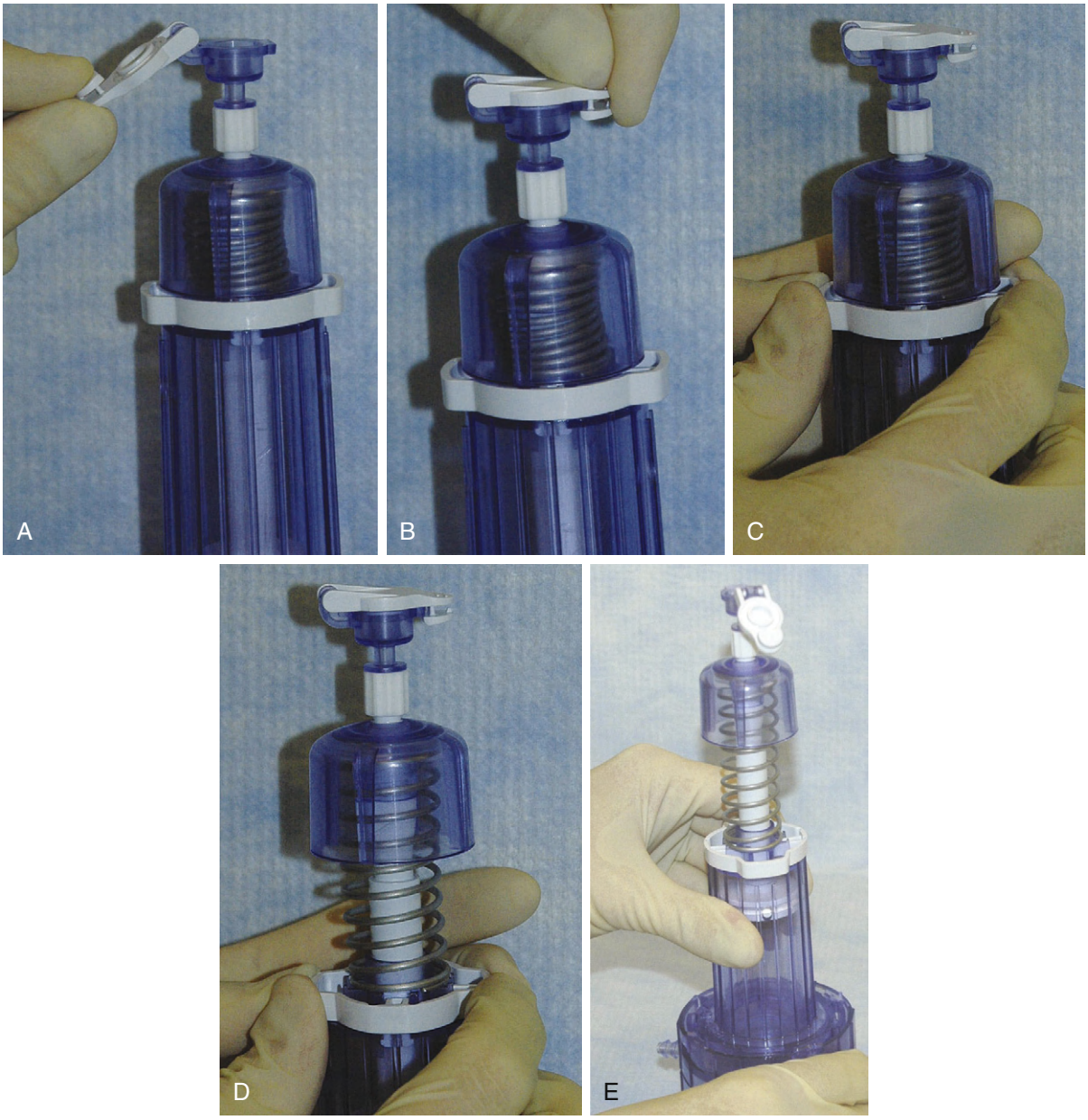

FIGURE 11-5 A to E Technique for activation of the disperser to uniformly distribute the cartilage fragments over the scaffold surface.

Staples are loaded onto the CAIS inserter instrument by inserting the prongs of the inserter tip into a staple. The staples are then placed into the pilot holes using the CAIS inserter and mallet (approximately one staple per 0.75 cm^2 of implant) (Fig. 11-8, *A-E,* and Fig. 11-9).

The scaffold implant is trimmed peripherally to ensure the implant is not proud, and the joint is exercised through a range of motion of flexion and extension to ensure no impingement from graft or staples.

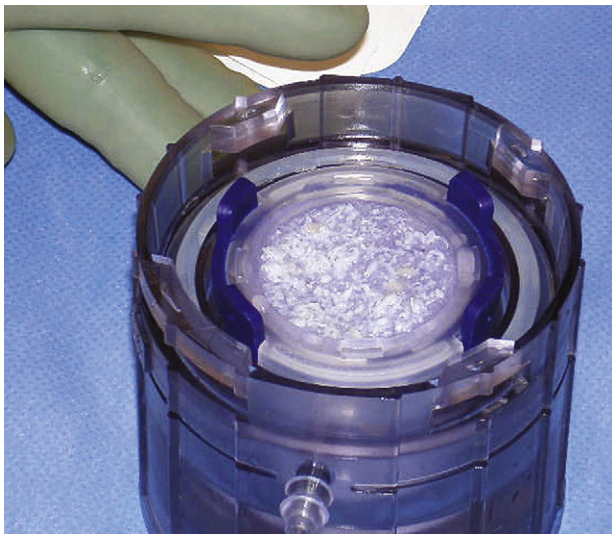

FIGURE 11-6 Representative image detailing uniformly dispersed cartilage fragments.

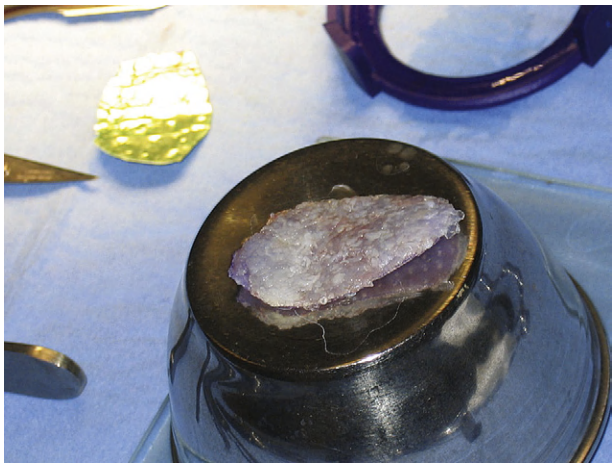

FIGURE 11-7 Sized and templated scaffold before implantation.

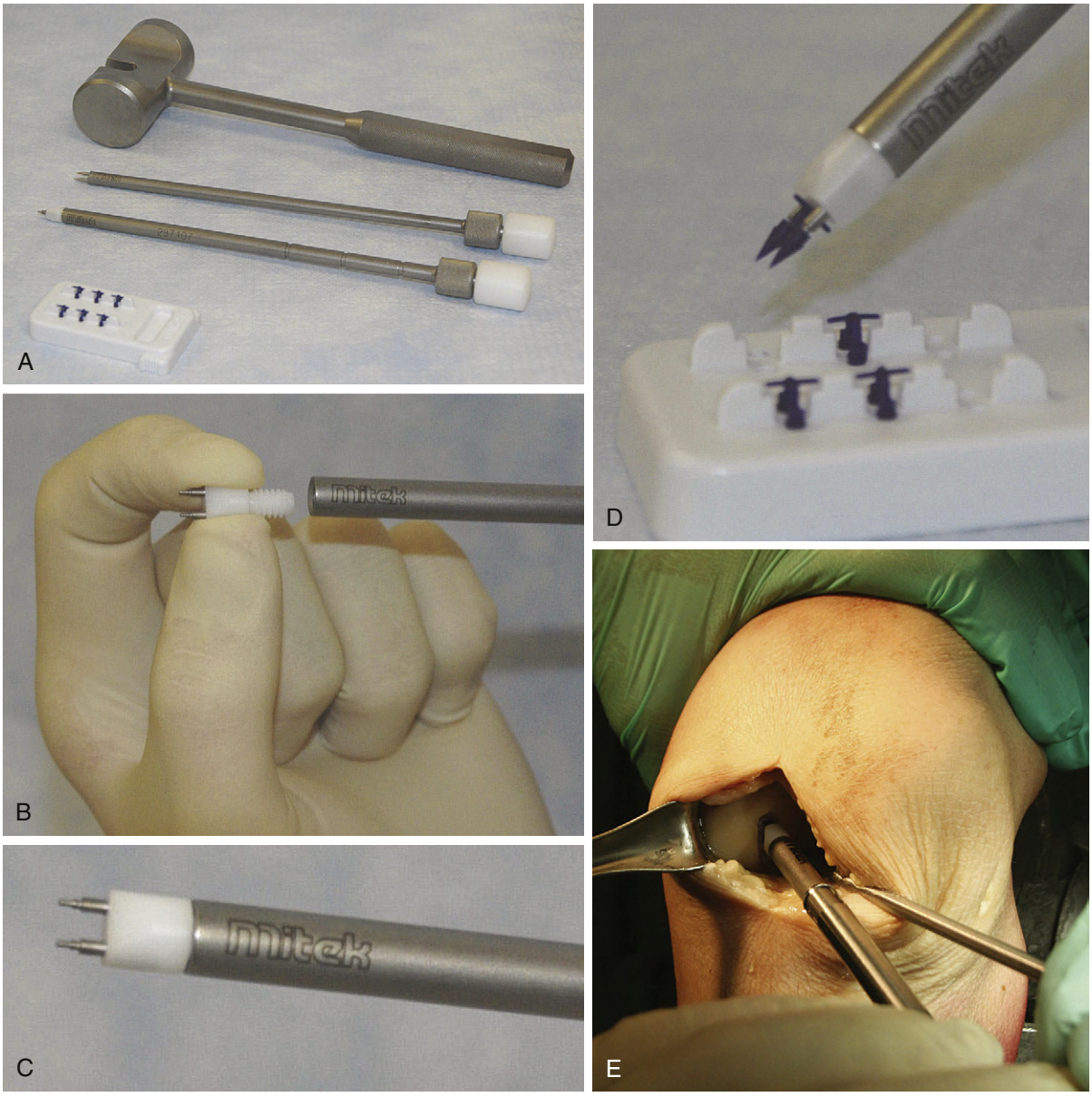

FIGURE 11-8 A to E Technique for scaffold fixation with bioresorbable staples.

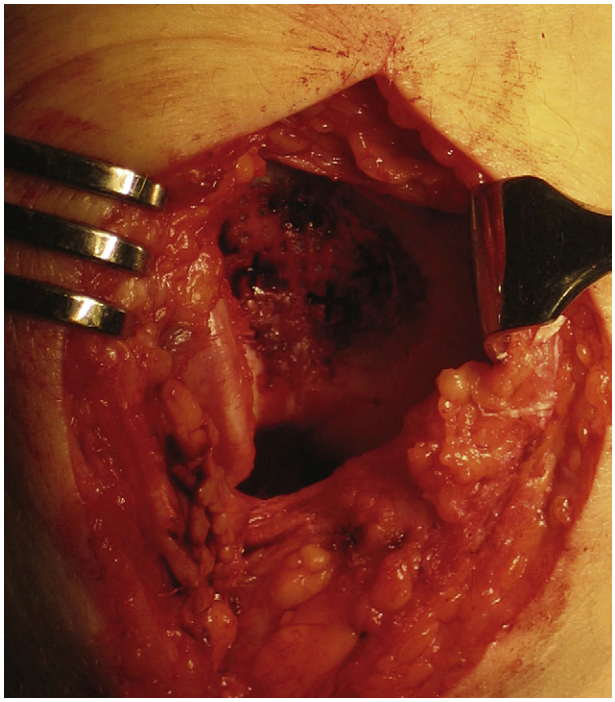

FIGURE 11-9 Image of a trochlear defect following treatment with CAIS demonstrating scaffold orientation and staple fixation.

POSTOPERATIVE REHABILITATION

Femoral Condylar Lesions

The first 2 weeks are non weight bearing in a brace locked in full extension. From week 2 until week 6, touch down weight bearing is permitted with an unlocked brace.

The use of a continuous passive motion (CPM) is recommended (with the brace removed) for the first 3 weeks. Specifically, CPM use is recommended for 6 to 8 hours/day in minimum 2-hour increments. CPM is initiated at 0 to 45 degrees and advanced to 90 degrees as tolerated.

Trochlear Lesions

For the first 6 weeks, the brace is locked in full extension and weight bearing is allowed as tolerated. The brace is removed only during CPM use. CPM is stared at 0 to 45 degrees and advanced to 90 degrees as tolerated.

For Both Lesion Locations (Week 0-6)

- Quad set-isometric quad strengthening
- Straight leg raising

- Hip abduction/adduction
- Hamstring isometrics
- Electrical stimulation for muscle reeducation
- Stationary bicycle for passive range of motion (PROM) only

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1. Lu Y, Dhanaraj S, Wang Z, et al. Minced cartilage without cell culture serves as an effective intraoperative cell source for cartilage repair. *J Orthop Res*. 2006;24:1261-1270.
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CHAPTER

12

Unloading Osteotomies: Effect on Cartilage and Cartilage Repair

Jens D. Agneskirchner, Alex E. Staubli, Philipp Lobenhoffer

INTRODUCTION

The main principle of correction osteotomies is to achieve a transfer of loading from diseased, arthritic areas of the joint to areas with relatively intact, healthy cartilage. The valgus opening-wedge high tibial osteotomy (HTO) is an option for the treatment of medial varus osteoarthritis of the knee that aims to change the loading of the tibiofemoral joint by a correction of the leg axis. The degenerated medial compartment cartilage is thus decompressed, resulting in a relief of pain and a delay of cartilage damage.

Good clinical short- and mid-term results have been reported.[1-8] However, favorable results seem to be strongly dependent on a precise correction of the loading axis.[9] Under-correction with persisting varus usually leads to poor results; overcorrection into large valgus may result in medial joint opening and rapid development of lateral osteoarthritis.[10] Various recommendations on the precise amount of the valgus alignment achieved postoperatively have been published. Some authors refer to the anatomical axes of the femur and tibia and recommend a postoperative alignment of 8 to 10 degrees valgus.[1-14] Others focus on the mechanical axes of the femur and tibia and suggest a postoperative alignment of 3 to 5 degrees valgus.[5,10,15,16] However, these suggestions are based on individual clinical experiences and a few retrospective studies.

Probably the most commonly applied concept in preoperative planning is based on the work of Fujisawa et al.[14] In this retrospective clinical study, preoperative and postoperative arthroscopy with a follow-up for 4 months to 6 years was performed on 54 knee joints before closing-wedge HTO, and the tibiofemoral joint cartilage was evaluated. The postoperative weight-bearing axis was correlated with changes in cartilage findings. The correction achieved postoperatively was measured with reference to the intersection of

the weight-bearing axis with the tibial plateau. The tibial plateau was divided into four sections and the point of intersection assigned to the corresponding section. Fujisawa et al.[14] concluded from their findings that for ideal correction the postoperative axis should lie within the lateral 30% of the tibial plateau as measured from its midpoint. From this study derived the recommendation that the weight-bearing axis should postoperatively pass through the "Fujisawa point" (i.e., it should intersect with the knee joint line at 62% of the tibial plateau width measured from its medial cortex).[17-19]

PEARLS

Principles of Osteotomy

- Goal of valgus opening-wedge high tibial osteotomy: redistribution of pressure on the tibiofemoral joint cartilage.
- Good results are achieved with high tibial osteotomy if correction is precise.
- Different statements are made in the literature on the necessary amount of correction and on the aimed weight-bearing axis after correction.

EFFECT OF DIFFERENT LOAD AXES ON TIBIOFEMORAL CARTILAGE

Literature

Surprisingly, despite the enormous increase of interest in osteotomies, to date no investigations have been reported that quantified the load-transfer effect of shifting the weight-bearing line on tibiofemoral joint contact pressure with reliable implication for the right amount of correction. The work of Fujisawa was undertaken as early as 1979, when knee arthroscopy, the only parameter used in the study to evaluate outcomes, was still developing. Further weaknesses of that study are a relatively small sample size per patient group (approximately 12 knee joints) and a complete lack of postoperative clinical data such as pain or joint effusion as parameters for good outcome.

Because of the discrepancy between the high number of osteotomy procedures being performed and the lack of experimental data on the actual intraarticular effects of correction osteotomies of the knee, the authors undertook a literature search on this subject and carried out the experimental study that will be presented in this chapter.

The effects of different load axes in the frontal plane on the distribution of pressure in the tibiofemoral compartments has already been the subject of several experimental studies with different measuring techniques and experimental designs.

Before direct measurement of joint cartilage pressure was technically feasible, indirect methods were employed based on evaluation of radiographs, eventually combined with gait analysis and measurements of ground reaction forces with force plates.[20-22]

The first direct measurements of transferred joint forces and contact pressures were obtained by application of strain gauges.[23,24] Next, pressure-sensitive films (Fuji film) were used that changed color as a result of applied pressure.[25,26]

The up-to-date techniques use pressure-sensitive film that measures changes in electromechanical resistance (K-Scan System, Tekscan, Inc., Boston, Mass.). These sensors offer the highest accuracy and best reproducibility and have provided the basis for the most recent studies on this subject.[27]

Most studies are tested under static conditions and rarely under dynamic conditions (i.e., simulation of gait cycle with an increase and decrease in loading). Nevertheless, all the studies were basically able to demonstrate that alterations of the axial alignment led to redistribution of load within the compartments of the tibiofemoral joint. Varus deformity resulted in greater loading of the medial compartment and valgus deformity in greater loading of the lateral compartment. This inequality in the distribution increased with the degree of axis deviation, proximity to the joint line, and amount of applied force.[24,25]

In addition to those studies describing tibiofemoral pressure distribution under the influence of different load axes in the frontal plane, only two experimental studies have been published that investigated the effect of high-tibial-correction osteotomy on contact pressures distributions within the knee joint. Only one of these studies was concerned with the correction of deformities in the frontal plane (valgus-varus)[26]; using the closing-wedge technique. The other study, published by the present author, investigated contact pressure changes after correction osteotomy in the sagittal plane.[27] Measurements of the contact pressure in the knee joint after correction osteotomy in the varus-valgus plane in open-wedge technique have not been published so far. Furthermore, data correlating the degree of valgus with the desired changes in intraarticular contact pressure distribution are currently not available.

In a biomechanical study with knee joint specimens, Riegger-Krugh et al.[25] investigated the effect of HTO in closing-wedge technique on the contact pressure distribution within the tibiofemoral joint. Fuji films were used for pressure measurement (i.e., only measurement under static conditions were possible and there were no repeated measurements). Both varus and valgus malalignments were simulated and a closing-wedge osteotomy of 5 degrees was carried out. The authors found differences in contact pressure distribution as expected, with higher contact pressure in the medial compartment in varus malalignment and higher contact pressure in the lateral compartment in valgus malalignment. Surprisingly, with a neutral loading axis, less contact pressure was recorded in the medial compartments than in the lateral compartments under these test conditions; after valgus HTO, the contact pressure distribution was similar to that with neutral loading axis. The authors concluded that because of those only minimal changes in the contact

pressure distribution, an HTO of 5 degrees would represent in most patients an under-correction.

Regarding the experimental setup, general conclusion for the amount of correction in the clinical situation can only be drawn to a limited extent. The mounting device used for the specimens allowed only for limited adaptations to the different preexisting anatomical axes and therefore did not simulate natural conditions.

In a biomechanical study conducted by the authors,[27] tibiofemoral contact pressure was measured after flexion HTO (i.e., after altering the mechanical axes in the sagittal plane). In a dynamic experimental model involving a knee joint kinemator, contact pressure was measured with the K-Scan System. Flexion osteotomy was performed as a supra tuberositous opening-wedge osteotomy parallel to the tibial slope of the tibial plateau, and then the tibial slope was gradually increased in 5 degrees increments from its original position to 20 degrees. This osteotomy exclusively modified the alignment in the sagittal plane; the alignment in the frontal plane (varus-valgus) was left unchanged.

The flexion osteotomy significantly altered the tibiofemoral contact pressure distribution: as the tibial slope increased, the tibiofemoral contact area in the medial compartment shifted anteriorly, whereas the posterior joint area was unloaded. This effect was most prominent in extension (i.e., in a position with high loading).

In addition to these biomechanical studies with cadaveric specimens, two other studies have been published that measured tibiofemoral contact pressure intraoperatively in vivo. One study used a knee prosthesis with an implemented telemetric pressure measurement device during the procedure of total knee replacement with the patient supine under general anesthesia, followed by testing in normal alignment and under varus and valgus stress produced by the manipulations of the surgeons. The second study measured tibiofemoral contact pressure during diagnostic arthroscopy with the patient under local anesthesia. F-scan pressure measurement sensors from the K-Scan System were inserted into the medial and lateral compartments, and contact pressure was recorded during two-legged and single leg stance and after application of a valgus splint.

EXPERIMENTAL STUDY OF THE AUTHORS

The authors conducted an experimental study to investigate the effect of different loading axes in the frontal plane on the tibiofemoral cartilage pressure.[19] Seven knee joints were tested in full extension under axial loading according to a standardized loading protocol (peak load 1000 N) in a materials testing system (MTS 858 Mini Bionix II test system, Eden Prairie, Minn.).

Different loading situations of the lower leg were simulated by varying the anatomical alignment angles of the distal femur and the proximal tibia as well as the offset created by the femoral head using a specially designed and constructed fixture. The fixture was allowed to compensate for different preexisting anatomical femoral and tibial angles, and a standardized and reproducible intersection between the mechanical loading axis the knee joint line was set up for each testing. The distal end of the tibia and the proximal end of the femur were potted in cylinders attached to universal joints, which allowed frontal- and sagittal-plane movement but constrained axial rotation.

The knee joint line was measured as the width of the tibial plateau and divided into percentages along its length beginning from the medial margin of the cortex (Fig. 12-1).

Accurate positioning of the load line was determined by a vertical laser beam translating the frontal plane rotation axes of the proximal and distal universal joints (Fig. 12-2). Zero percent varus alignment was defined as an offset of 0% of the width of the tibia plateau from the medial margin. Other axial alignments then tested were at 25%, 50% (neutral axis), 62% (Fujisawa

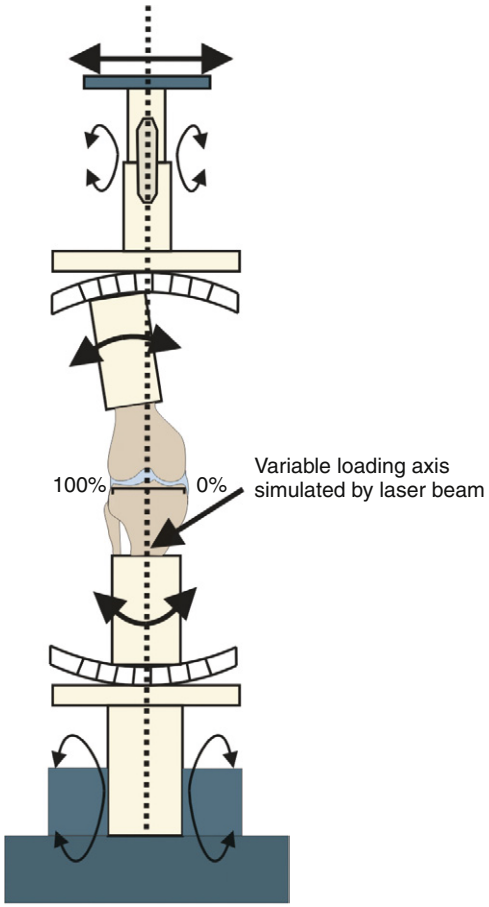

FIGURE 12-1 Axial loading of the cadaveric knee joint using a specially designed fixture in a mechanical testing machine (MTS).

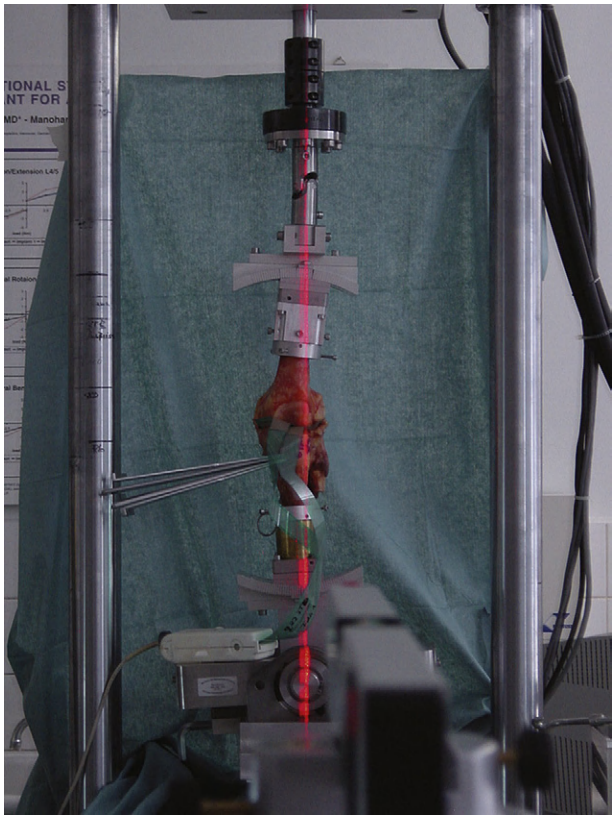

FIGURE 12-2 For simulation of the loading axis, a vertically projected laser beam was used, which allowed the precise visualization of the reproduced loading axis. Opening of the osteotomy was achieved by several flat chisels tapped into the osteotomy gap.

point), and 75%. Subsequently, an intraligamentous opening-wedge HTO was performed in standard technique with medial approach (discussed later). The opening was standardized at 9 mm, the medial collateral ligament initially left intact, and the load axis again adjusted to 62%. Finally, the distal superficial part of the medial collateral ligament bridging the osteotomy was dissected from anterior to posterior in two stages.

The pressure measurements were performed using pressure-sensitive films (K-Scan 4000) and contact force (N), contact area (mm^2), and contact pressure (MPa), as well as the topographical pressure distribution between the medial and lateral tibiofemoral joint were continuously recorded during the load cycle in every testing (Figs. 12-3 through 12-6).

PEARLS

Experimental Design for Cartilage Pressure Measurement

- Custom-made fixture with seven cadaveric human knee joints.
- Standardized loading protocol with maximum load of 1000 N.
- Pressure measurement with Tekscan sensors in the medial and lateral joint compartments.
- Testing of different load axes (varus, neutral, valgus) before the osteotomy.
- Open-wedge tibial head valgus osteotomy.
- Measurement at the Fujisawa point (62%) with intact and two-stage dissection of the medial collateral ligament.

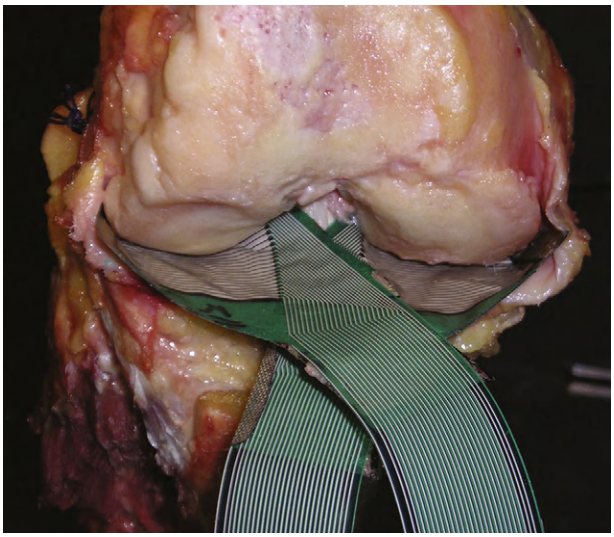

FIGURE 12-3 Pressure-sensitive film (K-scan 4000, Tekscan) comprising two separate measuring fields inserted into the medial and lateral tibiofemoral joint space.

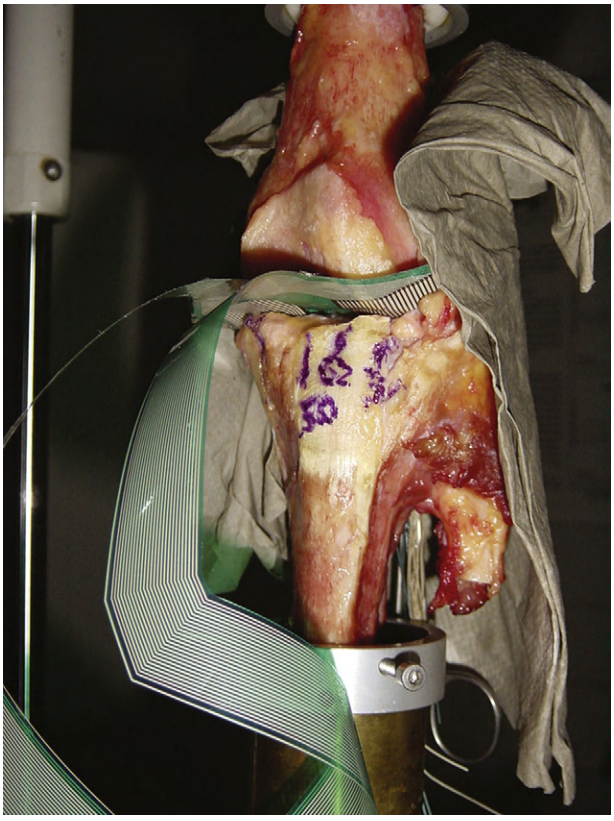

FIGURE 12-4 Several loading axes were simulated: varus (0%), neutral (50%), valgus (62%), and valgus (75%).

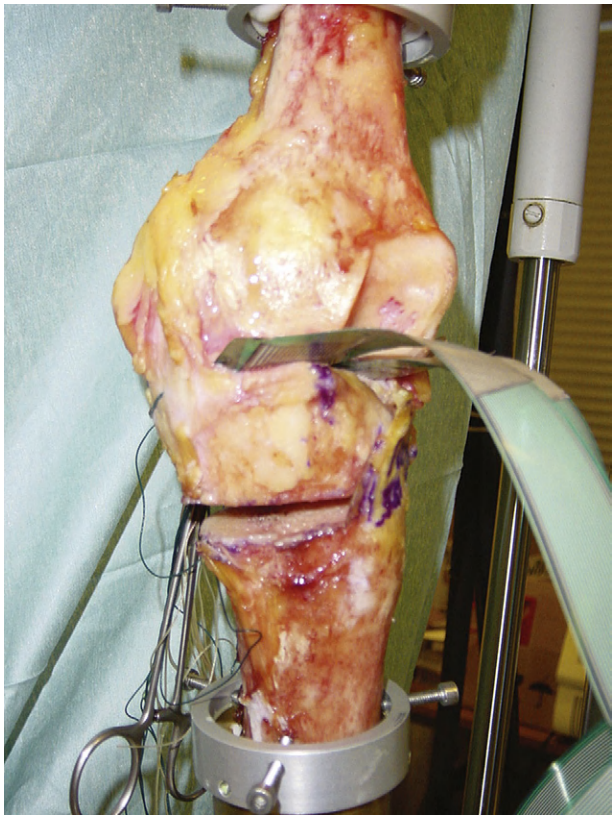

FIGURE 12-5 The valgus osteotomy was performed in an opening wedge technique from medial in a biplanar fashion.

The contact pressure distribution between the medial and lateral joint compartments was shown to be clearly dependent on the different load axes. For varus deformity, about 65% of the total pressure was measured in the medial compartment and 35% in the lateral compartment (Fig. 12-7). The more laterally the load axis was shifted, the lower were the percentages for contact pressure recorded medially and the higher the lateral percentages. Surprisingly, after medial, open-wedge osteotomy with intact medial collateral ligament under a loading of 1000 N the medial percentage of contact force was considerably higher than laterally (71.4% versus 28.6%), although the load axis was in a slightly valgus position at 62% of the width of the tibial plateau. Measurement with the same mechanical loading axis (62%) without osteotomy had produced a reverse and predicted pattern of contact pressure distribution (i.e., medial contact pressure was clearly lower than lateral contact pressure). Thus, the aim of decompressing the cartilage in the medial joint compartment was not achieved by osteotomy, but instead the contact pressure was even slightly increased despite a valgus instead of a varus malalignment (0%). Even without axial loading, a certain amount of contact pressure was measured in the medial compartment with an open HTO and intact medial collateral ligament. Only after step-by-step dissection of the superficial distal portion of the medial collateral ligament was medial contact

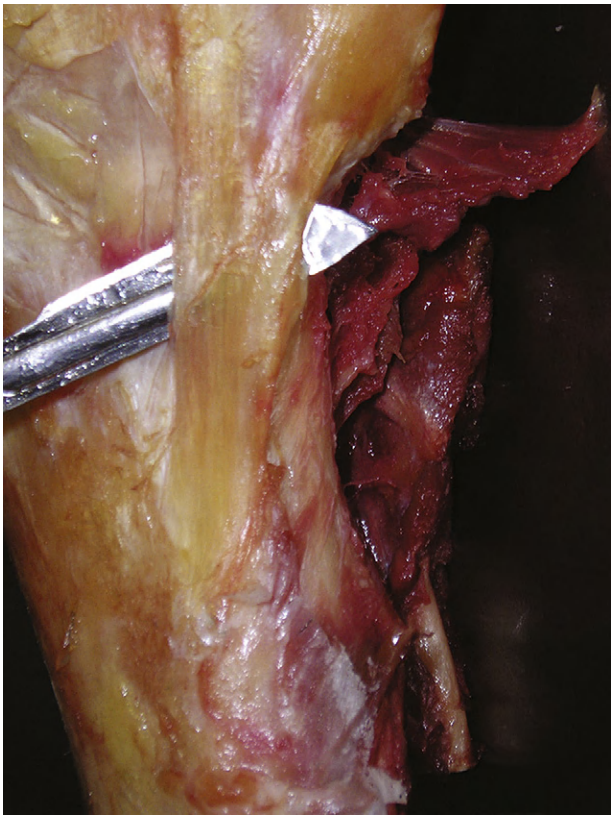

FIGURE 12-6 The fibers of the superficial medial collateral ligament, which run across the osteotomy, have to be released distally from the tibia.

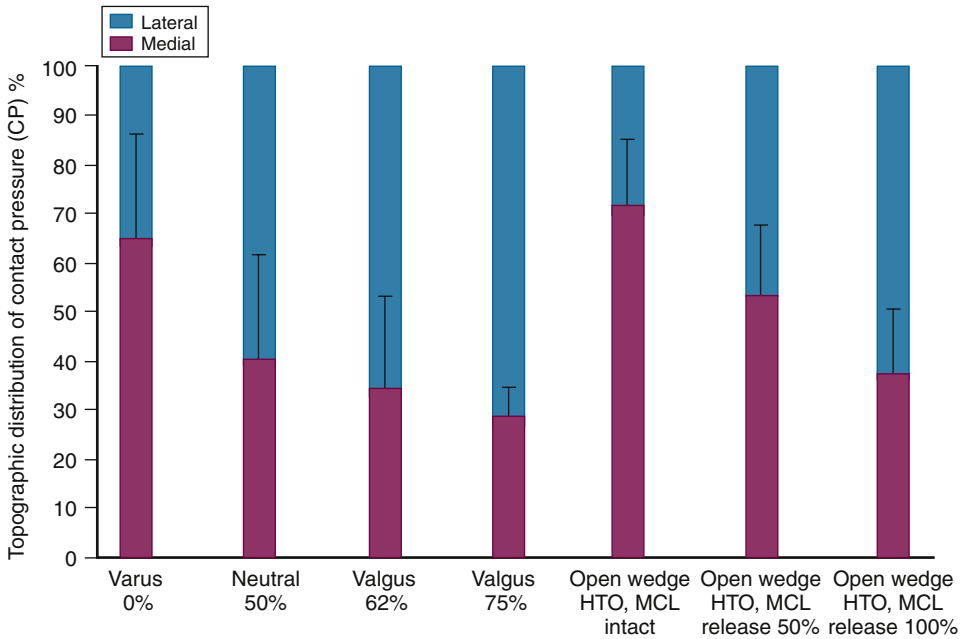

FIGURE 12-7 Topographical pressure distribution in the medial and lateral tibiofemoral joint space after valgus opening wedge osteotomy with intact medial collateral ligament (MCL) and after successive MCL release. Valgus opening wedge osteotomy resulted in a significant increase of the medial contact pressure, which was only decompressed after complete release of the medial collateral ligament (MCL).

pressure reduced and the lateral contact pressure increased, reaching values that were previously recorded in the 62% position without osteotomy (Fig. 12-8). Medial decompression compared to original simulated varus alignment was also achieved.

CLINICAL CONSEQUENCES OF THE STUDY

The results of the biomechanical experiments showed that a redistribution of contact pressure from the medial to the lateral tibiofemoral compartment as intended by a correction osteotomy is possible by shifting the mechanical axis laterally. In cases of medial (or lateral) tibiofemoral cartilage degeneration, an osteotomy is an effective tool to decrease the load in the diseased joint compartment. An efficient medial decompression requires a slight valgus over-correction, as with the use of the Fujisawa point. However, the mechanical axis should not be oriented purely on the basis of "geometric" considerations without taking into account ligament tension. In a valgus high tibial osteotomy the opening-wedge technique from the medial approach, (HTO) will eventually lead to an even greater mechanical loading medially than in the original varus deformity because of excessive over-tension of the medial collateral ligament. Therefore, in this type of osteotomy, a complete release of the distal superficial medial collateral ligament is mandatory to accomplish an effective decompression of the medial joint compartment.

INDICATION FOR HIGH TIBIAL OSTEOTOMY OF THE KNEE

An osteotomy is a biological procedure that aims to shift the peak load areas from the diseased compartment to central or contralateral joint areas. Basically the indication is a moderate monocompartmental arthritis of the knee combined with a malalignment of the leg in the frontal plane in younger patients. Most often varus malalignment results from a constitutional deformity, which is mostly located in the proximal tibia (primary varus). Often in symptomatic patients this primary varus is aggravated by medial meniscus loss or medial cartilage wear (secondary varus).

The patient should not be older than 65 to 70 years although this is not a hard criterion. The patient should not be severely overweight, and the range-of-motion should be at least 0/0/120°. Flexion contracture may be accepted if a saggital correction of the tibial slope is included in the surgical plan. Open-wedge osteotomy should not be used if leg lengthening is contraindicated and if the medial soft tissue coverage is compromised. Patella pain is not a contraindication; however, in cases with patella baja, a special type of osteotomy described later should be used. An intact lateral compartment of

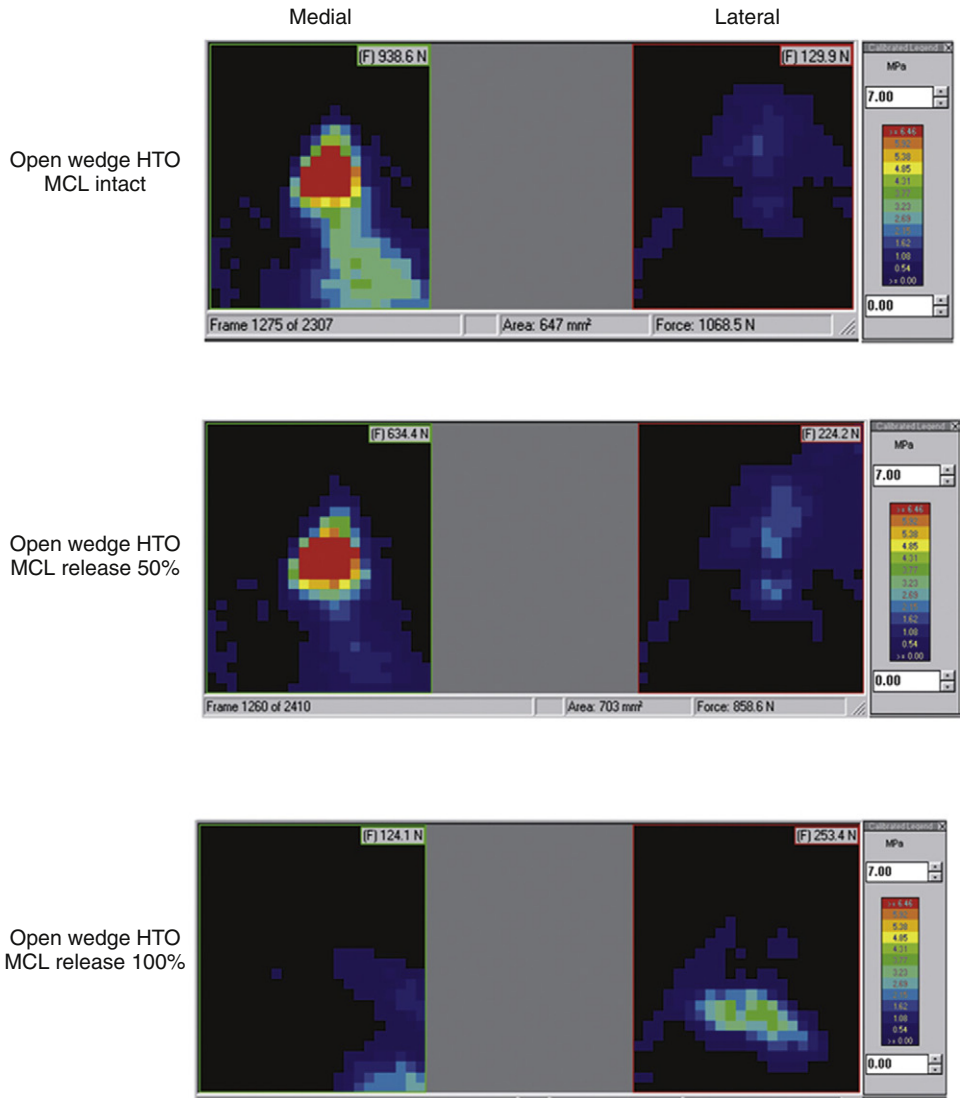

FIGURE 12-8 Mechanical load on the cartilage after open-wedge osteotomy (left field: medial; right field: lateral): for opening-wedge osteotomy and intact medial collateral ligament despite valgus axis (62%) significant mechanical loading in the medial compartment with contact pressure peak in the middle of the tibial plateau. After complete release of the medial collateral ligament, there is a substantial reduction in contact pressure medially and contact pressure increases laterally.

the knee is an obligatory prerequisite for this technique. The patient should not have lateral joint line pain, and no radiographic signs of lateral osteoarthritis should be present.

TYPE OF DEFORMITY AND PREOPERATIVE PLANNING

One of the most important factors for the success of an osteotomy is the preoperative analysis of the deformity and the planning of the correction. This means that the location and the amount of the malalignment have to be

investigated in a bipodal standing long leg x-ray. According to the recommendations of Paley,[17] the respective angles between the mechanical axes of the femur and tibia and the joint line (mechanical medial proximal tibial angle mMPTA and mechanical lateral distal femoral angle [mLDFA]) have to be measured. A varus deformity in the tibia means that the mMPTA is less than 87 degrees; a valgus in the distal femur by definition is a result of an mLDFA less than 87 degrees.

Ideally a correction osteotomy is carried out at or at least close to the area where the deformity is located (i.e. for a varus deformity the ideal location for the correction is located in the proximal tibia).

PEARLS

Selection Criteria for Clinical Indication of High Tibial Osteotomy

- Patient age: ideally under 65 years
- Stage and localization of osteoarthritis: monocompartimental moderate cartilage damage
- Ligamentous status: osteotomy can improve ligament insufficiency (tibial slope alteration)
- Type of deformity: best if performed at level the of deformity (e.g., HTO in tibia vara)

OPERATIVE TECHNIQUE

The principles of deformity correction as formulated by Paley[17] should be generally respected.

Most of the HTO techniques described in the literature are lateral based closing wedge osteotomies. Mostly they require either a fibula osteotomy or a release of the proximal tibia-fibular joint. Osteosynthesis is performed on the lateral side of the tibia. Large corrections cause shortening of the leg and often a large offset of the proximal tibia, which may compromise later placement of the tibial component of a total knee replacement. Furthermore, two saw cuts are needed and only frontal plane malalignment can be corrected. The required exposure on the lateral side, including release of the extensor musculature, has the risk of damage to the peroneal nerve.

Medial open wedge HTO techniques, on the other hand, avoid muscle detachment, peroneal nerve dissection, leg shortening, and fibula osteotomy. They only require one saw cut, and corrections in the frontal plane can be combined with corrections in the sagittal plane.

For this reason, the authors' preferred method of valgus osteotomy of the proximal tibia is the medial opening wedge technique (Fig. 12-9, *A-C*).

An oblique osteotomy level related to the knee joint base line should be achieved. This means that the starting point medially should be slightly above the pes anserinus and run obliquely upward to the lateral side aiming for the upper third of the proximal tibiofibular joint.

This has the advantage of avoiding a medial cortical offset, which would necessarily occur in cases of an osteotomy parallel to the knee base line.

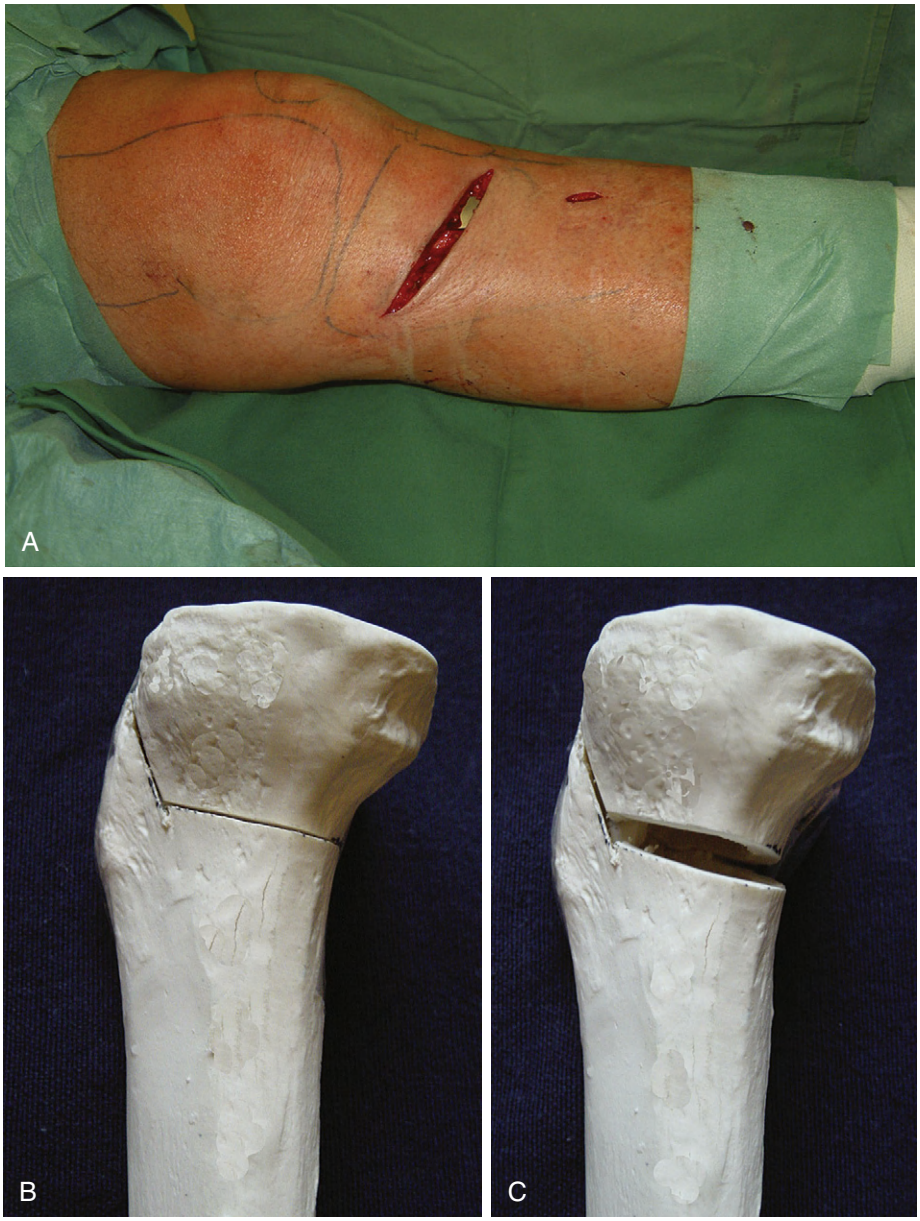

FIGURE 12-9 Operative technique for medial opening wedge valgus high tibial osteotomy. **A,** A transverse skin incision is made at the medial side of the proximal tibia. **B,** The osteotomy is made in a biplanar fashion and, **C,** opened medially, maintaining direct bony contact in the anterior bone surfaces behind the tibial tuberosity.

However, only the posterior two thirds (in posterior-anterior [pa] direction) of the tibial head should be intersected transversely with the anterior third including the region of the tibial tuberosity initially left intact. This is because a second osteotomy in the coronal plane angled approximately 100° related to the first and directed upward underneath the tibial tuberosity should be performed, thus creating a biplanar osteotomy. Essentially this modification has two advantages: first, interference of the transverse osteotomy with the insertion of the patellar tendon at the tibial tuberosity, which in many cases would occur, is excluded; more important, this biplanar arrangement

provides additional rotational stability and an anterior restraint against the extension force created by the quadriceps tendon. Moreover, instability in the sagittal plane created by the long lever arm of the distal tibia, which is probably only insufficiently excluded by any osteosynthesis, is minimized.

For quick and safe bone healing of the osteotomy, as much "bone biology" as possible needs to be maintained at the surface areas of the osteotomy. The bone cutting should be performed with an oscillating saw using K-wires placed under fluoroscopy as guides. Continuous cold irrigation and a careful and slow sawing technique should be applied to allow the bone to preserve as much of its potential healing factors as possible.

After completion of the biplanar osteotomy leaving about 10 mm of the lateral bone intact, which serve as a hinge for opening of the wedge, the tibia is gradually opened medially. The opening should be performed little by little over several minutes, and care should be applied not to overstress this elastic lateral deformation. In our experience, this can best be achieved by subsequently inserting several adjacent flat osteotomes into the tibial head. One chisel after the other is carefully tapped into the osteotomy gap under fluoroscopic control, thus slowly spreading the medial gap open. Even larger corrections can be accomplished without damage to the lateral bone bridge using this careful technique. Another advantage is that medially at the site of the opening the integrity of the cortical edges of the osteotomy is preserved, which is important because the implant for osteosynthesis is placed here.

Sagittal tibial anatomy, namely the posterior tibial slope, has been shown to be an important factor influencing the amount of knee extension and stability in the sagittal plane. If with the osteotomy the tibial slope is increased, hyperextension in patients with genu recurvatum can be corrected. Furthermore, a growth in posterior tibial slope has been shown as cause for increased anterior tibial translation, which is unfavorable in chronic (anterior) knee instability. The mentioned effect may be desired in cases of posterior knee instability because overextension bothering these patients is minimized and posterior tibial drawer is antagonized.

Sagittal tibial anatomy has to be carefully assessed in the opening-wedge technique. Preoperatively, the slope should be measured in the lateral x-ray and determined if with the osteotomy the present slope should be maintained or a correction (increase or decrease) should be performed.

The medial collateral ligament running across the osteotomy (discussed earlier) has to be released distally from the tibia to avoid ligament related overcompression in the medial compartment after opening of the wedge. An adjustable spreader is used in the posterior part of the osteotomy to keep the gap open. The spreader can be inserted as desired anteriorly or posteriorly in the osteotomy gap and the tibial slope thus directly be accustomed, which can additionally be monitored on the fluoroscope.

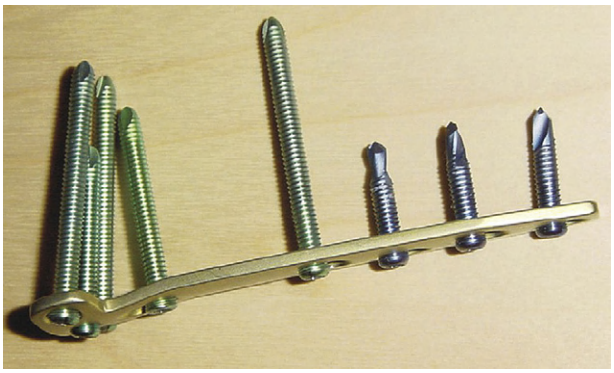

FIGURE 12-10 Rigid plate fixator for medial opening wedge osteotomy of the tibia (TomoFix). The system is anatomically precontoured to the medial proximal tibia and equipped with 4.5-mm locking bolts.

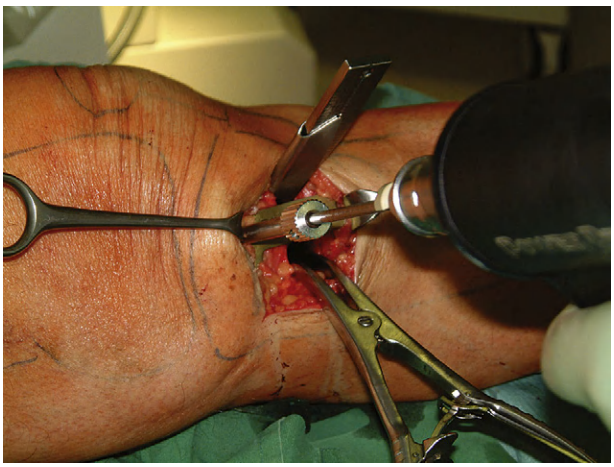

FIGURE 12-11 Percutaneous application of the plate fixator to the tibia.

Stability of the osteosynthesis after high tibial osteotomy is crucial for the outcome. It is not only important for quick and functional postoperative rehabilitation with immediate postoperative partial weight bearing but for safe healing of the osteotomy without any loss of the performed correction. Spacer plates designed by Puddu can be used to keep the osteotomy open and serve as osteosynthesis. However, they offer only minimal stability in cases of larger corrections as they cannot adequately eliminate the tremendous lever arm forces created by the quadriceps and the distal tibia. Probably this is why the authors and others have seen implant failures and nonunions in some (especially tall or obese) patients where the spacer implants were used. Therefore, in cases of larger openings (>10 mm), in tall or obese patients or in patients with minor bone stock quality, another more stable implant should be used for osteosynthesis. TomoFix (Synthes, West Chester, Pa.) is a specially designed rigid plate that serves as an internal plate fixator (Figs. 12-10 through 12-12, *A-E*). Angle-stabilized locking bolts, which can be positioned percutaneously, completely eliminate wobbling of the bolts within the plate, thus largely enhancing the stability of the osteosynthesis. In the case of fractures of the lateral cortex, which frequently occur in openings of more than

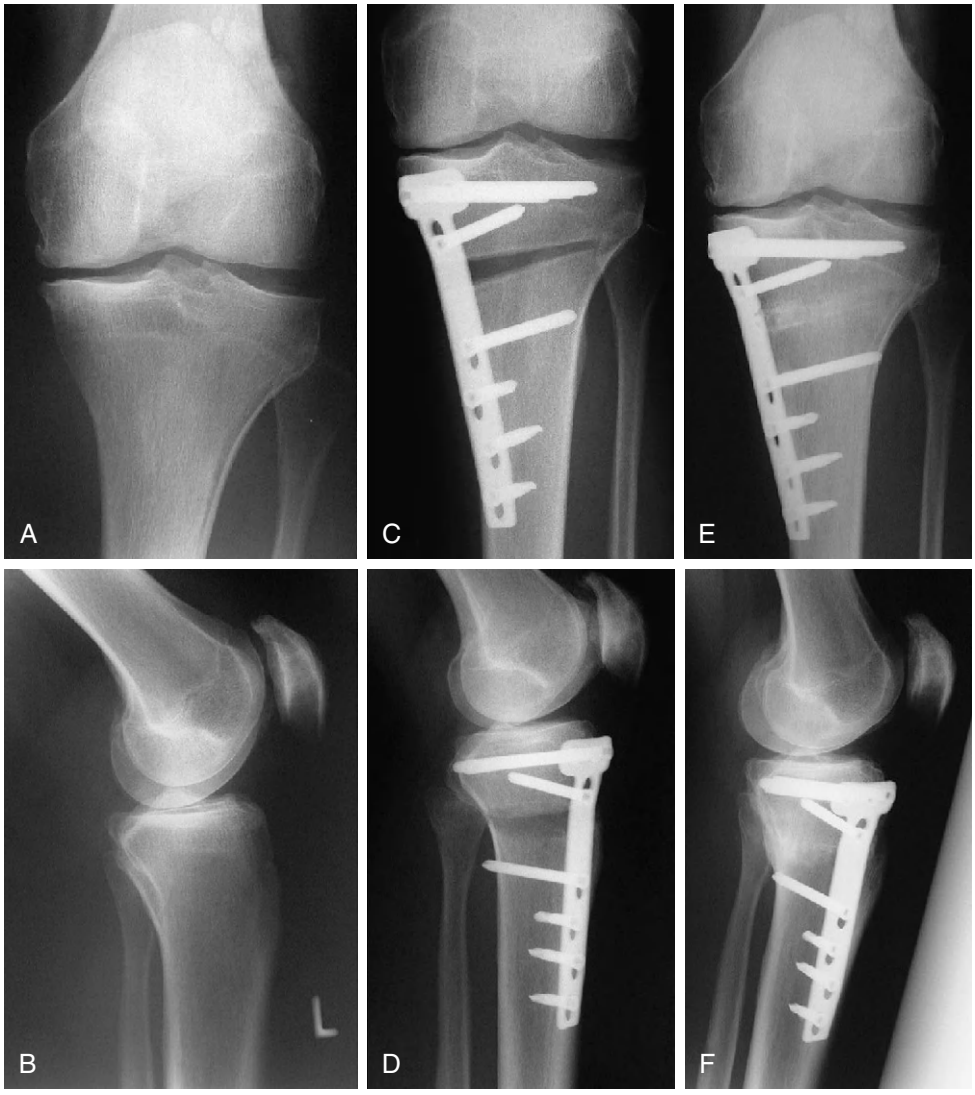

FIGURE 12-12 Preoperative (**A** and **B**), direct postoperative (**C** and **D**), and postoperative after 1 year (**E** and **F**) radiographs of a valgus opening wedge osteotomy of 9 mm showing the plate TomoFix fixator and the bony healing in the wedge.

12 mm, a lag screw can be applied. This screw is inserted in the first plate hole distal to the osteotomy, and after fixation of the plate it is proximally advanced in a posterolateral direction. By doing so, reapproximation of the lateral cortical edges of the osteotomy can be achieved. Altogether nine locking bolts are used with the TomoFix device, with three bolts proximal and four distal to the osteotomy.

PEARLS

Operative Technique of Valgus High Tibial Osteotomy (HTO)

- Medial opening wedge technique
- Release of distal part of superficial medial collateral ligament
- Oblique osteotomy level
- Biplanar osteotomy
- Control of tibial slope
- Preservation of lateral hinge of the osteotomy
- Osteosynthesis with plate fixator (TomoFix)

CONCLUSION

Osteotomy around the knee is an established procedure, which has been proven to provide significant improvement of joint function and pain level for 10 to 20 years, especially in younger patients and those with moderate cartilage degeneration. Decompression of diseased cartilage areas in cases of frontal place malalignment allows the patients to safely load and use their legs and knees and even perform sports activities and strenuous labor.

In patients with cartilage replacement procedures and a frontal plane deformity, an osteotomy eliminates hyper compression of the regenerated cartilage areas, avoiding the risk of early failure of these procedures.

ACKNOWLEDGMENTS

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CHAPTER 13

Unloading the Patellofemoral Joint for Cartilage Lesions

James Bicos

INTRODUCTION

Successful outcomes in patellofemoral cartilage restoration procedures rest on the need to unload the patellofemoral joint. Initial patellofemoral cartilaginous procedures were predisposed to failure because of overload of the patellofemoral compartment or failure to address patellar malalignment. Malalignment is defined as abnormal tilt and or subluxation of the patella,[1] and distal realignment (i.e., tibial tubercle osteotomy) is the most definitive method of either realigning a subluxated/tilted patella or offloading the patellofemoral compartment.

Anteromedialization of the tibial tubercle addresses patellar malalignment, patellar arthritis, or is used in conjunction with cartilage restoration procedures. The original technique, as described by Dr. Fulkerson in 1983,[2] has been shown in long-term studies to provide long-term relief from instability and patellofemoral pain.[3] The idea behind the osteotomy is to alleviate stress from the distal and lateral portions of the patella and trochlea to the proximal and medial patellar articular cartilage.[2,4-7] By changing the angle of the osteotomy cut, one can customize the procedure to include more medialization for instability cases or more anteriorization for cartilaginous unloading guidelines. Typically, in most procedures done for cartilage restoration, there is some evidence of patellar malalignment, so a combination of both medialization and anteriorization is chosen.

INDICATIONS/CONTRAINDICATIONS

Indications for anteromedialization of the tibial tubercle include patellofemoral pain with either lateral or distal patellar arthrosis or lateral subluxation/dislocation of the patella. Other indications include a failed lateral release[8]

and cartilage restoration procedures that need offloading of the newly regenerated or implanted cartilage cells. The ideal candidate is a patient with lateral patellar tilt (or subluxation) with grade III or IV articular cartilage degeneration localized to the lateral patellar or distal medial patellar facets. Not only should the patient be deemed psychologically mature to undergo the surgical procedure, but he or she should also have failed a course nonoperative management consisting of patellar taping, lateral retinacular mobilization, stretching of the extensor mechanism, bracing, and nonsteroidal anti-inflammatory medication.[1,2,7]

Contraindications to the procedure include no malalignment (except in unloading the patellofemoral joint in cartilage procedures), diffuse patellar articular cartilage disease, occult medial subluxation, tilt with no subluxation, mild articular cartilage changes (i.e., grade I or grade II) that would be best treated with an isolated lateral retinacular release, rheumatoid arthritis, bleeding disorders, a history of deep venous thrombosis, and complex regional pain syndrome. Proper patient selection is also important to the success of the procedure, and obesity was found to be the leading cause of tibial metaphyseal fractures or stress fractures in the postoperative period.

The benefits of the osteotomy include a long, flat, oblique cut that maximizes surface area to promote bony healing and allow screw fixation; the angle of the osteotomy cut can be adjusted to allow for more medialization or anteriorization, depending on the goals of the surgery; and the distal taper of the osteotomy minimizes the risk to the tibial metaphyseal bone and decreases the risk of iatrogenic fracture.

PREOPERATIVE PLANNING

Physical Examination

A complete review of the physical examination of the patellofemoral joint is beyond the scope of this chapter, but we will review the pertinent examination points. The exam should begin with a gait evaluation and hip range of motion to assess for increased femoral anteversion, in-toeing, or pes planus that can all predispose the patient to a relative genu valgum of the lower extremity and lead to patellar tilt or subluxation. Increased mobility of the joints is also assessed (elbow, thumb, etc.) because it may predispose the patient to early failure if a soft-tissue only technique is used for patellar stabilization. The skin should also be evaluated for changes associated with complex regional pain syndrome or previous incisions that would alter the standard approach to the tibial tubercle osteotomy. Muscle atrophy should also be assessed as a sign of nerve damage or the need for preoperative physical therapy for strengthening.

Specific tests for the evaluation of the patellofemoral joint include noting patellofemoral crepitance, joint effusion, lower extremity Q-angle, patellar

J-sign, lateral retinacular tightness, patellar quadrant mobility, patellar apprehension test, patellar grind test, and stability/pain relief with a lateral to medial force on the patella (i.e., you are simulating holding the patella in an unloaded/reduced position).

Imaging Studies

Imaging studies should start with a complete set of knee x-rays consisting of bilateral anterior-posterior (AP) standing views, bilateral posterior-anterior (PA) 45 degrees flexed views, a lateral view with the knee in 30 degrees of knee flexion, and a Merchant view.[9]

The Merchant view is needed rather than the skyline view because as the knee is hyperflexed in the skyline view, the patella is captured by the bony anatomy of the trochlea, and subtle variations of patellar tilt or subluxation are lost at knee angles greater than 30 degrees.[1]

The Merchant view allows the evaluation of patellar tilt (patellofemoral angle of Laurin),[10] trochlear dysplasia, and patellar subluxation (congruence angle)[9] (Fig. 13-1, *A–C*). The lateral view allows the evaluation of patellar joint space, trochlear dysplasia, patellar alta/baja, and patellar tilt (Fig. 13-2, *A–B*). One can also use MRI or CT scans to measure similar angles of patellar subluxation and tilt.[3,11-16]

Another important measurement for malalignment of the extensor mechanism is the tibial tubercle-trochlear groove (TT-TG) measurement (Fig. 13-3). This relates how far lateral the tibial tubercle is in relation to the central portion of the trochlea.[17] Normal TT-TG values are less than 10 mm, and grossly abnormal values are between 18 to 20 mm. The TT-TG can be easily measured on CT or MRI scans and should be thought of as a guide as to how far to move the tubercle during the osteotomy procedure. The final amount of anteromedialization is based on the intraoperative assessment of patellar stability.

SURGICAL TECHNIQUE

Holding Area

The patient is identified in the surgical holding area and the correct knee is identified according to the "Sign Your Site" protocol. The patient is given preoperative antibiotics and an exam is carried out showing the patient again the stability of the patella once the realignment is completed.

Any pain blocks can be done at this time by the anesthesia service, although in order to monitor for postoperative function and the possibility of a postoperative compartment syndrome, we do not routinely use nerve blocks for this operation.

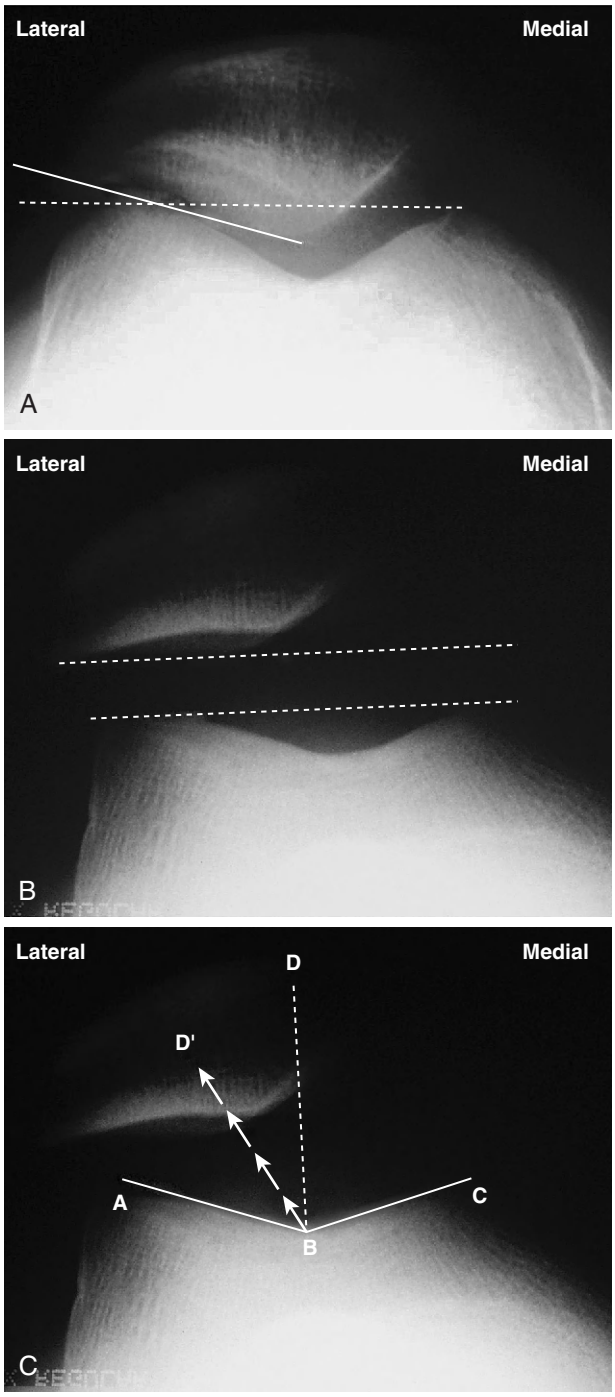

FIGURE 13-1 Measuring tilt and subluxation. **A,** Normal patellofemoral angle of Laurin. Used to measure patellar tilt. The solid line along the lateral patellar facet should open laterally when referenced to the dotted line along the medial and lateral trochlear ridges. **B,** Abnormal patellofemoral angle of Laurin. Both of the lines are parallel to each other and thus are consistent with lateral patellar tilt. **C,** Abnormal congruence angle. Used to measure patellar subluxation. Line AB is along the lateral trochlea, and line CB is along the medial trochlea. Line BD is drawn as the bisector of the trochlear groove angle. Finally, line BD′ is drawn from the central trochlea to the central ridge of the patella. Line BD′ should be equal or medial to the bisector line BD. If it is lateral (as in this case), patellar subluxation can be confirmed. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17. issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 225. Copyright 2007, with permission from Elsevier.)

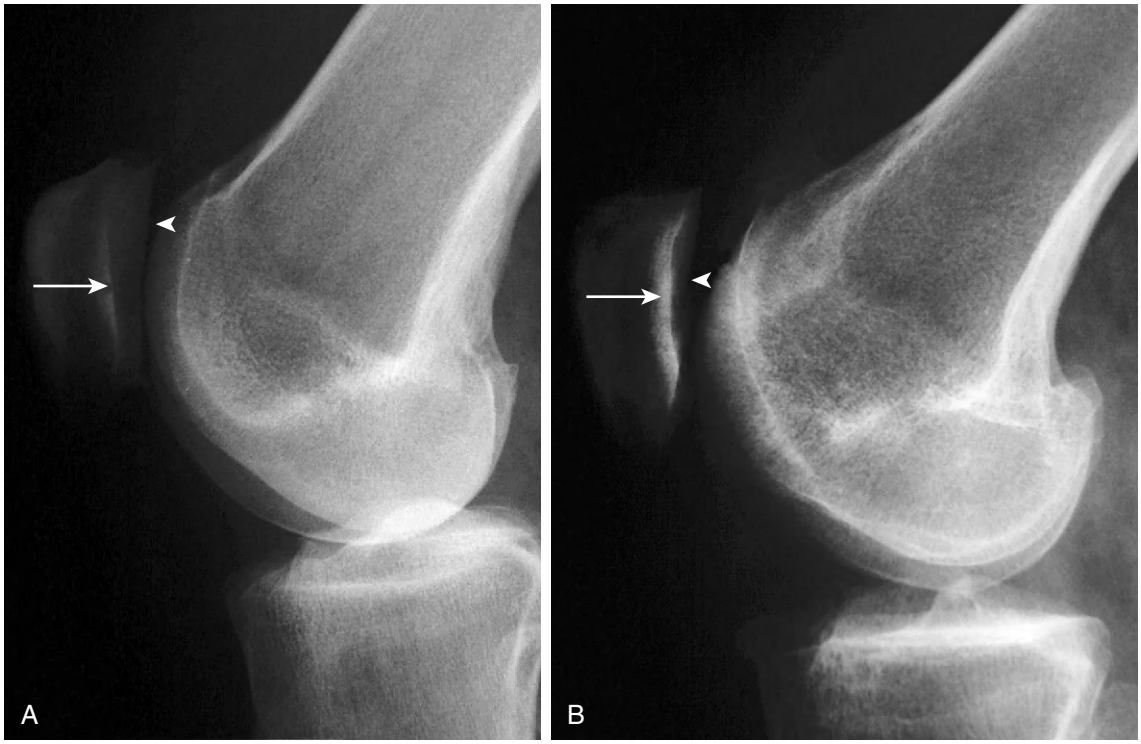

FIGURE 13-2 Lateral x-ray images showing a normal knee **(A)** and a knee with lateral tilt **(B). A,** Arrowhead showing the central patellar ridge, which should not overlap with the medial and lateral patellar facets (arrow line), in a normal knee without patellar tilt. **B,** Arrowhead showing near superimposition of the central patellar ridge on the lateral patellar facet, in a knee with patellar tilt. Note that the posterior femoral condyles should be superimposed for proper measurements of patellar tilt on the lateral x-ray view. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 224. Copyright 2007, with permission from Elsevier.)

Patient Positioning

The patient is brought back to the operating room and placed supine on the operating room table.

After the anesthesia service has secured an airway, a Foley catheter is placed in the standard fashion. The patient is kept supine during the procedure, and a small bump is placed under the ipsilateral hip to avoid the obligate external rotation that occurs in the lower extremity when the patient falls asleep. An exam under anesthesia is documented, looking specifically for knee effusion, passive range of motion, patellar tracking, patellar tilt, and the amount of lateral or medial patellar subluxation.

For the arthroscopy portion of the procedure, we use a lateral post.

A tourniquet is placed at the upper thigh area, and the lower extremity is prepped and draped in the standard fashion. To avoid capturing the quadriceps with tourniquet inflation and thus altering the normal patellar tracking, the knee is hyperflexed for tourniquet inflation.

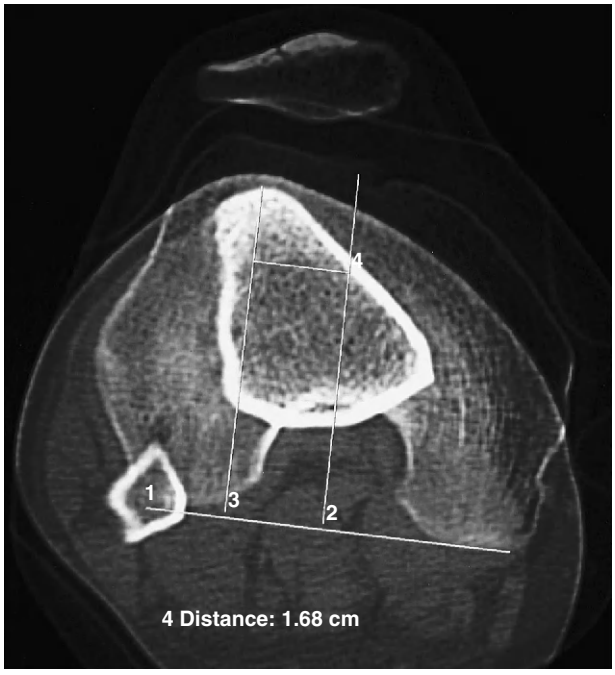

FIGURE 13-3 Tibial tubercle-trochlear groove measurement (TT-TG). A CT scan was obtained and an image through the tibial tubercle was superimposed on an image through the femur. Line 1 is parallel to the posterior femoral condyles. Line 2 is through the highest point of the tibial tubercle and perpendicular to line 1. Line 3 is through the nadir of the trochlear groove and also perpendicular to line 1. The distance between lines 2 and 3 is the TT-TG (labeled as line 4). It equals 1.68 cm, which is on the limits of being abnormal. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 226. Copyright 2007, with permission from Elsevier.)

Arthroscopy

A thorough arthroscopy is performed documenting any cartilaginous defects of the patella or trochlea. One should be acutely aware of defects of the medial or proximal patellar facet or medial trochlea, because this would be a contraindication for the anteromedialization procedure.

Patellar tilt and subluxation should be documented early in knee flexion (i.e., <15–20 degrees) because at greater knee flexion angles the patella is constrained by the trochlear bony anatomy, thus obscuring the patellar tilt and subluxation (Fig. 13-4, *A*). The other knee compartments are visualized, and any other concomitant arthroscopic surgery is performed at this time (Fig. 13-4, *B*).

Incision/Superficial Dissection

The arthroscope is removed but still kept sterile on the field in order to assess the postanteromedialization tibial tracking.

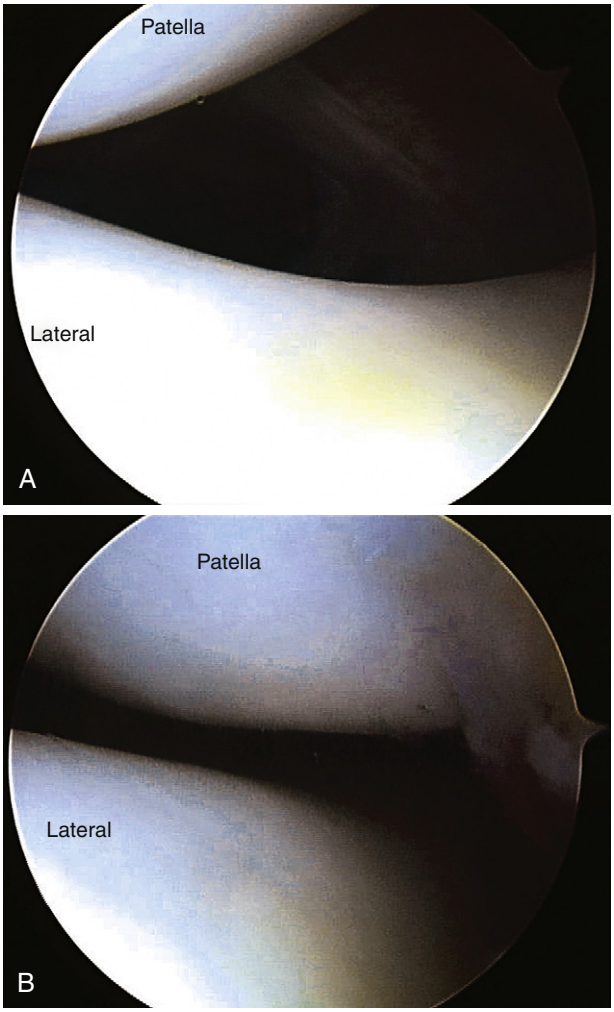

FIGURE 13-4 A, View of patellofemoral joint arthroscopically before tibial tubercle transfer. Note the severe lateral patellar tilt and subluxation. **B,** View of patellofemoral joint after tibial tubercle transfer with anatomic alignment of the patella on the trochlea. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 226. Copyright 2007, with permission from Elsevier.)

An 8 to 10 cm incision is made incorporating the inferolateral arthroscopy portal proximally and distally extending toward the tibial tubercle. The incision is kept just lateral to the anterior tibial crest to avoid having the incision over the subcutaneous bony skin. In addition, the line of the incision avoids placement of the hardware (tibial fixation screws) directly underneath the skin incision itself (Fig. 13-5). The incision is deepened down to the level of the patellar paratenon and just above the periosteum of the anteromedial tibia.

The medial and lateral borders of the patella are identified, in addition to the tibial tubercle and the anterior tibial muscular compartment.

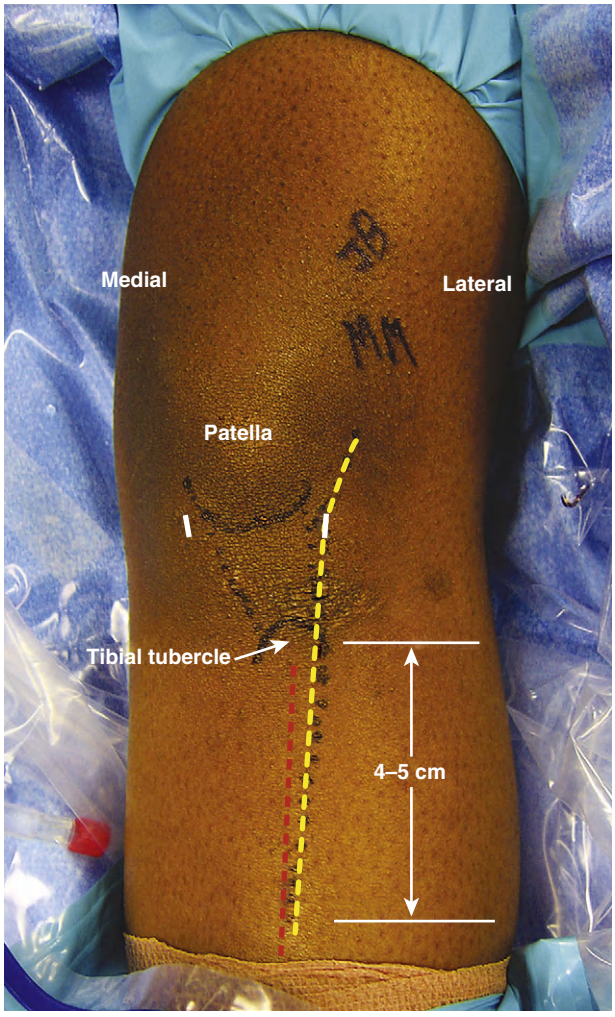

FIGURE 13-5 View of proposed incision. Note the initials on the knee according to the "Sign Your Site" protocol. The white lines show the arthroscopic portals. The red dotted line shows the tibial crest. The yellow dashed line shows the proposed incision. The incision incorporates the lateral arthroscopic portal and stays just lateral to the tibial crest.

Lateral Release

A subcutaneous skin dissection is made along the lateral retinaculum to the superior border of the patella. Using electrocautery, a lateral retinacular release is performed, taking great care to avoid injury to the cartilage at the lateral trochlea.

The proximal extent of the release is up to but not through the vastus lateralis tendon. Inadvertent sectioning of the vastus lateralis tendon could lead to occult medial instability.

The edges of the lateral release are cauterized to avoid a postoperative hematoma. Distally, the release is taken down to the level of the tibial tubercle, staying lateral to the patellar tendon (Fig. 13-6).

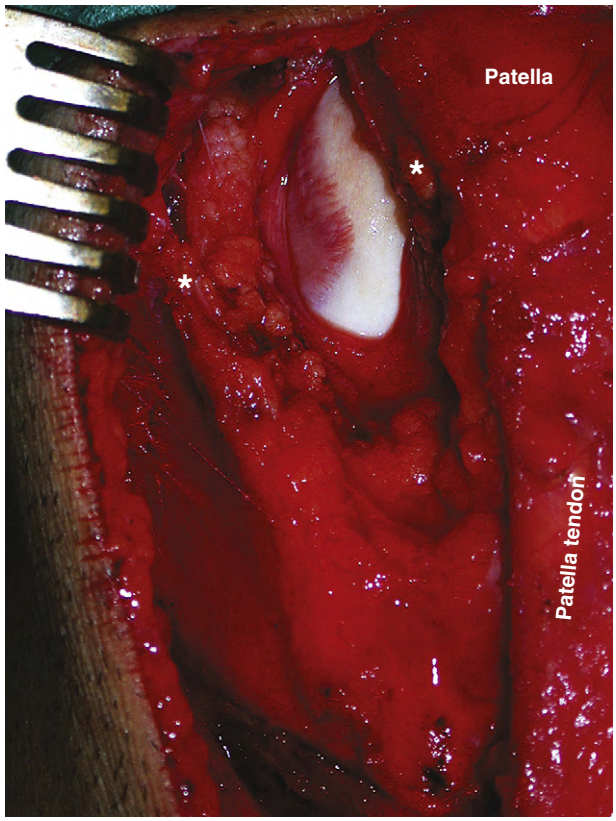

FIGURE 13-6 Open lateral retinacular release. Asterisk marks the lateral retinaculum that has been cut as part of the release. Note that this picture is of a right knee. The other pictures in the labeled figures show a left knee. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 227. Copyright 2007, with permission from Elsevier.)

Deep Dissection

The medial border of the patellar tendon is identified at the level of the tibial tubercle, and a hemostat is placed behind the patellar tendon. This ensures that the tendon has been freed from the proximal tibia but is still attached to the tibial tubercle (Fig. 13-7). Occasionally there is scar tissue tethering the distal pole of the patella to the fat pad. This should be released, as it could potentially prevent the proper anteromedialization of the patella.

The anterior tibial muscular compartment is subperiosteally taken off of the lateral border of the tibia using electrocautery, leaving a small cuff of the fascia of the muscular compartment still attached to the tibial crest for later reattachment of the muscle.

The anterior tibial muscle is taken proximally off of Gerdy's tubercle, and distally it is extended for approximately 4 cm past the tibial tubercle (i.e., enough to fit the osteotomy guide in place).

Posteriorly, the muscle is freed down to the posterolateral tibial border and a special retractor (Tracker AMZ Guide System [TRACKER System] Depuy

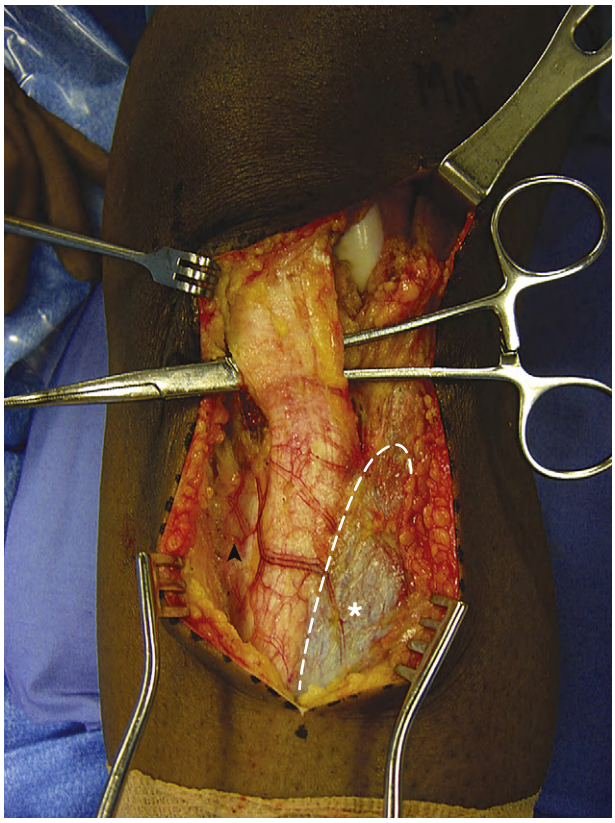

FIGURE 13-7 The medial and lateral borders of the patella have been identified and a hemostat has been placed behind the patellar tendon for retraction purposes. The asterisk marks the anterior muscular compartment. The arrowhead marks the anteromedial tibia. The dotted line marks where the anterior musculature is taken off of the tibial crest.

Mitek, Norwood, Mass.) is used to hold the anterior tibial muscle out of the way (Fig. 13-8).

One must be able to see the posteromedial tibial border in order to avoid the inadvertent extension of the osteotomy through the posterior tibial cortex.

The medial border of the patellar tendon attachment onto the tibial tubercle is identified, and starting 2 cm medial from the tibial tubercle crest, a mark is made in the anteromedial tibial periosteum and angled distally and laterally toward the anterior tibial crest.

The osteotomy cut is not only an oblique cut when looking at the tibia in the axial plane, but it also tapers distally toward the tibial crest in the coronal plane (Fig. 13-8).

Osteotomy

The preferred instrument system, the TRACKER System, was developed by Dr. Jack Farr and is a simple, reproducible way of performing the osteotomy.

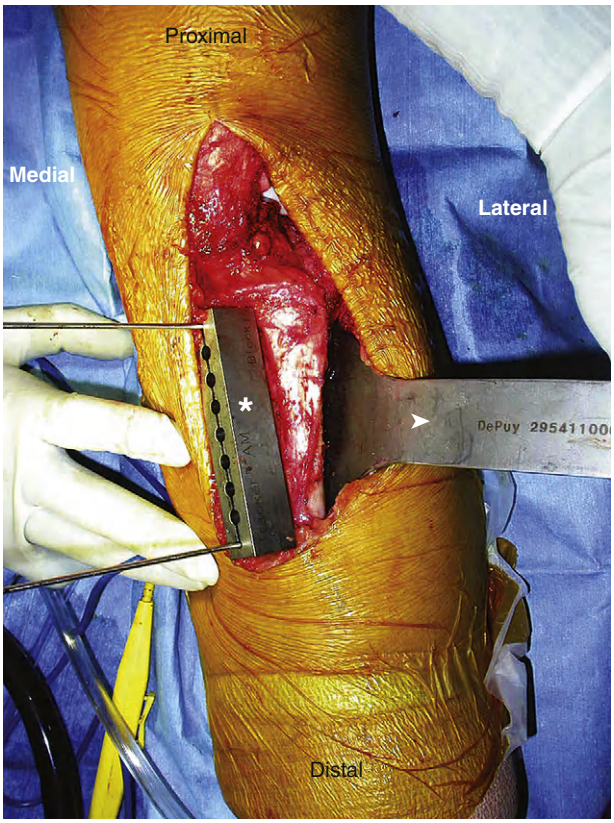

FIGURE 13-8 The patellar tendon has been skeletonized. The anterior tibial muscular compartment has been taken off of the tibial crest and a wide retractor from the Tracker AMZ Guide System (TRACKER System) set (white arrowhead) is retracting the muscle. The cutting block (asterisk) is positioned on the anteromedial tibia. Note how it is tapered from proximal to distal. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 227. Copyright 2007, with permission from Elsevier.)

The TRACKER System cutting block is fashioned on the anteromedial tibial cortex along the line marked on the periosteum. The cutting block should taper from proximal to distal (Fig. 13-8).

The TRACKER System tracker guide is then inserted into the second or third drill hole from the top of the TRACKER System cutting block. The tracker guide helps one to visualize where the osteotomy will exit along the posterolateral tibia (Fig. 13-9). It is imperative that the osteotomy not exit the posterior tibial cortex.

The angle of the osteotomy cut is now chosen. As previously stated, the steeper the cut, the more anteriorization you will have. Usually the goal is to have the osteotomy exit just anterior to the posterior lateral cortical surface, just before the flare of the metaphysis (Fig. 13-10).

The cutting block is held using two pins that are predrilled. The distal pin should just skirt the anterior tibial cortex to allow for the distal taper of the osteotomy.

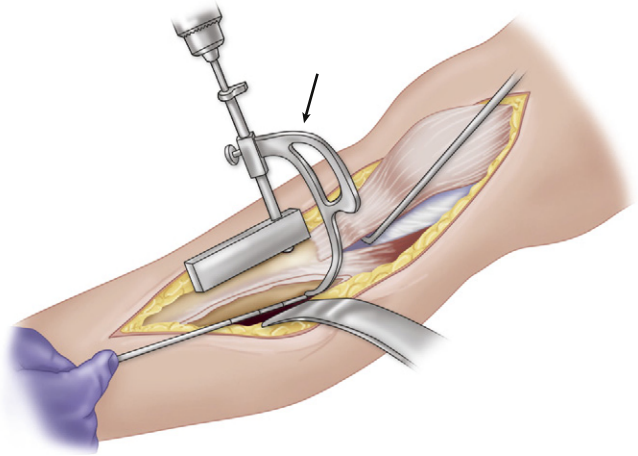

FIGURE 13-9 AMZ Tracker guide is shown positioned in the tibial cutting block (black arrow). The arm of the guide shows where the osteotomy will exit posterolaterally. Using the Tracker guide allows the surgeon to correctly place the slope of the osteotomy. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 227. Copyright 2007, with permission from Elsevier.)

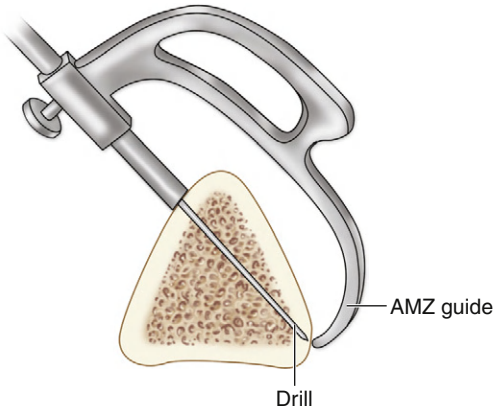

FIGURE 13-10 The proximal tibia in cross section looks like a triangle. The picture depicts the AMX Tracker guide starting on the anteromedial tibia and exiting the posterolateral tibia. Note that if the angle of the osteotomy is too steep, it will emerge through the posterior tibia and predispose the patient to a tibial shaft fracture.

A sagittal saw is used to begin the osteotomy cut (Fig. 13-11). The osteotomy is started anteromedially on the tibial cortex, and it exits posterolaterally. As the osteotomy nears the proximal lateral junction between the tibial diaphysis and metaphysis (i.e., metaphyseal flare), care should be taken to avoid penetration of the posterior tibial cortex.

At this area (i.e., under the tibial tubercle), the saw blade cut should be entirely within the bone. The lateral extent of the cut at this proximal location should be just lateral to the tibial tubercle. Distally, the last 1 to 2 mm of tibial crest bone is left intact (hinging on the periosteum) to create a hinge on which to rotate the osteotomy.

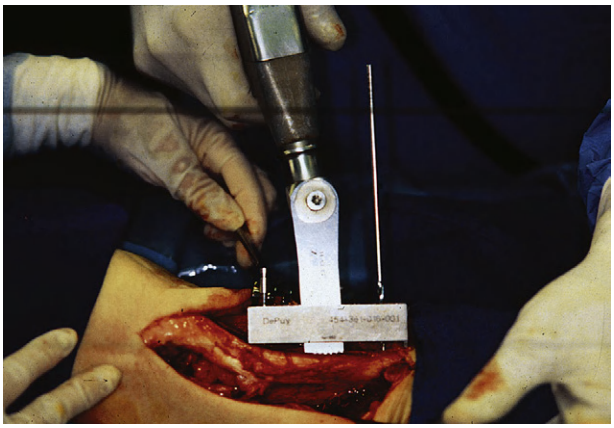

FIGURE 13-11 With the cutting block held in place, a sagittal saw is used to begin the osteotomy cut. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 228. Copyright 2007, with permission from Elsevier.)

The cutting block is now removed and the anteromedial tibial crest cut is carried more proximally with the saw to clear the medial attachment of the patellar tendon on the tibial tubercle. A 1-inch osteotome is used to make a back cut, starting from the most proximal location of the posterolateral tibial cut (i.e., at the metaphyseal/diaphyseal flare) proximally and anteriorly to just above the patellar tendon attachment on the lateral tibial tubercle (Fig. 13-12). A half-inch osteotome is used to make the back cut underneath the patellar tendon from lateral to medial. This should be done just proximal to the patellar tendon.

Care should be taken to avoid any distal orientation of this osteotomy cut because this will block the attempted medialization of the tibial tubercle. A 2-inch osteotome is then used along the oblique slope of the osteotomy cut to free it and create an osteoclasis at the distal taper.

Tubercle Fixation

With the osteotomy hinged distally, the proximal portion is anteromedialized along the slope of the osteotomy cut to the desired location. This location depends on your preoperative plan, but typically a 1-cm medialization is created (Fig. 13-13).

The osteotomy is held in place with two 3.2-mm drill bits placed in an anterior to posterior direction just medial to the tibial crest on the osteotomy and starting 1 cm distal to the attachment of the patellar tendon on the tibial tubercle (Fig. 13-13).

The knee is brought through a range of motion, and one should be able to achieve 90 degrees of knee motion without any undue tension on the osteotomy site.

The arthroscope is now reinserted, and the knee is taken through a range of motion to document the proper patellar tracking and the anatomic lateral

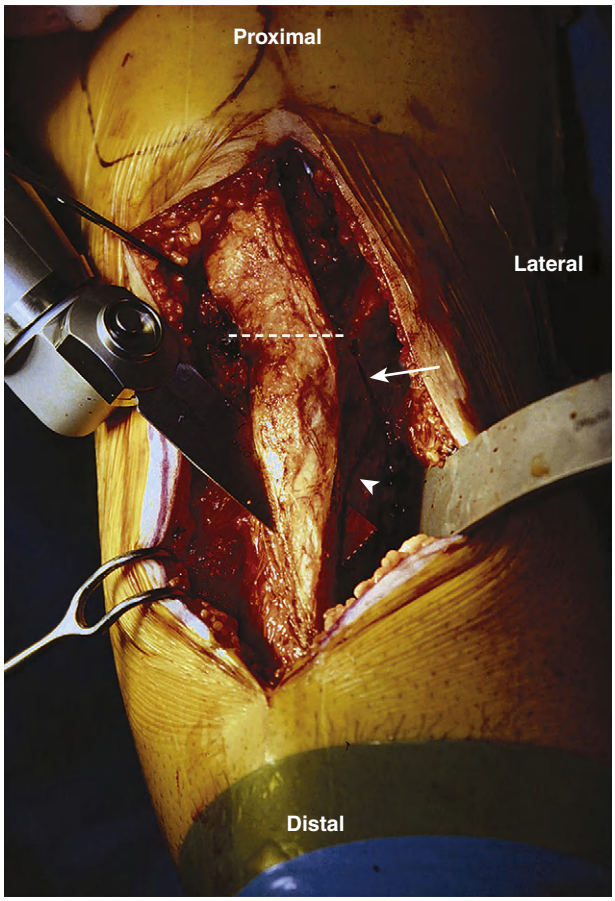

FIGURE 13-12 View of osteotomy just before anteromedialization. The saw blade is in the sloped oblique cut of the osteotomy. The white arrowhead points to the first osteotomy cut made with the saw blade. The arrow points to the back cut made with the osteotome. This back cut extends from the most proximal location of the posterolateral tibial cut (i.e., arrowhead osteotomy cut), proximally and anteriorly to just above the patellar tendon. What is not visualized is the lateral-to-medial cut under the patellar tendon (marked with a dotted line). (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 228. Copyright 2007, with permission from Elsevier.)

to medial engagement of the trochlea. Any medial subluxation of the patella should be corrected by decreasing the medialization of the osteotomy cut and replacing the 3.2-mm drill bits with screws.

A note on the placement of the drill bits for the screws. The purpose of starting 1 cm distal to the patellar tendon attachment on the tibial tubercle is so that if the osteotomy wedge is split when tightening the tibial tubercle screws, one has enough proximal bone on the tibial tubercle to insert another screw for fixation of the proximal fragment. The distal screw should be spaced another 1 cm distal from the proximal screw.

Using proper lag screw technique, two anterior to posterior 4.5-mm fully threaded cortical screws are placed in the proper fashion. They should be

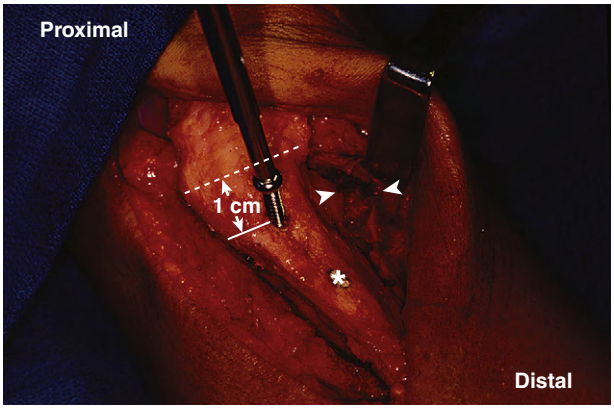

FIGURE 13-13 Arrowheads show the amount of anteromedialization of the osteotomy along the sloped plane. This is approximately 1 cm. The dotted line represents the proximal extent of the bony osteotomy under the patellar tendon. The proximal screw is placed approximately 1 cm distal to that point, to avoid splitting the osteotomy fragment. The asterisk represents the location of the second screw placement. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 228. Copyright 2007, with permission from Elsevier.)

countersunk below the anterior tibial cortex of the osteotomy wedge to minimize the postoperative irritation of the hardware on the subcutaneous tissues. Not only should the depth measurement of the screws be made after the countersink bore is done, but the more proximal screw (i.e., the first screw placed) should be downsized 2 mm from its depth gauge reading to allow for the compression of the osteotomy site with the lag screw technique.

For most cartilage restoration procedures, the entire patellofemoral compartment must be adequately visualized. Therefore, at this time, with the osteotomy predrilled, the screws are removed, the distal hinge of the osteotomy is broken and the entire osteotomy wedge/tibial tubercle/patellar tendon complex is retraced proximally.

Once the necessary cartilage procedure is done, the wedge is brought back down to its predetermined location and the screws are reinserted. This minimizes the need for any drilling to be done after the cartilage procedure, which can jeopardize the cartilage repair. While the osteotomy wedge is retracted proximally, it should be wrapped in a moist sponge (Fig. 13-14).

Closure

With the osteotomy secured, range of motion of the knee is once again checked and the tourniquet is deflated. Meticulous hemostasis is obtained.

Key areas to look for hemorrhage include the anterior tibial muscular compartment or posterolateral tibia (i.e., anterior tibial artery) and the lateral retinacular release (i.e., proximal lateral geniculate artery). The wound is irrigated and a drain is placed deep to the anterior tibial muscular compartment, exiting proximal lateral to the skin incision.

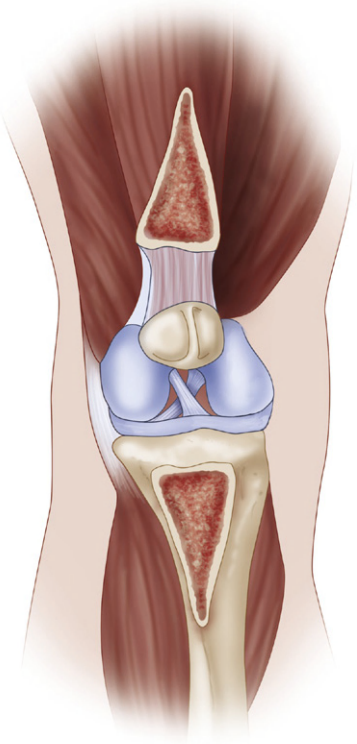

FIGURE 13-14 Figure showing the osteotomy cut retracted proximally.

To avoid a compartment syndrome, the anterior tibial musculature is reattached back to the tibial crest with 3 or 4 #1 Vicryl (Ethicon Inc., Somerville, N.J.) sutures. The subcutaneous tissues are reapproximated with a 2-0 Vicryl in an inverted interrupted fashion, and the skin is closed either with staples or a running 3-0 Prolene (Ethicon, Inc.) stitch. A sterile dressing is applied, followed by an elastocompressive dressing from the toe to the upper thigh. A cooling device is then placed on the knee, and a knee immobilizer is secured.

POSTOPERATIVE COURSE

I routinely admit the patients for a 23-hour observation stay in the hospital to monitor pain levels and to assess for compartment syndrome. Patients typically do well with an oral pain medication and an intravenous pain medication for breakthrough pain.

The drain is discontinued on postoperative day 1. Physical therapy consists of crutch training, ankle pumps, and quadriceps isometric exercises. The patients are kept nonweight bearing.

The therapist also works on active knee flexion exercises to 90 degrees (or the parameters set intraoperatively) and passive knee extension. Usually for

patellofemoral cartilage procedures, knee motion is not started for 6 hours postoperatively and is limited to passive knee flexion of 30 degrees. No straight leg raises are permitted.

Deep venous thrombosis prophylaxis consists of thigh-high compression hose, sequential compression devices to the contralateral extremity, and aspirin 325 mg twice per day for one month.

The patient is discharged on postoperative day 1, assuming he or she has tolerated the oral pain medication and understands the rehab.

REHABILITATION

The rehabilitation protocol can be found in Box 13-1. Important concepts about the rehabilitation protocol can be divided into weight-bearing status and range-of-motion goals.

BOX 13-1 Distal Realignment Rehabilitation

____ Weeks 0 to 2
No weight bearing; please use crutches
Knee immobilizer on at all times, except for ROM exercises and hygeine
Remove brace for passive ROM 0 to 90°
Begin quad sets co-contractions immediately in knee immobilizer; ankle ROM

____ Weeks 2 to 6
Start toe touch weight bearing; continue to use crutches
Continue knee immobilizer as above
Remove brace for passive ROM 0 to 90°;
Continue quad sets co-contractions; start abduction/adduction exercises; ankle ROM

____ Weeks 6 to 8
Transition to full weight bearing; may wean off brace/immobilizer
Start AROM to full
Start straight leg raises, partial wall sits no greater than 45°, terminal knee extension with Thera-Band (The Hygenic Corporation, Akron, Ohio); continue previous exercises

____ Weeks 8 to 12
Full weight bearing, no brace
Continue previous exercises as above and start hamstring strengthening, Thera-Band resistance 0 to 45°, light open chain exercises at 10 weeks

____ Months 3 to 4
Begin treadmill walking at slow pace, progress to balance/proprioception exercises
Initiate sports specific drills

____ Months 4 to 6
Advance close chain strength exercises, focus on single leg strength, progress to normal walking and backward movement
Start light plyometric exercises

AROM, A range of motions; ROM, range of motion.
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Except for cartilaginous procedures, which follow different rehabilitation guidelines, the patient should strive to achieve 90 degrees of knee flexion by the first postoperative visit (i.e., 5 to 7 days). Once the he or she reaches the goal of 90 degrees, the patient only has to perform the knee motion once or twice a day to keep up that goal. Active flexion is allowed with passive extension to limit the stress on the osteotomy site.

The patient is kept on strict non-weight-bearing status for the first 2 weeks. Toe-touch weight bearing is then allowed for the next 4 weeks. At the 6-week mark, assuming that the osteotomy shows signs of healing and no migration, the patient progresses to weight-bearing status over the next 2 weeks, so that by 8 weeks postoperatively the patient is at full weight-bearing status. Straight leg raises are started also at this time.

COMPLICATIONS

Complications of anteromedialization of the tibial tubercle can be divided into intraoperative and postoperative groups:

Intraoperative complications include violating the posterior cortex of the tibia with the oscillating saw, making too thick of an osteotomy cut because the cut was not tapered distally on the tibia, splitting the osteotomy with over tensioning of the lag screws, and neurovascular injury to the anterior tibial artery or deep peroneal nerve, which lie just deep to the posterolateral border of the tibia.[18]

Postoperative complications include infection, hematoma, compartment syndrome, hardware prominence, migration of the osteotomy, tibial stress fracture, creating a medial patellar subluxation from overzealous release of the lateral retinaculum or over medialization of the osteotomy, patellar baja/alta, arthrofibrosis, and deep venous thrombosis (Fig. 13-15, *A*–*C*).

Illustrative Case

Figure 13-16, (*A* and *B*) show a 23-year-old male with a long-standing history of patellar dislocations (>15–20 in each knee) who failed a conservative course of treatment consisting of physical therapy, bracing, and activity modification. Patellar taping helped stabilize his patellae, but this was unacceptable to him as a long-term solution to the dislocations. Preoperative Merchant views show bilateral patellar subluxation and tilt. An intraoperative arthroscopy image is shown in Figure 13-4, *A*. He subsequently underwent an anteromedialization of the tibial tubercle with anatomic alignment of his patella (Figs. 13-4, *B* and 13-7, *A*–*D*).

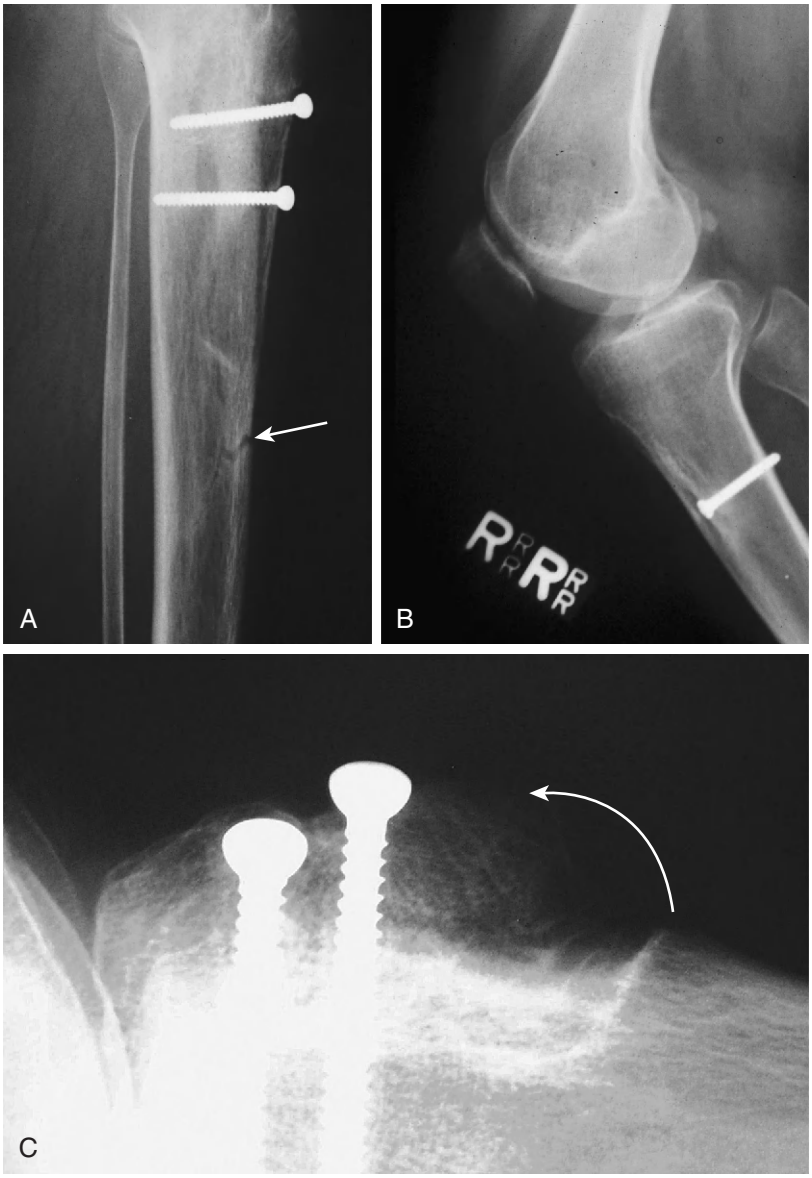

FIGURE 13-15 Complications of tibial tubercle osteotomy. **A,** Tibial stress fracture in the postoperative period. **B,** Patellar baja. **C,** Migration of osteotomy. Arrow shows abnormal location of distal tip of osteotomy. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 229. Copyright 2007, with permission from Elsevier.)

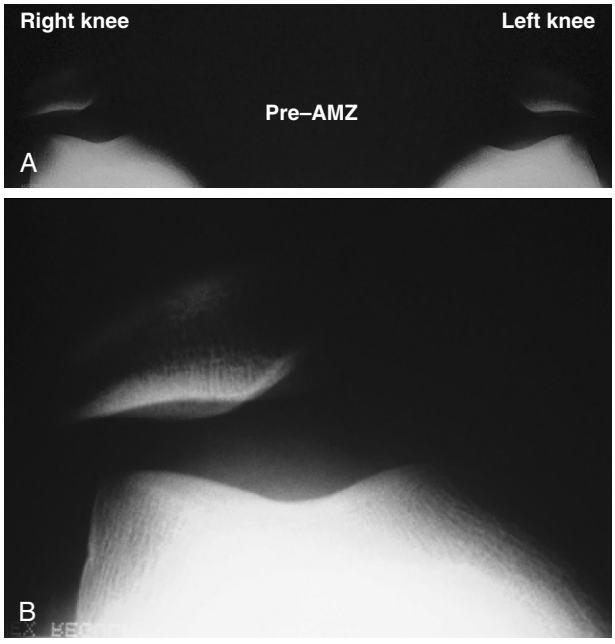

FIGURE 13-16 **A,** Bilateral patellar tilt and subluxation seen on Merchant view. **B,** Close-up view of right knee preosteotomy. (Reprinted from *Operative Techniques in Orthopaedics*, vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 230. Copyright 2007, with permission from Elsevier.)

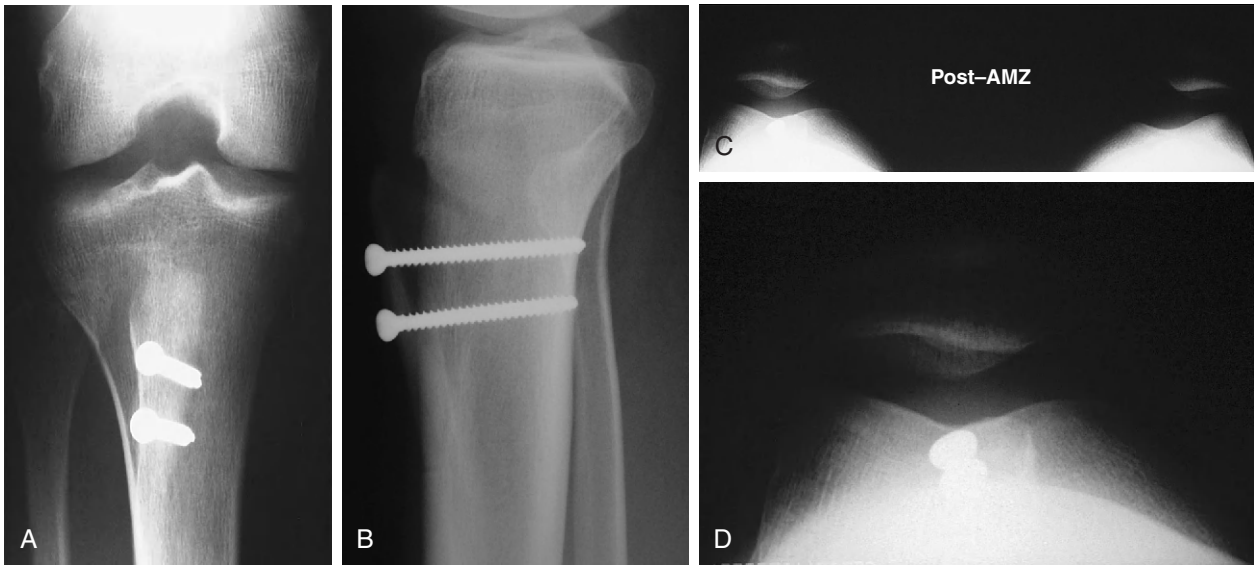

FIGURE 13-17 **A,** Anteroposterior view of right knee post osteotomy. **B,** Lateral view. **C,** Merchant view of bilateral knees after right knee tibial tubercle transfer. (d) Close-up of right knee tibial tubercle transfer. (Reprinted from *Operative Techniques in Orthopaedics,* vol. 17, issue 4, James Bicos and John P. Fulkerson, Indications and Technique of Distal Tibial Tubercle Anteromedialization, p. 231. Copyright 2007, with permission from Elsevier.)

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CHAPTER

14

Meniscal Allografts, Cartilage Repair, and Concomitant Procedures

Wayne Gersoff

INTRODUCTION: MENISCAL ALLOGRAFT TRANSPLANTATION

The preoperative planning for this procedure should include the identification of the meniscal pathology and obtaining sizing radiographs;[1,2] confirming the sizing, site, and side of the tissue match from the tissue bank; and assessing ligamentous stability, alignment, and articular cartilage status. Any ligamentous abnormalities, malalignment, or articular cartilage pathology should be corrected either concomitantly or staged. At the time of surgery, before the initiation of anesthesia, confirm that the meniscus allograft is in the operating room (OR) and that it is the appropriate patient, size, side, and site. Three techniques will be reviewed: the double bone plug,[3] the dovetail technique,[4] and the slot technique.[5]

GENERAL TIBIAL PREPARATION

1. Under arthroscopic visualization identify the anterior and posterior horn attachments. (Fig. 14-1)[6]
2. Utilizing both arthroscopic instrumentation and a shaver, debride the remaining meniscal remnant leaving 1 to 2 mm of meniscal capsular rim and horn attachments. (Fig. 14-2)
3. Confirm the presence of punctuate bleeding in the remaining tissue. It is preferable not to use a tourniquet for this part of the procedure. (Fig. 14-3)
4. To facilitate visualization of the posterior horn attachment and body, a high-speed burr can be used to remove a portion of the tibial spine. In addition, a partial release of the medial collateral ligament (MCL) deep fibers can be carried out (Fig. 14-4).

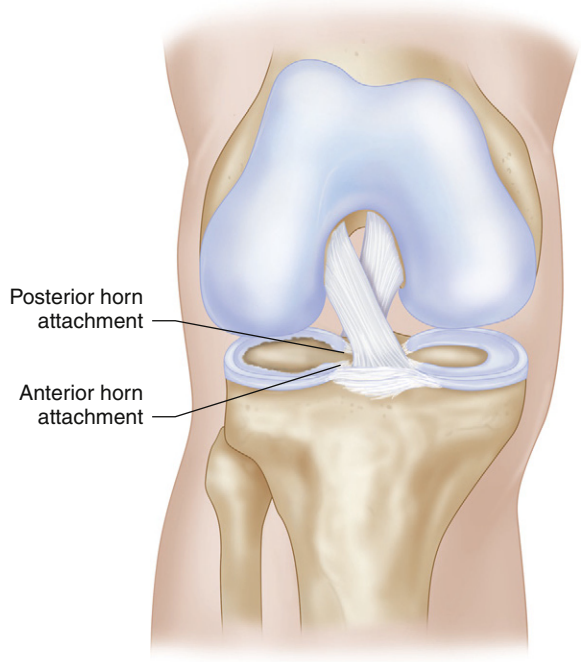


FIGURE 14-1

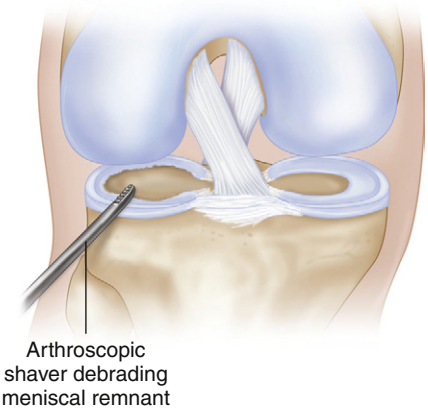


FIGURE 14-2

DOUBLE BONE PLUG TECHNIQUE

Graft Preparation

1. The bone plugs can either be prepared freehand or by using a coring reamer.
2. The anterior bone plug should be 8 mm in diameter and 10 mm long. The posterior plugs should be 6 to 7 mm in diameter and 8 mm in length. (Fig. 14-5)
3. The freehand technique is performed using rongeurs and high-speed burr.
4. If using a coring reamer, place a 2.4-mm guide pin through the center of the anterior and posterior horn attachment sites, extending through the bone block. (Fig. 14-6)
5. Insert a collared pin into the bottom of the bone bridge.

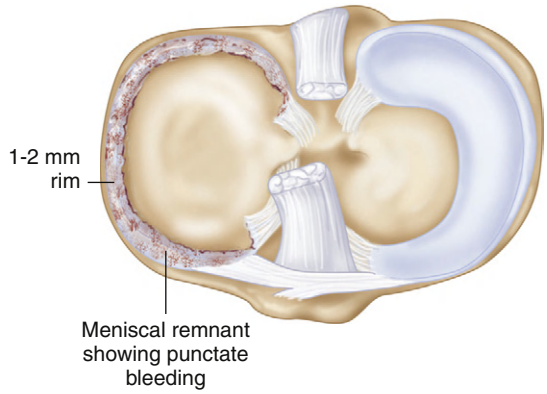


FIGURE 14-3

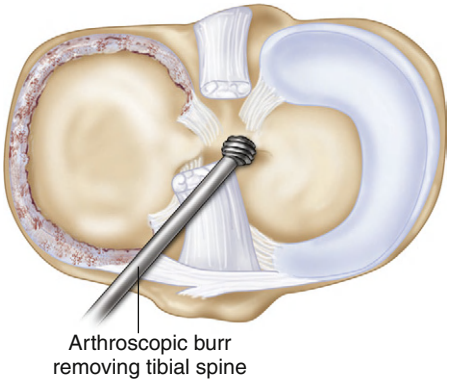


FIGURE 14-4

FIGURE 14-5

6. Place a coring reamer of appropriate size over the collared pin and create a bone dowel. (Fig. 14-7)
7. Trim the dowels to the appropriate length.
8. Pass a nonabsorbable size 0 or 1 suture up through the posterior plug. Place a horizontal mattress suture through the meniscal tissue at the attachment site. Pass the suture down through the bone plug. (Fig. 14-8)

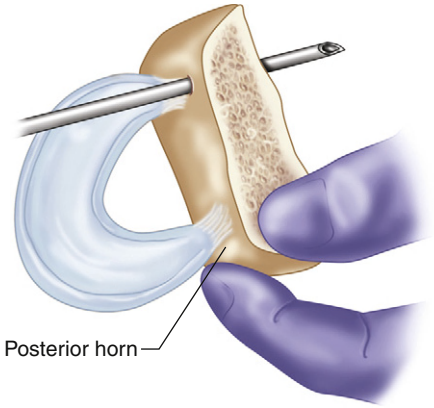
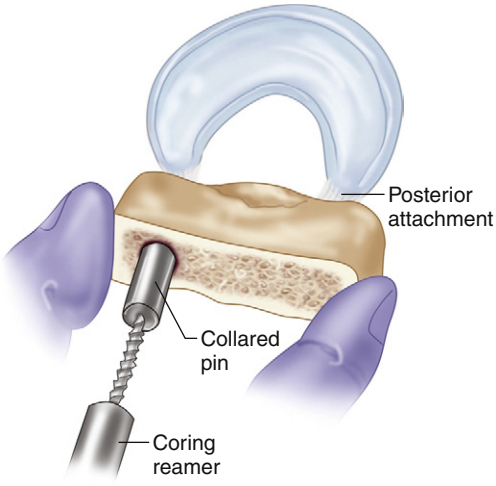


FIGURE 14-6



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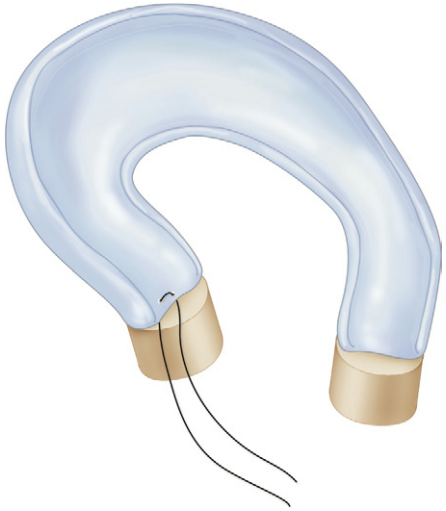

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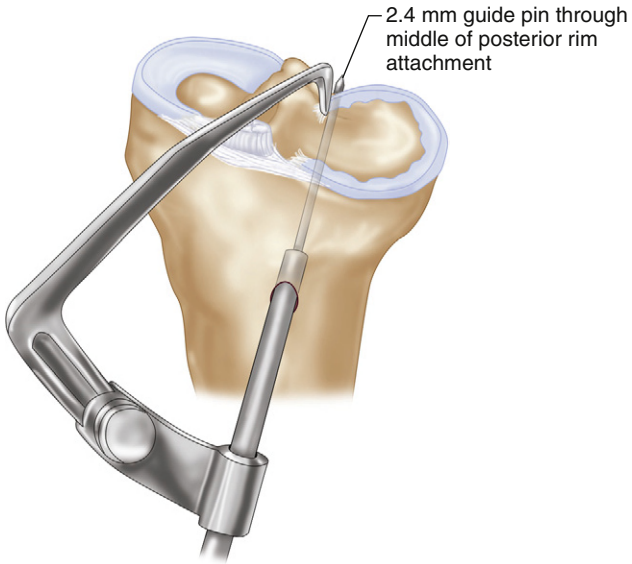

FIGURE 14-9

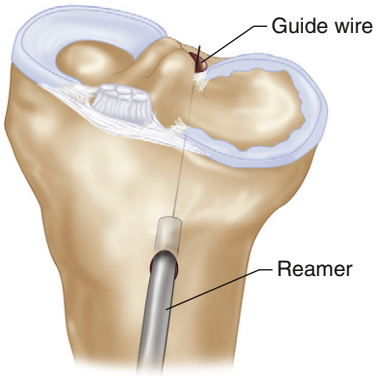

FIGURE 14-10

Posterior Tibial Tunnel Preparation

1. Using an anterior cruciate ligament (ACL) tibial guide, place the tip of the guide on the posterior horn attachment such that the 2.4-mm guide wire will be centered. (Fig. 14-9)
2. Select a cannulated reamer 1 mm larger than the posterior plug diameter, and drill a tunnel from the anterior tibia exiting at the posterior horn attachment. (Fig. 14-10)
3. Debride and smooth the intraarticular portions of the tunnel using rasps and a shaver.

Placement of the Meniscus Allograft

1. Create a limited or miniarthrotomy. (Fig. 14-11)
2. Pass the suture attached to the posterior horn through the previously created posterior tunnel utilizing a suture retriever. (Fig. 14-12)

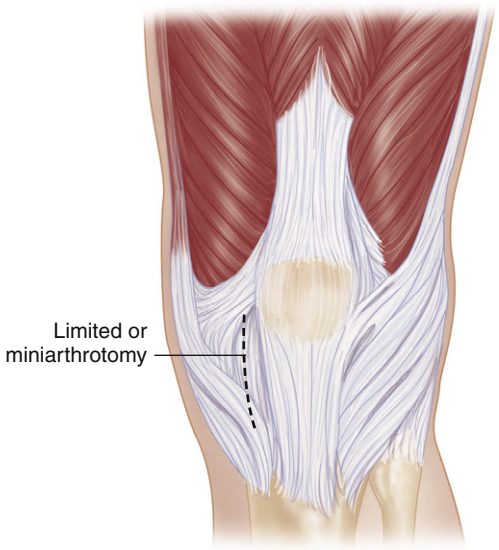

FIGURE 14-11

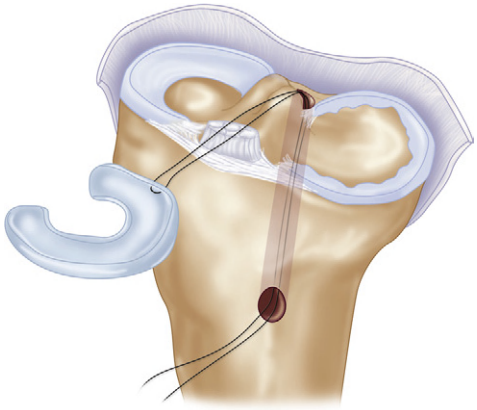

FIGURE 14-12

3. Place a pull-through suture guide into the body of the meniscus at the junction of the posterior and middle thirds. It is often helpful to use two separate pull-through sutures. (Fig. 14-13)
4. Create a small posteromedial skin incision, and dissect the subcutaneous tissue to the capsule.
5. Pass the pull-through guide suture through the knee at the corresponding position in the remnant meniscus such that it exits the knee through the posteromedial incision.
6. Pass the posterior bone plug through the notch, guiding it into the posterior tunnel using the posterior tunnel suture and a blunt instrument to help position it. (Fig. 14-14)
7. Use the pull-through guide suture and blunt instrumentation to reduce the remainder of the body of the meniscus. (Fig. 14-15)
8. Secure the posterior bone plug by tying the sutures attached to the bone plug over a button on the anterior tibia.

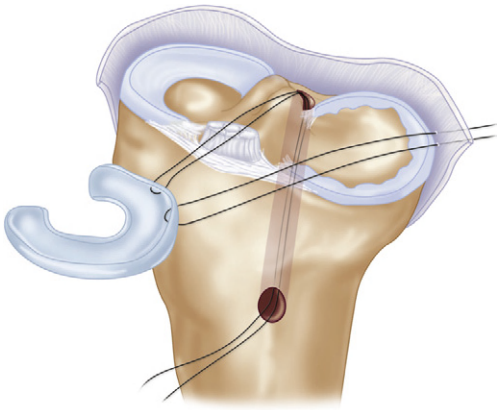

FIGURE 14-13

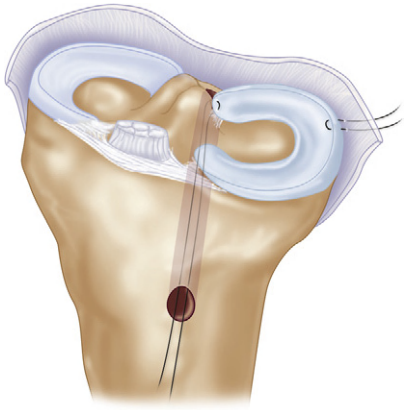

FIGURE 14-14

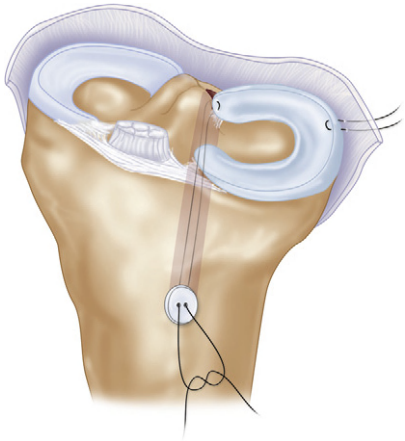

FIGURE 14-15

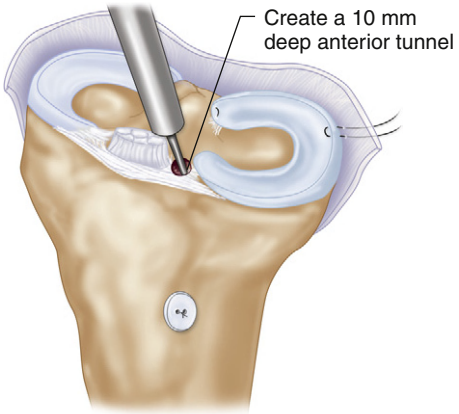

FIGURE 14-16

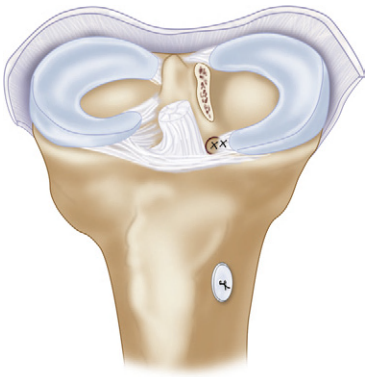

FIGURE 14-17

Placement of Anterior Plug

1. After securing the posterior plug and reducing the body of the graft, seat the meniscus by placing it through a range of motion. This will also facilitate the selection of the attachment site for the anterior horn.
2. Utilizing a 2.4-mm guide pin, place it into the center of the area of anterior attachment, keeping it as perpendicular to the tibial joint surface as possible. (Fig. 14-16)
3. Place an 8-mm cannulated reamer over the guide wire, and create a bone tunnel 10 mm deep.
4. Reduce the anterior plug into the tunnel. Although this allows for press fit fixation, additional stabilization may be required with nonabsorbable size 0 or 1 sutures. (Fig. 14-17)

Securing the Meniscal Allograft

1. Secure the meniscus utilizing either an inside-out technique, an all-inside technique, or a combination of both.
2. If using the inside-out technique, use 2-0 absorbable sutures and pass them through the previously created posteromedial or posterolateral incision. (Fig. 14-18)

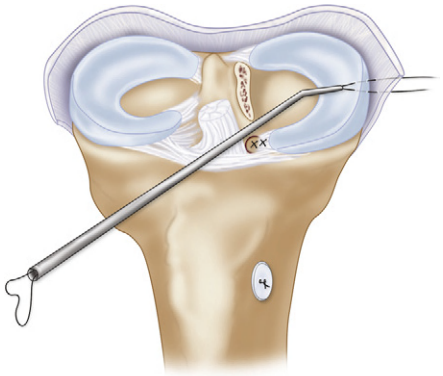

FIGURE 14-18

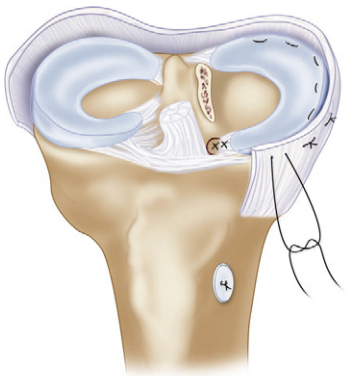

FIGURE 14-19

3. An all-inside technique is often used in the posterior body. This technique can be difficult if there isn't adequate meniscal rim to pass the fixation device into.
4. The anterior horn and body sutures can often be passed under direct visualization. (Fig. 14-19)

DOVETAIL TECHNIQUE

Tibial Preparation

1. After meniscal remnant preparation, under arthroscopic visualization use an arthroscopic burr to remove the tibial spine. Using the same burr, create a shallow trough into the cortical bone connecting the anterior and posterior horn attachment sites. (Fig. 14-20)
2. Create a miniarthrotomy corresponding to the side of implantation. (Fig. 14-21)
3. Place the alignment rod in the trough connecting the anterior and posterior horns. (Fig. 14-22)
4. Place a precalibrated osteotome vertically in alignment with the alignment rod and advance it into the tibial plateau. It should be advanced to the posterior cortex of the tibia. (Fig. 14-23)

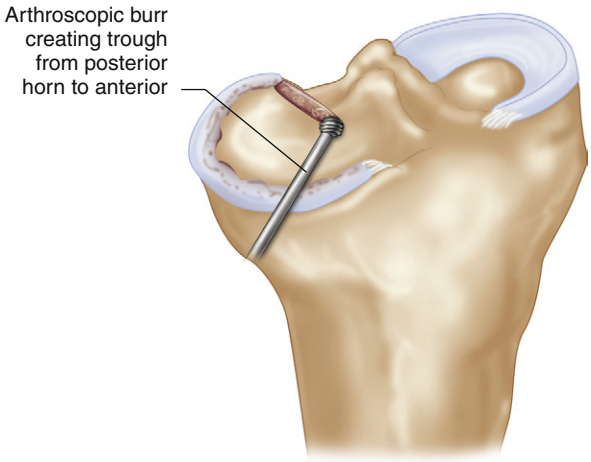

FIGURE 14-20

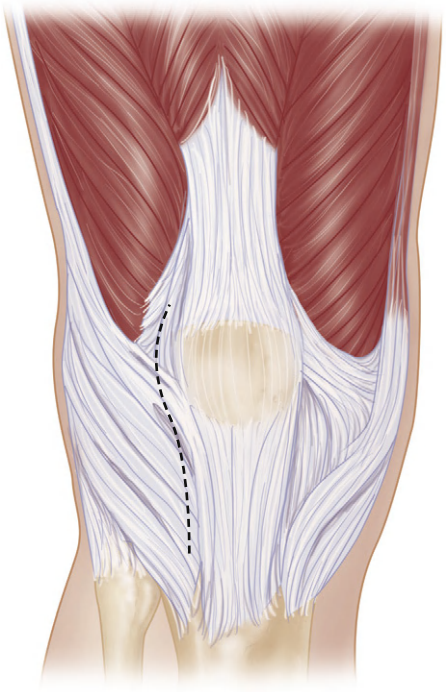

FIGURE 14-21

5. Remember that the anterior tibial plateau slopes inferiorly. Therefore the depth marker must be above the plateau anteriorly but flush more posteriorly.
6. Record the calibrated markings on the osteotome and use them to correlate with the bone block length during the remainder of the procedure. (Fig. 14-24)
7. Attach the first drill guide to the osteotome handle. (Fig. 14-25)
8. Place a 6-mm drill into the guide and advance it until you reach the posterior cortex. The depth markings on the drill will correlate with the previously recorded depth from the osteotome. During the drill advancement, the overlying tibial surface will be disrupted. (Fig. 14-26)

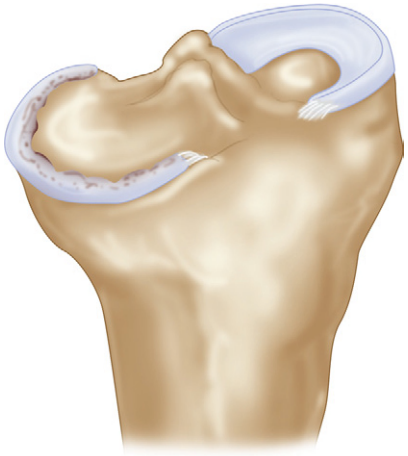

FIGURE 14-22

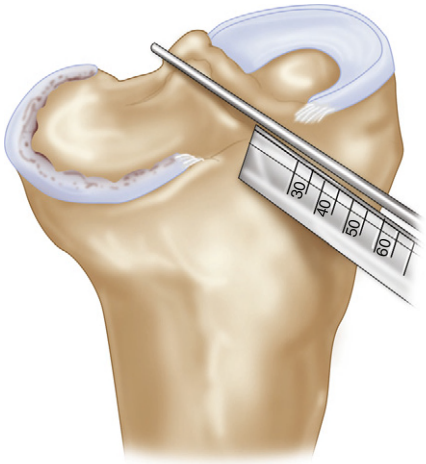

FIGURE 14-23

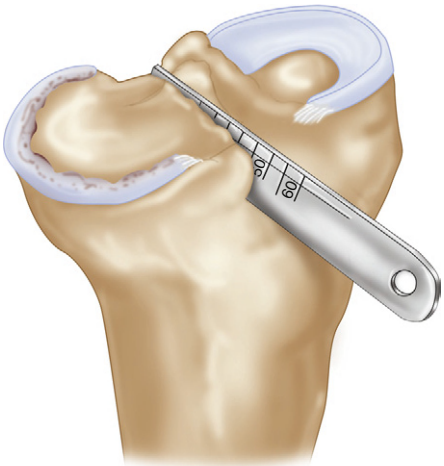

FIGURE 14-24

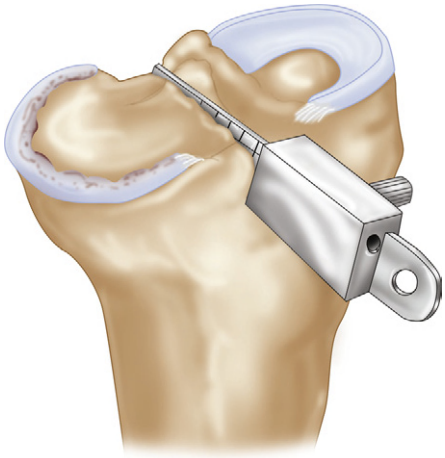

FIGURE 14-25

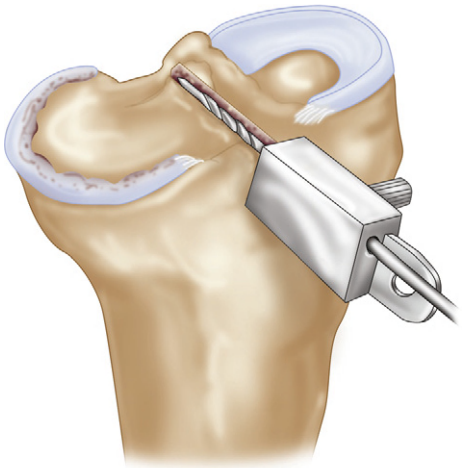

FIGURE 14-26

9. Remove all bone remnants and debris.
10. Secure the second drill guide to the osteotome blade. (Fig. 14-27)
11. Place a 7-mm drill into the guide and advance it to the posterior cortex. This hole, combined with the 6-mm hole, helps to create the trapezoidal shape of the recipient site.
12. Introduce the preshaped rasp into the now-created tunnel in the tibia. The rasp should be oriented such that the vertical side is toward the midline, and the top is flush with the tibial articular surface. (Fig. 14-28)
13. Advance the rasp slowly both by hand and by mallet until you contact the posterior cortex.
14. Insert the dovetail dilator into the trapezoidal slot until you contact the posterior cortex. (Fig. 14-29)
15. Correlate the precalibrated length markings on the rasp and dilator with the length of the meniscal allograft bone block. (Fig. 14-30)
16. Address any bone fragments or irregular surfaces before graft placement. (Fig. 14-31)

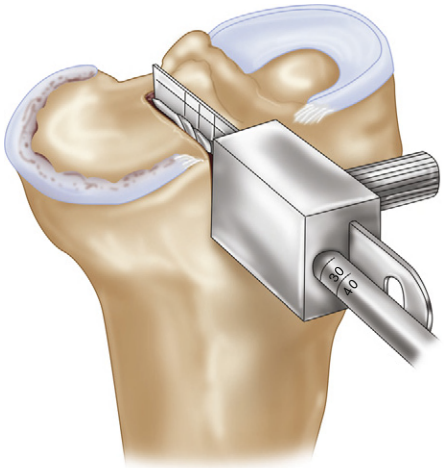

FIGURE 14-27

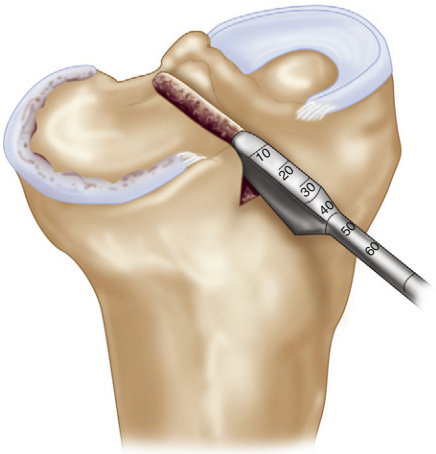

FIGURE 14-28

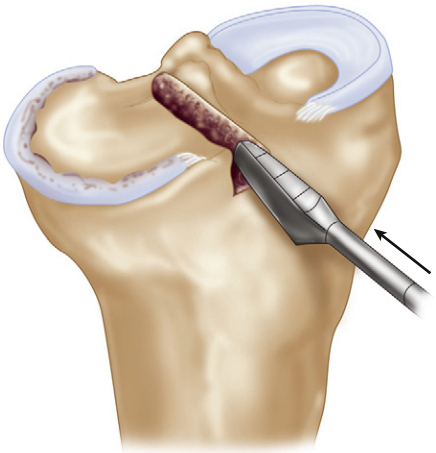

FIGURE 14-29

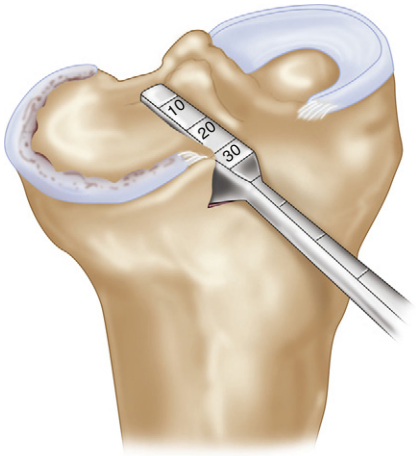

FIGURE 14-30

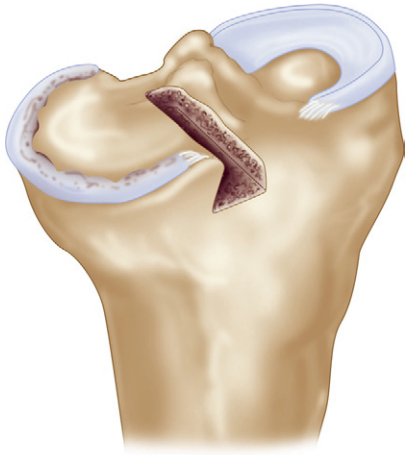

FIGURE 14-31

Graft Preparation

1. The initial large bone block can be trimmed to allow better placement in the graft holder. Anterior-posterior (AP) length should be cut in accordance with the premeasured length of the trapezoidal slot determined during tibial preparation.
2. Draw an outline of the dovetail bone block on the end of the bone block using the rasp as a guide. Align the vertical edge toward the midline and central to the anterior and posterior horn attachment sites (Fig 14-32).
3. Position the allograft in the workstation upside down. Align the midline edge of the dovetail outline with the vertical face of the holding posts. Align the soft tissue attachments with the lower face of the holding posts. The bone block is secure within the holding posts. (Fig. 14-33)
4. Position the first cutting guide so that the vertical cutting aligns face aligns with the vertical face of the holding posts. Use a sagittal saw to complete this cut. (Fig. 14-34)
5. Position the second cutting guide so it is flush to the bone block vertical cut. a horizontal or inferior side cut of the bone block complete using the sagittal saw. (Fig. 14-35)

FIGURE 14-32

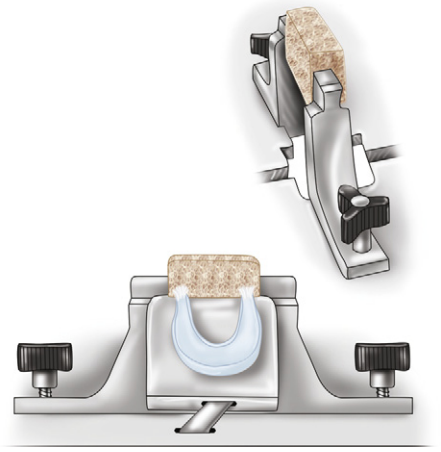

FIGURE 14-33

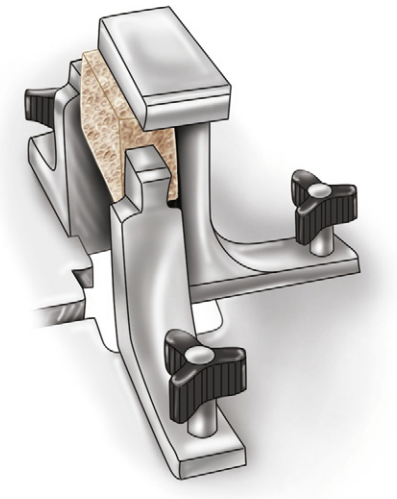

FIGURE 14-34

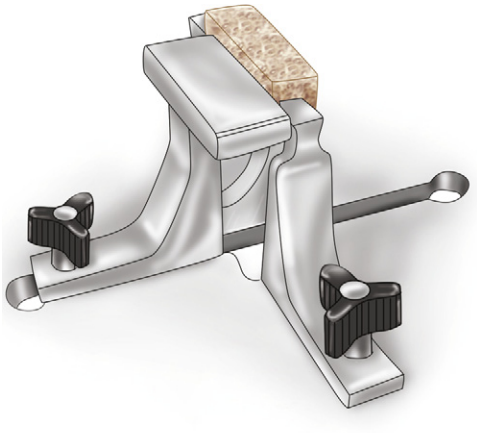

FIGURE 14-35

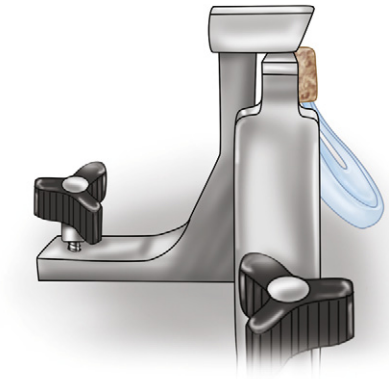

FIGURE 14-36

6. Place the third and final cutting guide such that it is in contact with the medial bone surface and positioned to guide the angled cut of the bone. Again, use a sagittal saw to complete this cut. (Fig. 14-36)
7. Use the graft sizing block to determine appropriate sizing and easy passage. (Fig. 14-37 and 14-38)

Graft Placement

1. Create a small posteromedial or posterolateral incision. Dissection is carried out to the capsular level. (Fig. 14-39)
2. Place a pull-through guide suture in the meniscus body and through the corresponding area of the meniscal remnant. (Fig. 14-40)
3. Introduce the bone block into the trapezoidal slot in the tibia. As the bone is passed into the trapezoidal slot, reduce the meniscus body utilizing the pull-through suture and blunt instrumentation. (Fig. 14-41)
4. Use a tamp to assist in the seating of the bone block.
5. When the graft is seated properly, place the knee through a range of motion to assure final positioning before suturing the meniscal body. (Fig. 14-42)

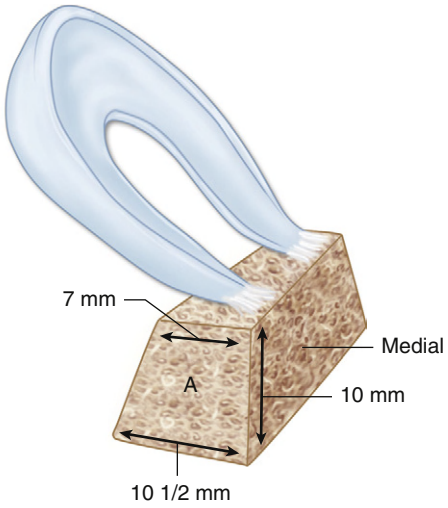

FIGURE 14-37

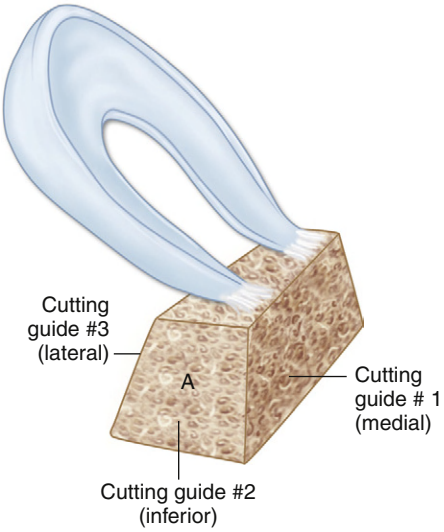

FIGURE 14-38

SLOT TECHNIQUE

Tibial Preparation

1. Debride the meniscal remnant and identify the anterior and posterior horn attachment sites as previously described.
2. Create a marker using a thermal device connecting the anterior and posterior horn attachment sites. (Fig. 14-43)
3. Using a 4.0-mm round burr, create a reference slot going from the posterior to the anterior horn. The reference slot should be equal to the height of the burr and parallel to the sagittal slope of the tibia. (Fig. 14-44)
4. Remove tibial spine along this reference slot as needed.

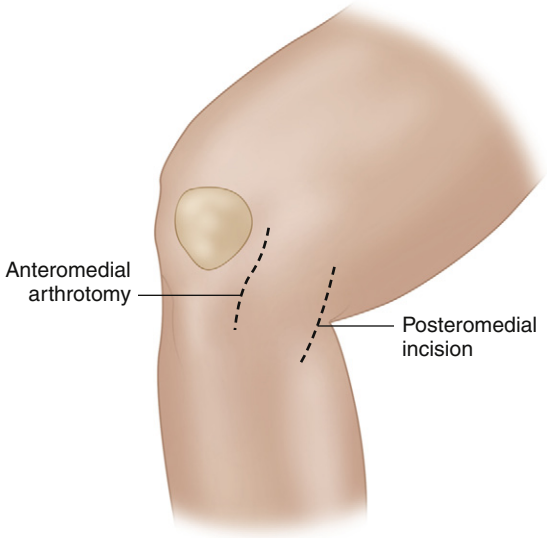

FIGURE 14-39

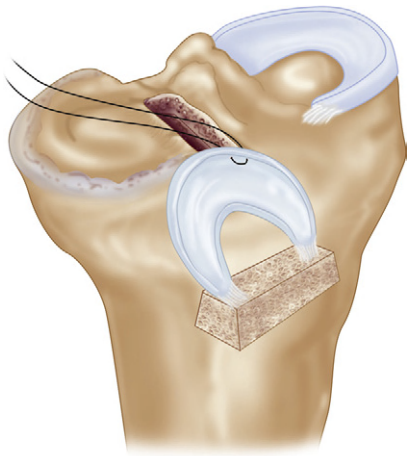

FIGURE 14-40

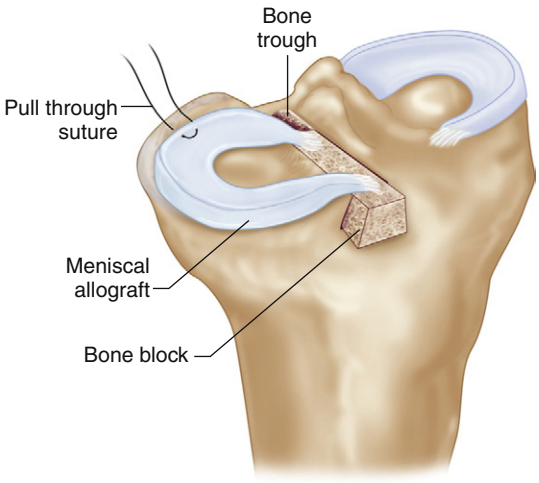

FIGURE 14-41

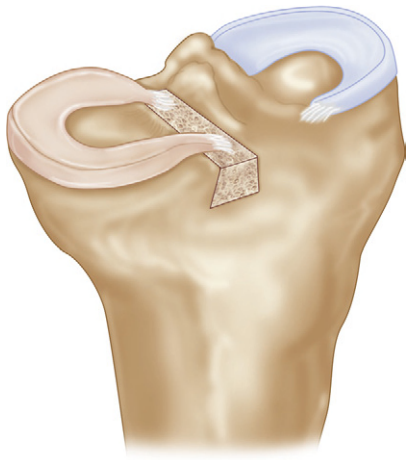

FIGURE 14-42

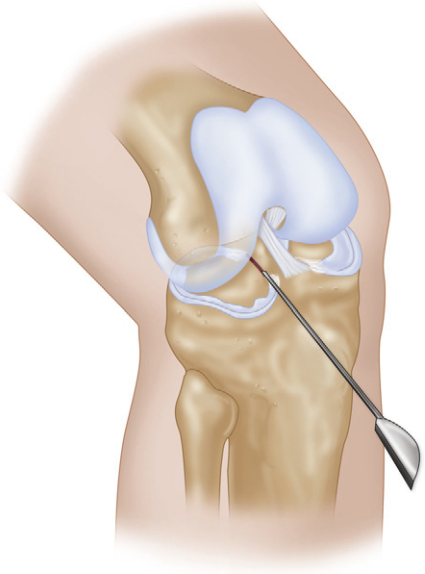

FIGURE 14-43

5. Place the initial depth gauge guide into the knee such that the hook passes over the posterior cortex and the shaft of the guide lies flush with the tibial surface. (Fig. 14-45)
6. Keeping the depth gauge against the posterior cortex and flush with the articular surface, note the length and then place the drill guide over the guide wire. The drill guide should be seated firmly against the anterior tibia. (Fig. 14-46)
7. Drill the calibrated 3/32" guide pin through the drill guide hole. Advance the drill guide until the red marking on each instrument lines up. This will indicate that the end of the pin is 3 mm from the posterior wall. (Fig. 14-47)
8. Again confirm the length on the calibrated depth gauge and guide wire. (Fig. 14-48)

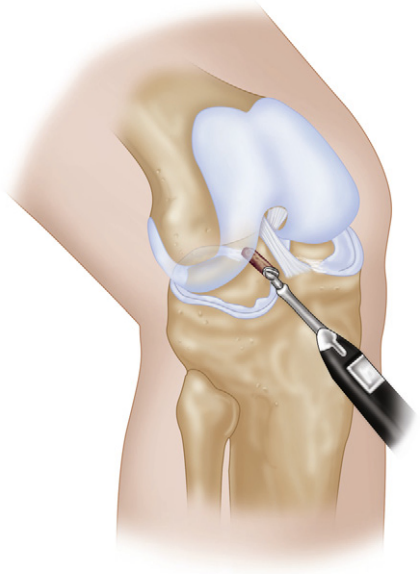

FIGURE 14-44

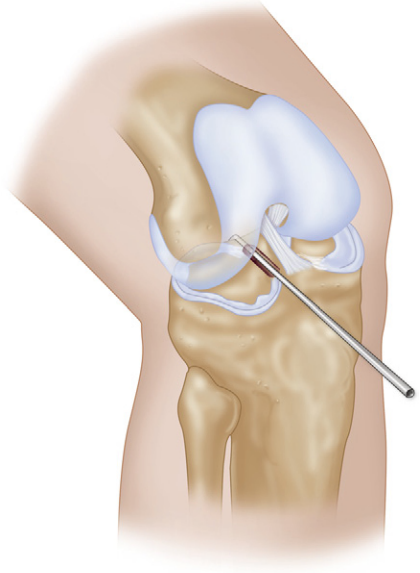

FIGURE 14-45

9. Preset this length on the drill before drilling the tibial plateau. (Fig. 14-49)
10. Remove the drill guide and depth gauge, leaving the guide pin in place. (Fig. 14-50)
11. Place the 8-mm cannulated drill, with depth set, over the guide wire and advance until the depth set chuck contacts the anterior tibia. The superior aspect of this tunnel may disrupt the tibial surface. (Fig. 14-51)

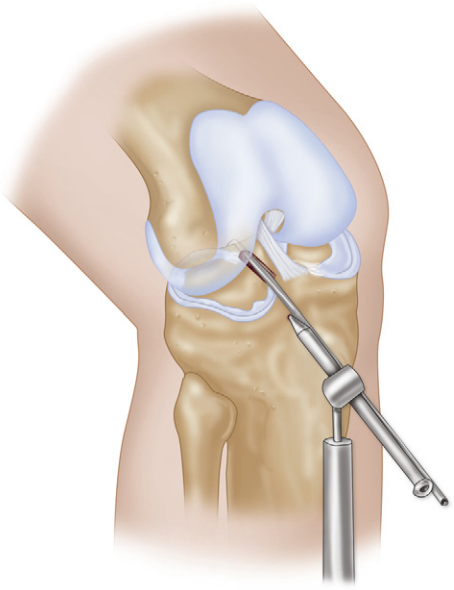

FIGURE 14-46

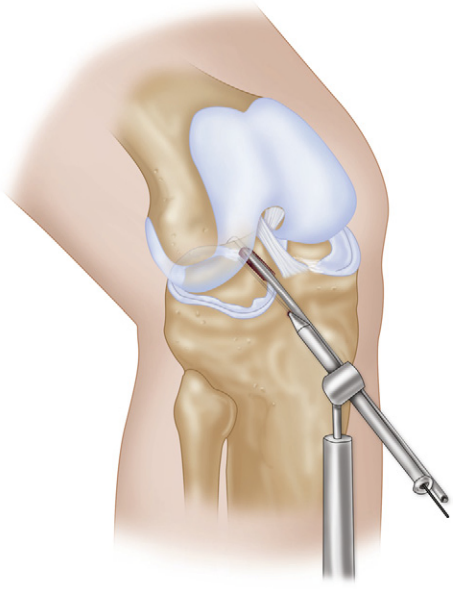

FIGURE 14-47

12. Insert the 8-mm box cutter over the guide pin and into the drilled hole. Advance slowly by gently tapping with a mallet. The markings on the box cutter correlate with the depth measurements and can be monitored to prevent overpenetration. (Fig. 14-52)
13. Create a slot that is 8 mm wide by 10 mm deep.
14. Use a 7-mm and 8-mm three-sided rasp sequentially to smooth the final slot. Remove any additional boney or soft tissue debris at this time as well. (Fig. 14-53)

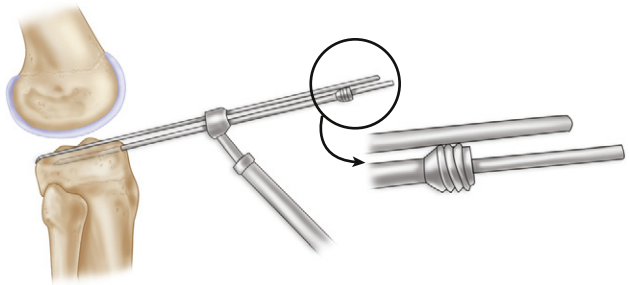

FIGURE 14-48

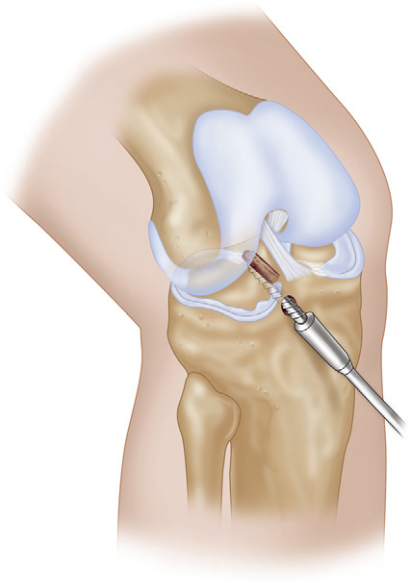

FIGURE 14-49

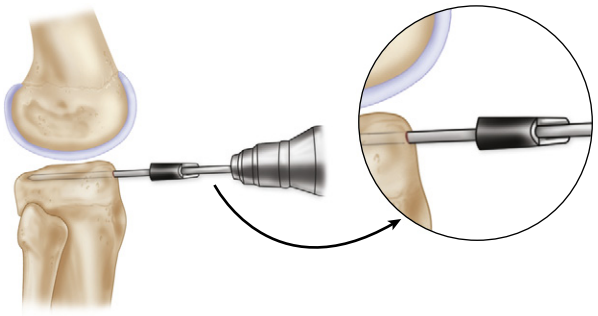

FIGURE 14-50

Graft Preparation

1. Excess bone can be removed from the bone block to facilitate placement into the sizing block.
2. Place the meniscus onto the sizing block, making certain that the horns are flush with the markers of the inner surface of the sizing block. These marks assure a 10-mm height. (Fig. 14-54)

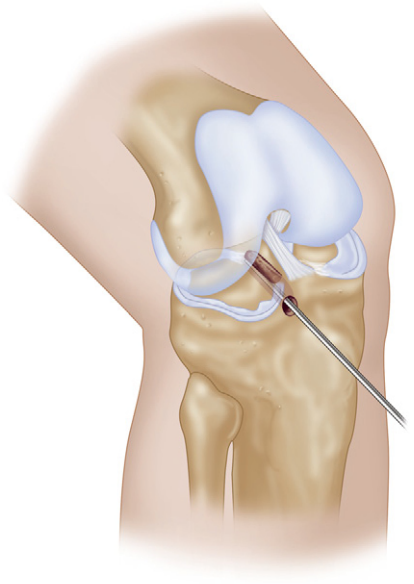

FIGURE 14-51

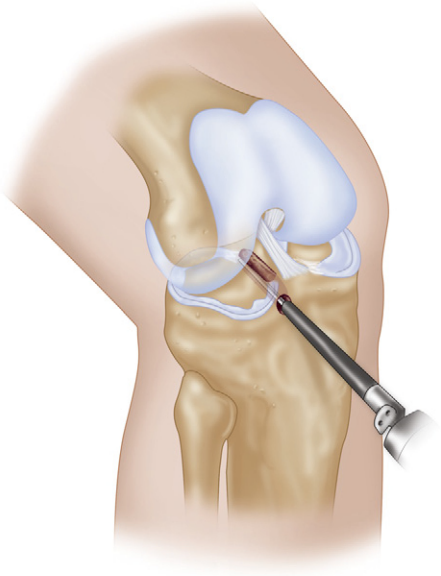

FIGURE 14-52

3. Once the graft is aligned appropriately, the U-pin will hold the meniscus in place in the block.
4. Measure the height using the anterior and posterior horns as reference marks. Remove excess bone using the bottom of the sizing block as a guide to achieve a 10-mm height. (Fig. 14-55)
5. The cartilage covering the tibial spine can be removed, but the cortex of the bone should not be violated. Violating the cortex may weaken the bone bridge and cause fracture during insertion.

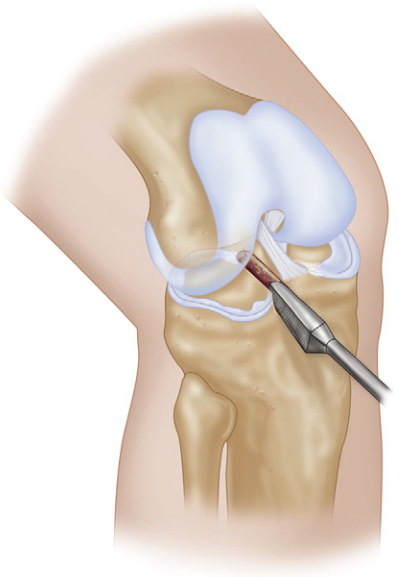

FIGURE 14-53

FIGURE 14-54

FIGURE 14-55

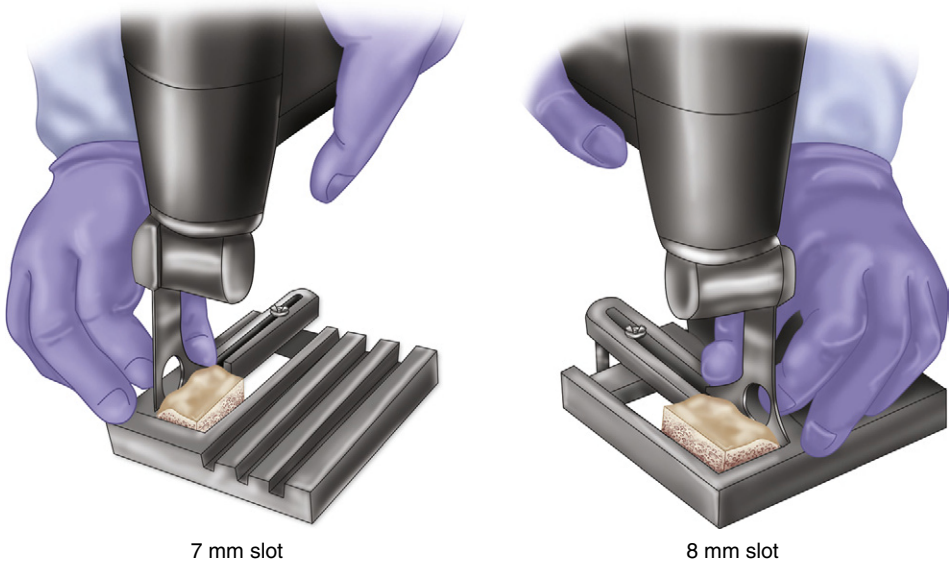

FIGURE 14-56

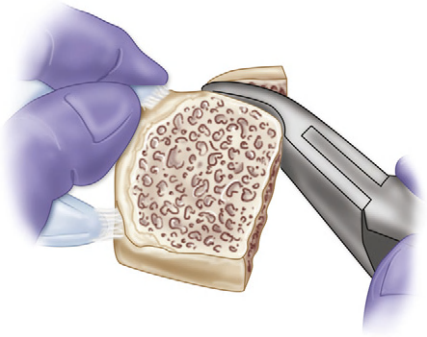

FIGURE 14-57

6. The sizing block is designed with slots to allow for the creation of either a 7-mm or an 8-mm wide bone block. Select the desired width slot and, using a sagittal saw, cut to the appropriate width. (Fig. 14-56)
7. Excess bone extending beyond the posterior horn attachment can then be removed to adjust length. Leave any excess bone on the anterior horn until after bone block insertion so as not to compromise graft integrity. (Fig. 14-57)
8. Slide the bone bridge through the sizer to confirm height, width, length, and easy passage.

Graft Placement

1. Place either one or two pull-through sutures into the body of the meniscus at the posterior and middle third junction. If using two, they should be separated by 8 to 10 mm. The advantage of two pull-through sutures is that in a tight compartment they will give more leverage and puts less stress on the bone bridge. These two sutures can then be tied together over the capsule to provide additional fixation. (Fig. 14-58)

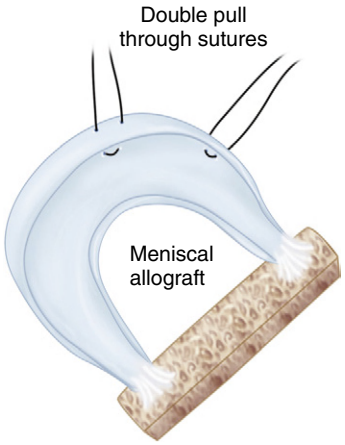

FIGURE 14-58

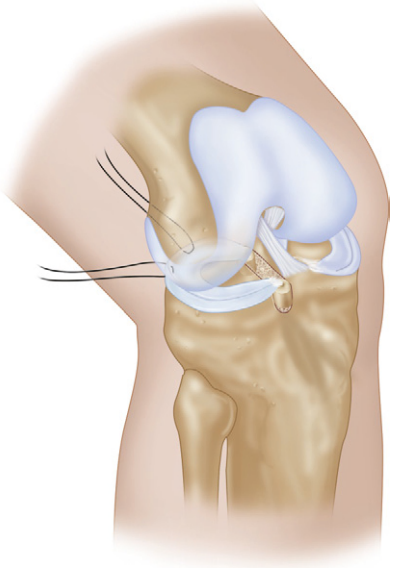

FIGURE 14-59

2. Introduce the bone bridge into the tibial bone slot and slowly advance using the pull-through sutures to help guide the meniscal body into position. (Fig. 14-59)
3. As needed, an assistant can apply either varus (lateral meniscus) or valgus (medial meniscus) stress to facilitate reduction of the meniscus.
4. Once reduced and in place, the knee is cycled through a range of motion to obtain final seating before suture fixation.
5. The bone bridge can be secured by either using a small interference screw or a suture anchor device acting as an interference screw. The preloaded sutures can then be utilized to secure the anterior horn and capsule. (Fig. 14-60)
6. Suture fixation is then achieved by using either the inside-out technique, all-inside technigue, or a combination of both.

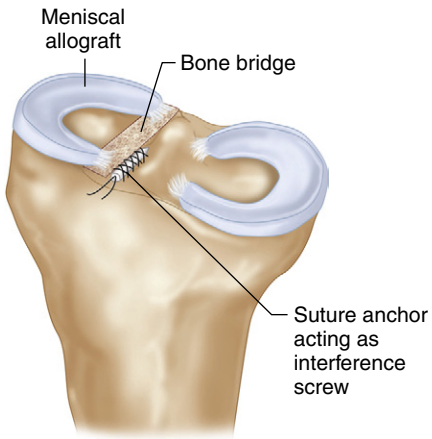

FIGURE 14-60

Cartilage Repair and Meniscal Allograft Transplantation

Meniscal allograft transplantation can be performed concomitantly with articular cartilage restoration techniques.[7-9] It is imperative that appropriate preoperative planning is undertaken. The techniques of articular cartilage restoration are outlined in this text. The following is a general guideline for the combined procedures:

1. Perform an arthroscopic assessment of the knee joint, and prepare the meniscal remnant.
2. Proceed with all initial arthroscopic steps in the tibial preparation of the selected meniscal allograft transplantation (MAT) procedure.
3. Upon completion of the arthroscopic portions of the tibial preparation, proceed with creating an arthrotomy as will be required for the cartilage repair procedure. Most aspects of the tibial preparation in the MAT procedures can be done via an arthrotomy.
4. Identify the articular cartilage defect.
5. The meniscal allograft can be prepared by an assistant while the primary surgeon is preparing the articular cartilage defect. This will decrease operative time.
6. Prepare the articular cartilage defect in accordance with the selected articular cartilage repair technique as described elsewhere in this text.
7. Upon completion of the meniscal allograft preparation, place the appropriate pull-through sutures in the meniscal body and place aside in a moistened sponge.
8. After completion of the preparation of the articular cartilage defect it is recommended that the meniscal allograft be placed before completion of the articular cartilage repair. This will protect the repair site from being damaged during the reduction of the meniscus.
9. Create the posteromedial or posterolateral incision and dissect to the capsular layer. Pass the pull-through sutures into the joint, through the meniscus, and out the incisional area.

10. Proceed with the placement of the meniscal allograft. Pass the suture fixation mostly using inside-out sutures, but do not tie down. Again, this will prevent the risk of injury to the articular repair site while securing the meniscus. Leaving the suture untied allows for the extremes of motion of the knee during the articular cartilage repair without compromising meniscal fixation.
11. Meniscal allograft reduction can be challenging if the articular cartilage defect extends posteriorly. The meniscus can be caught on the rim of articular cartilage at the defect site.
12. The articular cartilage repair is then completed.
13. Final stabilization of the meniscal allograft is then achieved.

Cartilage Repair and ACL Reconstruction

1. Perform an arthroscopic preparation of the meniscal remnant and debridement of ACL remnant and intercondylar notch.
2. Proceed with the notchplasty as indicated.
3. It should be noted that any of the MAT techniques can be performed in combination with ACL reconstruction.
4. Proceed with arthroscopic portion of tibial preparation for the selected MAT procedure.
5. Proceed with arthroscopic creation of tibial and femoral tunnels for the selected ACL reconstruction procedure. There may be slight overlap of the tibial ACL tunnel and tibial tunnel if using a bone bridge technique for MAT.
6. Create a miniarthrotomy, and complete the tibial preparation for the MAT procedure.
7. Prepare the meniscal allograft tissue in accordance with the selected MAT technique. If an assistant is available to do this part of the procedure, it will reduce operative time.
8. If using autograft, the graft can be harvested and prepared simultaneously to the meniscal allograft preparation.
9. Pass pull-through suture into the knee as previously described.
10. Place separate pull-through sutures in the meniscal body.
11. Proceed with placement of the ACL graft, fixating only the femoral side.
12. Proceed with placement and reduction of the meniscal allograft. Allowing the knee to be lax will facilitate the reduction of the meniscal allograft into the appropriate position.
13. Two methods are recommended if using a bone bridge technique and there is overlap of the ACL tibial tunnel and bone bridge tibial tunnel. A burr or ronger can be used to gently remove some of an overlapping bone bridge. Take care not to injure the ACL graft. The graft can always be pushed up out of the tunnel during this procedure and then reduced once completed. If there is less overlap, then the ACL graft, which at this point will be soft tissue, can be gently compressed to the side allowing for passage of the bone bridge. (Fig. 14-61)
14. Once the meniscus is in place and the bone bridge reduced, complete the fixation of the meniscus. Again having the knee lax will facilitate fixation access.
15. After the completion of meniscal fixation, the ACL graft can be tensioned and fixed at the tibial tunnel site.

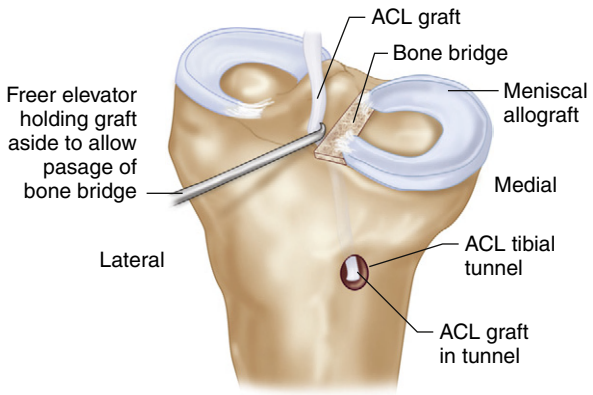

FIGURE 14-61

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CHAPTER

15

Bone Grafting around an Articular Joint

Marcus Head, James B. Richardson

INTRODUCTION

No substitute has been proven to be better than autograft. Bone is formed by stem cells, and most arrive in the circulation and migrate to an injured surface of bone, attach, and begin to form bone.

The contribution of stem cells in the graft is thought to be small, but the scaffold of bone and its contained growth factors is ideal for the formation of new bone. William Macewen of Glasgow proved the ability of bone graft to regenerate a humerus, and this followed an exemplary series of studies and research.[1]

Circulating monocytes also migrate through the endothelium of adjacent capillaries and become either alternatively activated (AA) macrophages or, under the influence of receptor activator of nuclear factor-κβ (RANK), osteoclasts. These three cell types are the basis of repair, bone regeneration, and remodeling.

The early hematoma forming around an injured bone surface (whether the result of your osteotomy or a fracture) immediately contains stem cells.[2] These multiply rapidly in the hematoma and are in the right place to contribute to healing.

Of note, only the first bleeding from an injured bony surface provides these cells, so the initial hematoma is particularly precious; it should not be thrown away but should be used to amalgamate your bone graft or mix into bone graft substitutes.

The osteoblasts are particularly sensitive to the mechanical environment.

Stability is defined as the maintenance of reduction and correlates with strength. Stiffness is a distinctly different parameter from strength and in fracture or osteotomy fixation is defined as the rigidity of the construct.

Osteoblasts are evolved for a rigid environment with cyclic strains of less than 1% to 2% of their length.

It is particularly useful for graft to be packed tight, for early callus to be bulky, and to limit cyclic movements or a rigid plate be applied while an osteotomy or cancellous fracture is healing.

Weight bearing is good for the maintenance of bone and muscle and the prevention of deep vein thrombosis, but the biological plate of callus or the internal or external fixation must be able to sustain these loads, otherwise weight-bearing loads will need to be limited.

Flexible fixation and early cyclic movements are appropriate for the bulky callus formation needed in diaphyseal fractures.[3]

This external callus is rarely needed in the metaphysic or epiphysis where there is sufficient bulk and well vascularized cancellous bone that will allow rapid union. John Charnley took biopsies at 6 weeks following knee arthrodesis to prove that union is achieved in this time.[4]

TAKING AUTOGRAFT

Cancellous Graft

Before surgery, and even if the possibility is remote, explain to your patient that he or she may need a bone graft and that this will be taken from the iliac crest.

It is useful to know if the patient always sleeps on one side, as you should warn the patient that the donor site will be tender for some time.

When possible, a small sandbag behind the hip is useful.

Prepare the area of the iliac crest with antiseptic, and use adherent paper drapes with an adherent plastic sheet to prevent the drapes from moving around while you are operating on the knee.

Use a skin incision that ends 2 cm from the anterior superior iliac spine to avoid cutting the lateral cutaneous nerve of the thigh. This happens in 10% of cases, and it is of note that in 10% of cases the nerve passes through the bone of the iliac crest.

If there is no spinal anesthetic, it is useful to infiltrate bupivacaine or a similar long-acting anesthetic in the tissues around your incision at this time to prevent painful stimuli reaching the brain.

Cut the fibers of gluteus maximus as they arise from the lip of the iliac crest.

Hemostasis will be needed at the posterior part of your incision.

Use a saw to cut the outer table of the iliac crest and then a broad osteotome to lift a lid. This exposes the cancellous layer (see Fig. 15-1, *A*-*C*).

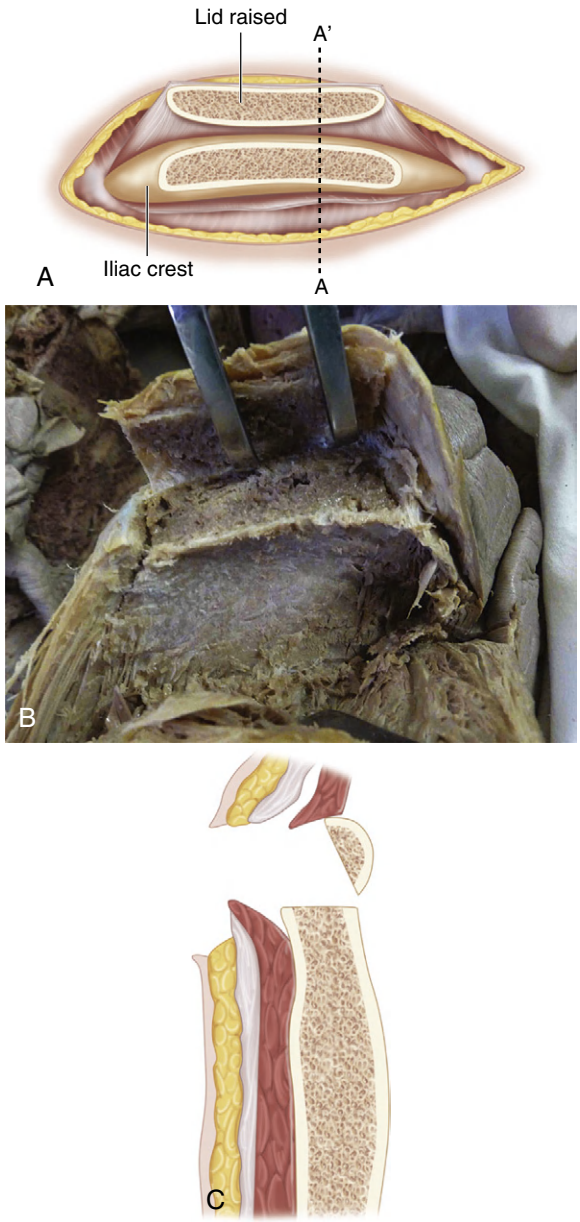

FIGURE 15-1 **A,** Exposure of the iliac crest. A slice of the iliac crest has been raised by an oscillating saw, although a sharp osteotome is an alternative. **B,** Exposure of the iliac crest. Cadaver image. **C,** Section through A-A′. Skin and deep fascia have been incised and the iliac crest osteotomized to expose the internal cancellous bone.

Use a sharp, long-handled curette to remove cancellous bone from between the cortical sheets (Fig. 15-2).

Keep the hematoma that gathers in the wound with your graft.

Corticocancellous Strips

Expose the iliac crest as explained earlier. Use the saw to make an initial vertical cut, and then use a narrow and thin osteotome or chisel to cut thin vertical strips. A hammer is actually safer for controlling the instrument, as

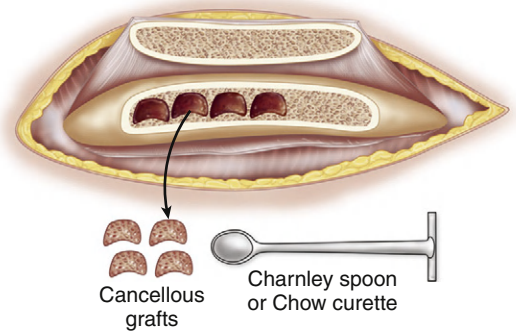

FIGURE 15-2 The cancellous bone has been removed in scoops using a suitable sharp spoon.

it avoids plunging that can occur if an osteotome is pushed by hand (see Fig. 15-3, *A-B*). The saw can also be used to cut the strips.

Tricortical Graft

Expose the iliac crest as descried, and then strip all periosteum from the bone to be taken; otherwise it will not expand in the months and years following incorporation. Macewen described periosteum as the limiting membrane of bone. He undertook many studies on bone and was the first person to use allograft successfully.[1]

Use a saw to cut an accurately sized block including both inner and outer walls of the iliac crest. There is a risk of herniation through the iliac crest, so for large blocks of bone greater than about 4 × 4 cm I would advise suturing a suitable membrane such as one used for inguinal hernia repair across the inner table to reduce this risk.

For closure after harvest of the different bone grafts described earlier in the text, follow these steps:

- Close the lid earlier raised by suturing the inserting fibers of external oblique to the gluteus maximus origin (Fig. 15-4).
- Place a suction drain outside the lid. If placed inside the bone, it will simply extract fresh blood in large volumes.
- Consider using a local anesthetic catheter for continuous infusion, as bone donor sites are very painful.

Percutaneous Techniques

Small amounts of graft are taken most conveniently and with less postoperative pain using systems such as the Precision Bone Grafting System (Kaltee Pty Ltd, Edwardstown, SA, Australia) (see Fig. 15-5). A small incision is made over the iliac crest 2 cm posterior to the anterior superior iliac spine. A trocar and cannula is provided as means of excluding soft tissues.[5]

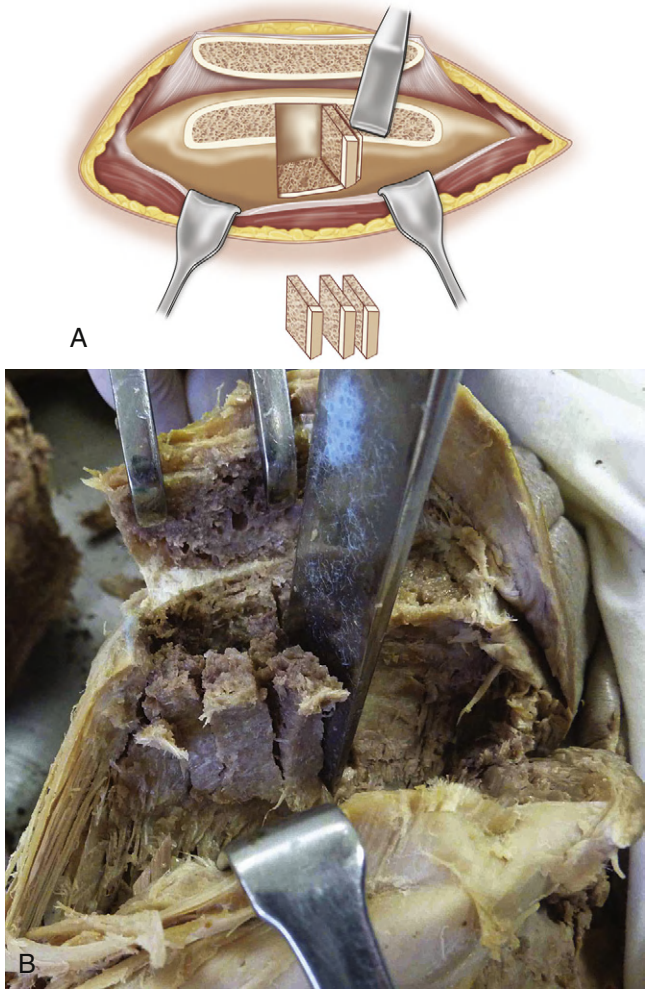

FIGURE 15-3 **A,** The ilium has been more widely exposed by stripping off the origin of gluteus maximus. Retractors are holding the muscle down. A sharp osteotome is being used to cut strips of corticocancellous graft. **B,** Cadaver image of the harvest of corticocancellous grafts.

Attach the large circular handle to the hollow mill of appropriate diameter, and direct it downward and inward in the plane of the pelvis.

It is useful to have a plastic model of the pelvis in theatre if you are unsure of the plane of the pelvis. Alternatively, slip a spike-type retractor down the outer table of the pelvis to ensure the correct orientation.

Rotatory movements of the mill will allow the device to advance and graft to be obtained.

Take care not to plunge the device into the pelvis.

ALLOGRAFT: FRESH FROZEN

Allograft bone will carry a small risk of infection, despite all the screening measures used. All nonautologous graft does, however, carry the advantages of avoiding the complications of an autologous graft.[6]

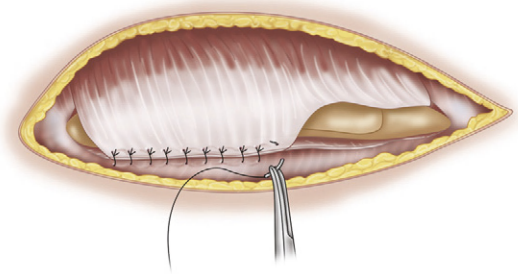

FIGURE 15-4 Closing the muscle fascia will restore the iliac crest and maintain a normal contour. Place a drain outside this layer; otherwise excessive amounts of blood can be aspirated. Consider wound infiltration with a local anesthetic or place a catheter or a pump that can provide a continuous infusion of local anesthetic under the control of the patient.

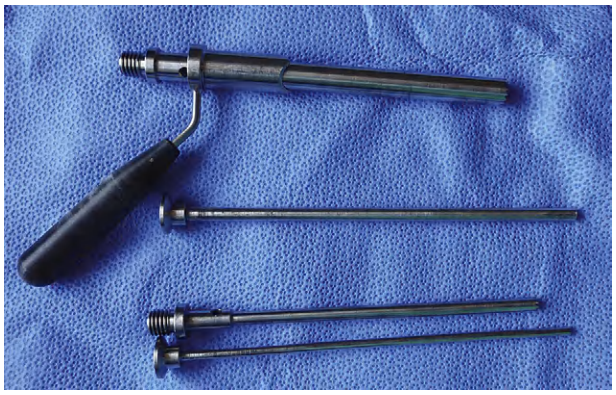

Figure 15-5 The Precision Bone Grafting System allows a percutaneous collection of small grafts. The cannula protects surrounding muscle and a circular handle (not shown) allows the graft to be cut. The blunt trocars provide a means of removing the plugs of graft. Made by Kaltec, www.kaltec.com.au.

Femoral Heads

Femoral heads are useful as bulk graft in osteotomies or in supporting reconstructed tibial plateau. They need to come from initially strong femoral heads found in osteoarthritis, not from femoral head fracture.

Wash away as much fat as possible with a power washer.

Cartilage must be removed, as it will prevent the ingrowth of blood vessels because of the proteoglycan content.

Allograft chips can be produced for impaction grafting using a mill for this purpose.

If large volumes are being filled, then some 1-cm-sized chips should be generated using an osteotome.

A polythene cutting block is better than a wooden one and available from kitchen shops.

A polyethylene jug with the base cut out is useful for preventing loss of these chips while working on the femoral head.

Excellent long-term results are seen either with allograft or with synthetic hydroxyapatite graft.[7]

Cortical Strips

Cortical strips are provided by most bone banks from femoral shaft. They are particularly useful when undertaking plate fixation in osteoporotic bone. Place them opposite your plates so that the screws pass from the plate into the cortical allograft.

In a complex reconstruction there is usually wide exposure so you may have the opportunity to tap these holes from the opposite side to the screw entry.

A clockwise thread is always clockwise, so the thread you generate will be in the correct orientation.

The cortical strip will become incorporated only at the edges, and it will only very slowly become vascularized. This is an advantage, as revascularization will initially weaken the graft.

ALLOGRAFT: FREEZE-DRIED GRAFT

This may be useful as a filler or expander of cancellous graft, but it is weak. Better and stronger bone graft substitutes are now available. Porous or solid hydroxyapatite can be used depending on the strength required.

AUTOGENOUS OSTEOCHONDRAL GRAFTS

These can be taken as Mosaic or the longer OATS plugs (see Chapters 5 and 6). Different systems are available, but choose a device that allows insertion without impaction of the cartilage.

Apoptosis of chondrocytes results from high impaction forces. Apoptosis also follows blunt cutting of the edges, so it is important to use sharp instruments on cartilage edges that will remain.

Bone can be replaced, as well as overlying cartilage loss, with these techniques.

ALLOGRAFT: OSTEOCHONDRAL GRAFT

Those grafts require careful harvesting and regulatory control. It is possible to keep 67% of cells alive for 44 days if the graft is kept sterile.[8] Alternatives include freezing of the graft in sequential steps with increasing concentrations of antifreezing agents such as dimethyl sulfoxide (DMSO). This

TABLE 15-1 Examples of Bone Graft Substitutes

Demineralized Bone Matrix	Grafton, Allomatrix
rhBMP-2	OP-1 Implant
rhBMP-2	INFUSE
β-tri-calcium phosphate (TCP)	Allogran-R
Calcium sulphate	Stimulan
Hydroxyapatite	Actifuse, Allogran-N
Bi-phasic calcium based ceramics	geneX
Bioglass	Vitoss, NovaBone

provides greater flexibility in timing of procedures and can also maintain a high proportion of viable chondrocytes. Close liaison with a tissue bank is necessary for these options.

BONE GRAFT SUBSTITUTES

These are numerous in composition, and handling has greatly improved. Table 15-1 lists only a selection.

There are few reports of histology or of clinical trials against autogenous bone graft demonstrating successful incorporation of bone graft substitutes, but even the simple calcium sulphate is in widespread use.

We use Allogran-N for load bearing in impaction grafting,[7] geneX for tibial, and femoral tensegrity osteotomies,[9] and for cultured stem cells in nonunion.[10] Stimulan is used with added antibiotic for chronic osteomyelitis.

Autologous bone graft is now only used for osteochondral defects in combination in autologous chondrocyte implantation.

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CHAPTER

16

Postoperative Cartilage Repair Rehabilitation

Holly J. Silvers, Karen Hambly

INTRODUCTION

Participation in physical activity is at the forefront of international health promotion agendas, and there is increasing encouragement for the maintenance of participation in sports and exercise activities throughout an individual's life span.[1] Moderate recreational physical exercise is associated with a decrease in the risk of knee osteoarthritis.[2] However, participation in high-impact sports can increase the risk of developing articular cartilage lesions,[3,4] and athletes are at a higher risk of developing knee osteoarthritis.[5] There is increasing evidence that excessive stress on a joint with an articular cartilage lesion may accelerate further degenerative changes[6] and that, if unaddressed, small cartilage defects progress to osteoarthritis.[7] Messner and Maletius established that 75% of young athletes demonstrated radiographic joint space reduction an average of 14 years after sustaining chondral damage and returning to their preinjury sport levels.[8] Consequently, it is not surprising that individuals are seeking out elective surgical procedures more frequently in order to address cartilage defects with the aim of maintaining or regaining their ability to participate in sports and exercise activities.

The ultimate goal for surgical intervention on chondral defects is the restoration of the joint surface to restore "normal" hyaline articular cartilage. Since the late 1980s, orthopaedic surgeons and tissue engineers have immersed themselves in this quest, resulting in the development of a new range of surgical procedures to restore the structure of normal articular cartilage.[9] The treatment of articular cartilage defects has undergone a rapid and exciting evolution in recent years, most notably in the field of advanced cell-based orthobiological technologies. However, although some of these surgical interventions have demonstrated great promise, the new tissue in its current state does not precisely replicate natural articular cartilage in terms of form and function. Consequently, these interventions can only be considered reparative rather than the desired restorative.

Postoperative rehabilitation protocols have been developed for articular cartilage implantation, but they continue to be invalidated in a statistical manner. At present, the evidence base for autologous chondrocyte implantation (ACI) rehabilitation is in its infancy. Prior experience with related surgical procedures that are quickly evolving has shown that when the evidence base for rehabilitation is limited, fears of graft failure are paramount. This concern, in conjunction with the relative minority of therapists with experience treating ACI patients, is likely to be reflected in an overcautious approach to ACI rehabilitation at the present time.

To maximize the benefits of ACI surgery, it is essential for patients to be well informed and educated in order for them to comply to a specific rehabilitation program.[9-11] Patient education, the management of patient expectations, and clear goal setting are indispensable within ACI rehabilitation. These values are reliant on a collaborative environment, with thorough communication between the surgeon, therapist, and patient. In addition, patient selection and the patients' respective characteristics can affect the functional outcome in an inordinate way. deWindt et al. published a study examining the prognostic factors related to cartilage implantation and found that in lesions smaller than 3 cm^2, defect location and defect age were statistically linked to better outcome scores on the knee injury and osteoarthritis outcome score (KOOS) at three years after ACI surgery.[12] We cannot underestimate the notion of patient selection and the characteristics of the defect itself.

The two primary goals for an ACI rehabilitation program are as follows:

1. Local adaptation and remodeling of the repair
2. Return to function (The rehabilitative challenge is to optimize the achievement of these goals within an individualized and progressive framework.)

The three main components of the rehabilitation program are as follows:

1. Progressive weight bearing
2. Restoration of range of motion (ROM)
3. Enhancement of muscle control, restoration of proprioception, and strengthening

The repair site is at its most vulnerable during the first 3 months after ACI. At this time, it is important to avoid impact as well as excessive loading and shearing forces.

There is a consensus of opinion that weight bearing and ROM should be restricted in early rehabilitation, but there is considerable variation across cartilage repair centers as to the extent and duration of these restrictions.

Rehabilitation following an ACI procedure typically begins the day after the surgery, beginning with continuous passive motion (CPM). The frequency, duration, and ROM will depend on the location and size of the lesion. Active and passive motion is also utilized to facilitate the integration of the graft

into the surrounding articular cartilage and subchondral bone. CPM is clinically recommended for 2 to 8 hours per day (depending on the site of the lesion) at one cycle per minute during the early phase of rehabilitation.

This provides a cyclical compression/decompression to allow mechanical stimulation of the graft to promote chondrocyte growth. Additional goals include alleviating pain and edema, addressing soft tissue adaptive changes, restoring muscle strength and function, and gradually including progressive resistive exercise to allow a return to the prior level of function. The insight gained from a preoperative evaluation will be invaluable to the physical therapist when designing the postoperative rehabilitation protocol. Having the knowledge of the underlying biomechanical deficits present before surgery, obtaining the perioperative report to delineate the nature and location of the articular cartilage repair, and having an open dialogue with the respective surgeon will ultimately improve the overall functional outcome of both the surgical and rehabilitation interventions imparted to the patient.

An understanding of applied clinical biomechanics and an appreciation of the forces and loads that will be exerted on the graft are essential in the design of an ACI rehabilitation program.

The contact area (distribution and magnitude), contact load, and contact pressure during rehabilitation should be considered to minimize the danger of damaging the graft and to support the healing process by stimulating the graft physiologically in harmless positions. The articulation and contact area at various degrees of knee flexion are of crucial importance to ACI rehabilitation in relationship to the graft location (Table 16-1).

TABLE 16-1 Summary of Patellar Articulation During Knee Flexion and Extension

	Articulation	Contact Area
Full extension	Patella sits above femoral articular surface and rests on supratrochlear fat pad.	No patellofemoral contact with femur.
10°–20°	Initial contact occurs between inferior patella and trochlea.	Joint contact area increases steadily with flexion. Mean contact area at 10° = 126 mm^2; mean contact area at 60° = 560 mm^2.
30°–60°	Middle surface of patella makes contact with middle third of trochlea.	
60°–90°	Superior patella makes contact with trochlea.	Contact area remains constant.
90°–135°	Superior patella contact area splits into medial and lateral contact areas that articulate with the opposing femoral condyles.	Controversial—research differs, with contact area either leveling off after 90° or continuing to increase with increasing flexion.
135°	Odd facet of patella contacts medial femoral condyle.	
Full flexion	Lateral femoral condyle is fully covered by patella, and medial femoral condyle is nearly completely exposed.	

The patella has a large articulating surface, presenting with the thickest layer of articular cartilage in order to optimize the distribution of forces and stresses.[13-15] The patellar cartilage presents with multiple facets in a pattern that is unique to each individual, and it does not follow the contour of the underlying subchondral bone.[13] The articular surface of the joint is congruent in the axial plane but not in the sagittal plane, and the material properties of the patellar cartilage differ from those in the cartilage of the articulating trochlea.[5,13]

The kinematics of the tibiofemoral joint is initiated, guided, and limited mainly by the cruciate ligaments, muscles, and capsular structures. Injury or loss of function to one of these structures leads to altered arthrokinematics, which may be deleterious to the menisci and cartilage.[16]

During normal activities, the joint contact forces (shear and compressive forces) that are produced are attenuated by several structures of the joint. Shear forces are primarily restrained by the cruciate ligaments. Compressive forces are mostly attenuated by the menisci and the articular cartilage.[5,17] Excessive shear and compressive forces can be deleterious to the menisci and the cartilage. Numerous studies have measured these forces;[16] the exact level of musculoskeletal loading is influenced by a number of individual factors such as weight, gender, movement coordination, and the activity being undertaken.

To develop a safe and effective ACI rehabilitation program, shear forces have to be minimized, and the size and location of the defect have to be known because during several activities only parts of the femur/tibia are articulating.[5,18-21] For example, the posterior aspect of the medial femur condyle contacts the tibia between 90° and 120°; therefore, loading in positions between 0° and 80° of knee flexion are unlikely to be injurious to an ACI in this area.

Neuromuscular reeducation is a critical component in the restoration of functional joint stability. Neuromuscular function broadly involves the detection of afferent input via mechanoreceptors locally in the joint, the processing of a motor response to the stimulus in the central nervous system, and the initiation of an efferent reaction to maintain balance, stability, and mobility.[22] Rehabilitation can assist in the restoration of proprioception, but high-level studies are scarce.[23-25]

Neuromuscular control and retraining involves varying movement speed from slow movements that target the feedback system in the early stages of rehabilitation through progressions to quick movements that focus more on retraining the feed-forward system in the later stages of rehabilitation.

The exercises should be performed throughout the full available ROM and should be performed on both the involved and the uninvolved limbs because

of the likelihood that proprioception deficits are also present in the contralateral limb.[13,26-29] Specific exercises for neuromuscular rehabilitation after ACI should be addressed on an individual basis in line with any weight bearing or ROM restrictions that may be in place.

Generally, proprioceptive challenges tend to be introduced through balance training and progressed in the following ways:

- Bilateral to unilateral stance
- Eyes open to eyes closed
- Slow to quick movements (increasing velocity with proper technique)
- Introduction of unstable foundation (mats, unidirectional/multidirectional wobble boards, and gym balls)
- Introduction of resistance or center of gravity shift
- Introduction of distractions and perturbations
- Introduction of sport or occupation specific drills

In addition, it is essential that more functional, dynamic tests are incorporated into the rehabilitation program. These tests involve working with the patient on the quality of his or her neuromuscular control in activities such as descending stairs, gait, rising from chairs, and in the later stages, running, hopping, and jumping.

HYDROTHERAPY

Exercises in water allow early active mobilization and early loading and improve neuromuscular performance, especially during the initial phase of a rehabilitation program.[15,25,30,31]

The reduction in gravity under water decreases the deleterious effects of weight bearing and dissipates the impact forces on joint structures during movement,[13,32] enabling ROM exercises to be performed in a functional position with a reduced risk of high shear forces under compression. Factors such as water depth and flow will also influence the loading demands on the knee joint, so it is important to base the rehabilitation program on the general principles of hydrotherapy.

Exercises under water produce lower electromyography (EMG) activity during isometric and dynamic conditions when compared to similar exercises on dry land,[33] thereby leading to lower joint forces. Research has shown that an early and intensive application of hydrotherapy for improving coordination and strength during rehabilitation is advisable.[34] In addition, moving in water endows patients with a "feeling of freedom," as they can walk without assistive devices and move around without restriction. This is an important psychological advantage.

MANUAL THERAPY AFTER ACI

Two conceptual approaches to manual therapy need to be mentioned within ACI rehabilitation: the clinical investigation and the application of manual techniques to reestablish physiological mobility.

The ability to define passive movement disorders in a joint, the localization of swelling, the involvement of anatomical structures, and temperature, are necessary for good clinical practice and for a comprehensive tailoring of the rehabilitation.[5,35,36]

Manual therapy as an independent application of manual techniques for general knee disorders is questionable. However, the combination of manual therapy with exercises and specific manual techniques for the enhancement of ROM prove to be more effective than exercises alone.[2,37,38]

Manual therapy is often cited as being used to facilitate the restoration of local function, and ACI rehabilitation protocols often mention gentle manual mobilization techniques to prevent adhesive scar tissue formation.

ELECTROTHERAPEUTIC MODALITIES

The role of electrotherapeutic modalities in postoperative ACI rehabilitation is controversial. In the first few weeks after ACI, rehabilitative exercises are often difficult to perform, not only because of edema and pain but also as a result of the joint receptor feedback disruption that is an inevitable consequence of surgical intervention.

The proposed therapeutic benefits of electrotherapy include pain reduction, increased ROM, reduced edema, enhanced voluntary muscle recruitment, and the promotion of cartilage healing. However, research remains limited and is often restricted to animal studies, and to date, the effect of electrotherapy on chondrocytes and their maturation in vivo is largely unknown.

THERAPEUTIC ULTRASOUND AND LASER

Low-intensity pulsed ultrasound (LIPUS)[28,34,39] and low-level laser therapy[17,25,40,41] have been proposed as providing appropriate stimuli for the acceleration of chondrogenesis. Naito et al. studied the effect of LIPUS on cartilage in a rat osteoarthritis (OA) model using serum biomarkers such as CTX-II (type II collagen degradation) and CPII (type II collagen synthesis). CPII was significantly increased in +LIPUS group compared to –LIPUS and the sham control group. In addition, the histological damage on the cartilage (Mankin score) was ameliorated by LIPUS, and type II collagen was immunohistochemically

increased by LIPUS in the cartilage of an OA model. Of interest, mRNA expression of type II collagen was enhanced by LIPUS in chondrocytes. Low-intensity pulsed ultrasound affects human articular chondrocytes in vitro.[32]

Korstjens et al. investigated whether utilizing LIPUS stimulated chondrocyte proliferation and matrix production in explants of human articular cartilage obtained from donors suffering from unicompartimental osteoarthritis of the knee.[42]

Chondrocytes were exposed to LIPUS (30 mW/cm^2; 20 min/day, 6 days). Stimulation of [35S]-sulphate incorporation into proteoglycans by LIPUS was 1.3-fold higher in degenerative than in collateral monolayers and 1.9-fold higher in explants. LIPUS increased the number of nests containing four to six chondrocytes by 4.8-fold in collateral and by 3.9-fold in degenerative explants. This suggests that LIPUS stimulates chondrocyte proliferation and matrix production in chondrocytes of human articular cartilage in vitro.[42]

Further research studies utilizing LIPUS as a pre- and postoperative modality are necessary. However, the initial findings are quite promising.

INTERFERENTIAL THERAPY

Interferential therapy (IFT) has been shown to have significant effects in reducing postoperative pain, increasing ROM, and reducing edema after knee surgery.[20]

However, there are issues regarding functionality, efficiency of therapy time, and clinician dependence.

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION

The effectiveness of transcutaneous electrical nerve stimulation (TENS) as a pain-relieving modality has been studied in a range of populations with variable outcomes. On one hand, several studies have found TENS to be effective in decreasing pain after knee surgery,[35,43] but other studies have found no significant benefit in pain reduction.[44]

A review of the role of TENS concluded that it had no place in the treatment of acute postoperative pain, as it was not an effective analgesic.[25] Bjordal et al. found that transcutaneous electrical nerve stimulation (TENS, including interferential currents), electroacupuncture (EA), and low-level laser therapy (LLLT) offered clinically relevant pain relieving effects of 18.8 mm [95% CI: 9.6 to 28.1] (n = 414), 21.9 mm [95% CI: 17.3 to 26.5] (n = 73), and 17.7 mm [95% CI: 8.1 to 27.3] (n = 343) on the visual analog scale (VAS), respectively, versus placebo control.[45]

NEUROMUSCULAR ELECTRICAL STIMULATION

An alternative strategy to address arthrogenic muscle inhibition (AMI) utilizes the production of involuntary muscle contractions by neuromuscular electrical stimulation (NMES). Neuromuscular electrical stimulation has been found to be effective in reducing quadriceps extensor lag[46] and in strengthening the quadriceps after knee arthroplasty and anterior cruciate ligament (ACL) reconstruction.[39] However, it is important to note that voluntary muscle strengthening has been found to be just as effective as NMES.[47]

We therefore suggest that NMES is a useful adjunct to the primary exercise program in ACI rehabilitation and acknowledge that there may be an increased role for NMES in those patients who are poorly motivated, have long-term muscle weakness, or are slow responders.

THERAPEUTIC EXERCISE

There is currently no ACI-specific evidence base to directly support the frequency, intensity, type, and timing of exercise modalities during rehabilitation.

Recent studies have advocated the avoidance of certain ranges of knee movement, for example, active knee flexion between 40° and 70° in the early stages after patellofemoral ACI.[48] However, virtually all exercise modalities, including common activities such as walking, cycling, and rowing, involve a knee flexion/extension pattern within this range.

The incorporation of exercise modalities into ACI rehabilitation programs may be better considered in terms of minimizing joint stress as opposed to the complete avoidance of specific ranges of movement. This result can be achieved through the selection, introduction, and progression of exercise modalities that are appropriate for the graft age, size, and location. An understanding of the variations in the magnitude and direction of loads at the knee and the knee flexion angle at which the peak load is exhibited is therefore required for each proposed exercise modality. Exercise modalities should complement but not replace functional movement retraining.

CYCLING

In comparison with other activities of daily living such as walking or stair climbing, the maximum load-moments on the knee joint in cycling are small.[42]

Increases in the cycling workload result in a significant increase in knee load-moments and compressive and shear forces, but increases in the pedaling rate

do not appear to affect the maximum knee load-moment.[42] It is therefore possible to introduce stationary cycling at an early stage as long as resistance is minimal and there is sufficient ROM to allow a complete pedal revolution.

Along with the correct selection of resistance, another important factor in cycling that needs to be considered is saddle height because of its direct influence on knee flexion angles (Table 16-1).[42] If the saddle height is too low, increased patellofemoral joint reaction forces (PFJRFs) occur,[49] especially if combined with too high a gearing; tibiofemoral joint (TFJ) load-moments decrease with increasing saddle height.[37] Too high a saddle height, often as a consequence of insufficient available range of knee flexion, results in frontal plane rocking from the pelvis and hip, which is unfavorable for rehabilitation in terms of control and muscle activation patterns.

High saddle heights are a predisposing factor for an increased risk of developing iliotibial band friction syndrome (ITBFS), especially if knee ROM is not full.[2] An increase in saddle height for a short postoperative period is unlikely to significantly predispose a patient to ITBFS because the condition is predominantly due to overuse.

However, if the saddle height is increased to initially accommodate restrictions in knee ROM, then it is important to normalize the saddle height in parallel with the restoration of knee ROM to reduce the future risk of problems such as ITBFS.

Analysis of the effect that changing the direction of pedaling has on knee joint biomechanics has shown that reverse pedaling requires quadriceps muscle activity in ranges of greater knee flexion compared with forward pedaling[50] and that the vastus medialis is more active in reverse pedaling.[50]

Tibiofemoral compressive loads have been shown to be lower in reverse pedaling, especially near peak extension of the knee.[47] However, PFJRFs have been found to be significantly higher in reverse pedaling compared with forward pedaling.[51]

On the basis of this evidence, reverse pedaling may be considered for TFJ rehabilitation to reduce loading on the knee but should not be advocated for PFJ rehabilitation because of the increases in loading on the knee joint.

OTHER EXERCISE MODALITIES

Other low-impact exercise modalities commonly available in fitness centers include elliptical trainers, cross-trainers, ski trainers, and stair climbers. These modalities have the advantage of being closed kinetic chain activities; however, clinical biomechanical data are limited, and the implications for loading on the knee joint are not fully understood.

A major consideration is the potential lack of synchronization between the hip and knee joints that could increase the transfer of forces to the knee and subsequently increase the stress that is placed on the knee joint.

Whole-body vibration (WBV), in which the patient undergoes a sensory bombardment, has recently become a popular training modality for gaining strength.[40,44,50,52]

Liphardt and associates researched the effects of WBV following 14 days of immobilization of young healthy subjects to see if it would reduce cartilage thickness in the knee and serum cartilage oligomeric matrix protein (COMP) concentration. The control intervention resulted in an overall loss in average cartilage thickness of –8% (pre: 3.08 mm ±0.6 mm, post: 2.82 mm ±0.6 mm) in the weight-bearing regions of the tibia. The average cartilage thickness increased by 21.9% (pre: 2.66 mm ±0.45 mm, post: 3.24 mm ±0.63 mm) with the vibration intervention. No significant differences were found in the weight-bearing regions of the femur. During both interventions, reduced serum COMP concentrations were observed (control intervention: –13.6 ±8.4%, vibration intervention: –9.9 ±3.3%). The results of this study suggest that articular cartilage thickness is sensitive to unloading and that vibration training may be a viable countermeasure against these effects.[53] There is a need for further research concerning cartilage tissue repair, the overload in a sustained exercise position, and the exact effect of different training parameters are all reasons for not implementing whole-body vibration in the early stages of rehabilitation after ACI at this time.

RETURN TO SPORT AFTER ACI

Rehabilitation after ACI is widely recognized as being lengthy, with maximum improvement in knee symptoms taking up to 3 years postoperatively.[20] This is crucial to consider because of the level of impact that the duration of the rehabilitation has on the time out of sport. Only one multicenter study to date has researched return to sport after ACI.[15,24,54]

Mithöfer et al. studied the ability of 45 soccer players to return to soccer in a 40-month (± 4 months) follow-up period after ACI. They found that despite 72% of players reporting good to excellent knee function, only 33% were able to return to soccer.[5,9,39,45]

What is unclear is whether the two thirds of players who did not return to soccer were clinically unable to return to play or whether they either chose to switch to a lower-impact activity or opted not to return to sport at all. The definition of "ability to return to sport" and the relevance of current outcome measures to sporting participation require further exploration and clarification. Younger age and shorter preoperative duration of symptoms were also shown to significantly improve the ability to return to soccer.[55,56]

However, this improved potential to return to soccer could well be due to a greater influence of psychosocial factors and changing life priorities rather than to physiological properties such as healing and chondrocyte maturation.

Clinicians perpetually pontificate the notion of whether or not the rehabilitation process can be accelerated to advance the rehabilitation process more quickly without negatively impacting the newly implanted chondrocytes.

Wondrasch and associates published a study examining the effects of accelerated weight bearing after a matrix associated autologous chrondrocyte implantation (MACI). Thirty-one patients (22 male, 9 female) after MACI on the femoral condyle were randomly assigned to the accelerated weight-bearing group (group A) or the delayed weight-bearing group (group B). In both groups, there were no differences with regard to the clinical outcome. For the radiological outcome, group A showed a higher prevalence of bone marrow edema after 6 months without correlation to the clinical outcome (P=0.06-0.1). However, after 104 weeks, there were no differences in the radiological outcome between group A and group B. A rehabilitation protocol with accelerated weight bearing leads to good clinical and functional outcome after 2 years without jeopardizing the healing graft.[36]

Della Villa et al. also recognized the challenge of developing a timely postoperative rehabilitation that would optimize a return to preinjury activities without jeopardizing the integrity of the newly implanted graft. Thirty-one athletic males with a grade 3-4 cartilage lesion of the medial or lateral femoral condyle or trochlea were evaluated at 1-, 2-, and 5-year follow-up. The athletic cohort was compared with a similar control cohort of 34 nonathletic patients who were treated with autologous chondrocyte implantation. A greater improvement in the group of athletes was achieved at 5-year follow-up (P=0.037) in the self-assessment of quality of life and International Knee Documentation Committee (IKDC) subjective evaluation at 12 months and at 5 years of follow-up (P=0.001 and P=0.002, respectively). When analyzing the return to sports activity, 80.6% of the athletes returned to their previous activity level in 12.4±1.6 months; athletes treated with the on-field rehabilitation and isokinetic exercise program had faster recovery and an even earlier return to competition (10.6±2.0 months). For optimal results, autologous chondrocyte implantation rehabilitation should not only follow but also facilitate the process of graft maturation. Intensive rehabilitation may safely allow a faster return to competition and also influence positively the clinical outcome at medium-term follow-up.[17]

With the uncertainties that surround ACI rehabilitation at present, the general consensus of opinion among cartilage repair centers appears to be that ACI surgery should be targeted on the reduction of symptoms and on improving functional daily activities rather than as a method of returning to high-level sports participation for competitive athletes with chondral damage.

General recommendations are that low-impact sports and exercise such as swimming, cycling, and golf can usually be resumed within 6 months.[1,34,42,52,57-59] Recommendations for timescales for a return to higher-impact activities such as racquet sports, team sports, martial arts, and running range from an earliest postoperative return at 12 months up to 18 months. However, there is considerable variation between people, so the return to sports after ACI should be based on the key criteria that address the following factors:

- The patient's graft is able to withstand the specific demands of the chosen sport
- The patient has been rehabilitated to a point at which he or she is able to safely return to sports involvement

Where a return to sport is planned, it is important that sport-specific activities are included as functional progressions within the rehabilitation program.

Discussion

Cartilage repair rehabilitation is lengthy,[27,60,61] and autologous chondrocyte implantation (ACI) has one of the longest rehabilitation processes in the field of elective orthopaedic surgery. Numerous papers have been published since the late 1990s documenting surgical techniques and clinical outcomes of articular cartilage repair procedures.[1,43,62-65]

The quality of these cartilage repair studies has been variable, and follow-up time periods are generally short.[40,66,67] Time frames have been indicated, but we do not recommend the adoption of a rigid timetable, as the proposed phases are not mutually exclusive and considerable variation exists between people. Modifications to the rehabilitation program may be necessary based on defect size, location, age, previous activity level, concomitant surgical procedures, and individual patient demands.[57,68]

Progression should not be totally dependent on postoperative time; it is more important that goals are reached at the end of each phase. Effective individual patient programming is reliant on good patient education and on regular, informative communication between all members of the rehabilitation team.

SUMMARY

Osteoarthritis (OA) is a degenerative disease with a tremendously detrimental impact on an individual's quality of life. It is the most common form of arthritis, and it accounts for more pathology during walking, stair climbing, and other lower-extremity activities of daily living than any other disease, especially in the elderly.[50] Its economic impact is truly remarkable. Yelin completed a meta-analysis to determine that the estimated cost of treating

OA in the United States is $15.5 billion, roughly three times the cost of rheumatoid arthritis.[31]

Articular cartilage lesions have produced deleterious effects to the patients subjected to them. The goal to achieve full restoration of hyaline cartilage to a compromised joint continues to elude the medical community. The surgical interventions to address such lesions and the subsequent postoperative rehabilitation efforts to address them continue to be actively researched and refined.

INDICATIONS

Articular cartilage defects are not life threatening, but they can, and frequently do, threaten a person's quality of life, especially in an active population.[10,28] Internationally, thousands of people each year experience symptoms related to chondral defects, with the knee being the most prevalent joint affected.[25] Articular cartilage lesions of the knee are relatively common, one study found that of more than 31,000 arthroscopies, up to 63% of patients had articular cartilage lesions.[1] More recently, in 993 arthroscopies, 11% of patients demonstrated a localized full-thickness cartilage lesion,[69] and in 1000 arthroscopies, 19% of patients had a focal chondral or osteochondral defect.[70] It has been estimated that between 4% and 11% of cartilage lesions may be suitable for cartilage repair procedures.[58,69]

RESULTS

There is a distinct paucity of research regarding the optimal rehabilitation following an articular cartilage repair procedure. Many research studies published in peer review journals do not specifically detail the nuances of the rehabilitation program, the compliance to such a program, and the functional outcome of the patient longitudinally. To date, many of the standardized protocols have been conservative because of the lack of level I research in this area. Recent studies by Wondrasch and Della Villa have reported on the role of accelerated weight bearing after an articular cartilage repair.[33,36]

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