CHAPTER
49 Articular Cartilage

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In This Chapter

INTRODUCTION

- **Cartilage injuries are increasingly recognized due to dramatic increases in sports participation at all ages and improvements in musculoskeletal imaging.**
- **Pain and symptoms from articular cartilage lesions are variable. Similar-appearing articular cartilage lesions in the knee may be asymptomatic or may cause disabling pain, swelling, or mechanical symptoms.**
- **The decision of how to treat articular cartilage lesions is dependent on lesion characteristics such as location, size, and depth coupled with patient factors such as symptom intensity, age, activity level, and the presence of concomitant pathology.**
- **A variety of methods are available to treat articular cartilage lesions, including microfracture, autologous osteochondral transplant, allograft osteochondral transplant, and ACI.**
- **The success following surgery for a focal chondral or osteochondral defect is dependent on concomitant treatment of additional knee pathology and equally dependent on patient commitment to and diligence in the postoperative physical therapy regimen.**

CLINICAL FEATURES AND EVALUATION

Complete evaluation of the patient with an articular cartilage injury of the knee includes a thorough history, physical examination, specific radiographs, and review of previous surgical notes or arthroscopic images.

The initial step in the workup is the history. This should include mechanism of injury, time course and quality of symptoms, and review of previous treatments and the effects of those treatments. Patients will often report pain and swelling with weight bearing and increased activity. Direct communication with previous surgeons may be required to have a more complete understanding of the surgical history and pathoanatomy within the patient's knee.

The mechanism of injury, if determined, is a valuable source of information and should be noted. Damage to articular cartilage can be caused by an acute injury yielding a focal chondral or osteochondral defect, can be the result of a chronic development such as osteochondritis dissecans (typically in younger patients), or simply present insidiously due to focal or diffuse degeneration related to mechanical (e.g., malalignment or instability) or genetic factors.

During the physical examination, the surgeon should be careful not to assume that the articular cartilage lesion is responsible for all symptoms. Often concomitant pathology exists and can play a role in the symptoms that the patient may be experiencing. It is important to also assess gait and alignment carefully as well as range of motion and patellofemoral tracking. Evaluation for effusion, ligamentous integrity, and areas of point tenderness or crepitus are additionally valuable in considering concomitant pathologies of the knee.

Required radiographs include standing anteroposterior, lateral, patellar skyline (or Merchant), a 45-degree flexion posteroanterior weight-bearing view, and full-length alignment film. The posteroanterior flexion view is crucial for adequate assessment of the posterior femoral condyles where significant wear may not be recognized on a standard weight-bearing anteroposterior view. Full-length alignment films should be obtained to assess the mechanical axis. 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.

Other important information can come from imaging of the knee with magnetic resonance imaging. The quality of magnetic resonance imaging technology continues to improve dramatically. In fact, magnetic resonance has established a niche in evaluating articular cartilage irregularities and the degree of cartilage pathology, while also providing information regarding ligament injury. With high-resolution fast spin echo sequencing techniques in the sagittal, coronal, and axial planes, articular cartilage surfaces can be well imaged.[1,2] Computed tomography scanning may be necessary to assess the subchondral bone for anatomic considerations including defect geometry and depth 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 for instability. This is performed routinely prior to every knee arthroscopy. The first operation after the diagnosis of an articular cartilage defect is often not the definitive proce-

dure. At times, arthroscopy is performed initially as a diagnostic tool to assess the lesion, the surrounding articular surfaces in the uninvolved compartments, and the state of the menisci and to determine the presence or absence of additional pathology. If one is considering definitive treatment with 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. Finally, in the setting of mechanical axis malalignment, preoperative discussions might include performing an osteotomy at the index procedure, especially in slightly older patients who might have articular disease patterns considered more marginal for cartilage restoration. Most importantly, however, the initial arthroscopy should be used to define the lesion fully in terms of its location, geography, surface area, and depth. Careful attention to alternative sources of pain and the condition of opposing surfaces is also important.

Lesions are most often graded based on direct visualization using the system of Outerbridge[3] or the International Cartilage Repair Society, which established a grading system to help surgeons communicate clearly about cartilage lesions.[4] The two systems are nearly identical and grade the degree of cartilage damage on a scale from 0 to 4, with a 0 indicating normal cartilage and a 4 indicating injury that penetrates the subchondral bone. A grade of 2 indicates nearly normal cartilage with minor softening or superficial fissures. Grade 3 reflects fissuring to the level of, but not violating, the subchondral bone. Regardless of the system used, always classify lesions with a written and diagrammatic description including the delineation of how the defect contacts opposing surfaces in varying degrees of flexion. In establishing a surgical plan at the time of initial arthroscopy, consider the status of the menisci for the possible inclusion of a meniscal transplant as well as the standing mechanical axis for consideration of a concomitant osteotomy.

RELEVANT ANATOMY AND BASIC SCIENCE

Chondrocytes of mesenchymal origin are responsible for the production and maintenance of the extracellular matrix of collagen. This matrix is composed mainly of type II collagen but also includes types V, VI, IX, X, XI, XII, and XIV to a lesser degree. The combination of this collagen network and water affords the viscoelastic properties that resist compressive and shear forces experienced between the articulating surfaces. Articular cartilage provides a smooth, nearly frictionless surface that protects the subchondral bone through shock absorption and wear resistance.

While highly specialized and multifunctional, this tissue ironically maintains itself with little contribution from systemic sources and is in fact avascular. As a consequence, hyaline cartilage has trouble repairing itself when damaged. Should the defect penetrate the subchondral bone (i.e., full thickness), the defect may fill with fibrocartilage repair tissue. This replacement may be sufficient in some instances to render patients less symptomatic but is typically inferior in ultrastructure and function compared to native hyaline cartilage. At this juncture, healthy articular cartilage has properties that are unmatched by any man-made substance.

TREATMENT OPTIONS

The spectrum of articular cartilage injury is broad and varies principally in terms of location, size, and depth. A diligent evaluation of these characteristics as well as considerations for patient age, activity level, concomitant pathology, and symptomatology is crucial to making appropriate treatment decisions.

It is important to recognize that not all chondral lesions cause symptoms. Conversely, not all symptoms are related to the chondral or osteochondral defect. The first step in management of articular cartilage lesions is usually conservative, nonsurgical treatment. Common methods include weight loss, shoe modification, bracing, cane use, and various pharmacologic interventions. Physical therapy may also play a role by improving strength and flexibility; however, this and the previously mentioned treatment are often ineffective in reducing the symptoms associated with an articular cartilage lesion. Medications and nutritional supplements that should be considered are nonsteroidal anti-inflammatory drugs, acetaminophen, or glucosamine and chondroitin sulfate. Intra-articular injections of corticosteroid and hyaluronic acid can be helpful for symptom control but are generally reserved for the older population.

If the preceding conservative treatments prove ineffective, both the patient and clinician need to consider surgical options. The specific surgical technique, or techniques, chosen will depend first on the general state of the knee with regard to mechanical alignment, meniscus status, and compartment involvement. Any clinically significant malalignment must be corrected before or concurrently with the cartilage restoration procedure or the restoration will likely fail because the affected compartment will continue to suffer unnecessarily high loads. In a demand-match approach, the senior author (B.J.C.) routinely performs a medial opening wedge high tibial osteotomy for the patient with a medial compartment lesion and varus alignment, a distal femoral osteotomy for the knee with valgus alignment and a lateral compartment lesion, or an anteromedialization of the tibial tubercle for most patellofemoral defects. Given this generality, it is important to note the medial shift in patellofemoral pressures as a result of anteromedialization.[5] For example, in cases of superomedial patellar disease, no anteromedialization is performed because the procedure would overload the repaired defect.

In addition to mechanical malalignment, any untreated ligament insufficiency or significant meniscus deficiency is a contraindication to articular cartilage restoration alone. While most comorbidities can be corrected simultaneously with cartilage restoration; staging of procedures is an acceptable alternative. For all surgical candidates, it is necessary that a comprehensive plan be formed and this plan be discussed with each patient so he or she understands the procedure and complies with postoperative instructions. Whenever possible, the initial treatment of an articular cartilage lesion should allow for further treatment if unsuccessful.

Despite the availability of several techniques, judicial use of each remains challenging. There are relatively few convincing data on the superiority of one technique over another for some lesions. In fact, every articular cartilage lesion is different and requires its own, unique evaluation. Part of the difficulty in treatment decision making is the fact that the natural history of asymptomatic lesions is unclear and unpredictable. However, it is widely believed that if left untreated, a symptomatic cartilage lesion is likely to persist or worsen.[6,7] The risk of a lesion being symptomatic likely depends on its location, size, depth, patient activity level, and any associated knee pathology. Pre-existing instability, meniscal damage, or malalignment provides an inhospitable environment for any articular cartilage lesion and predisposes it to progressive degeneration.

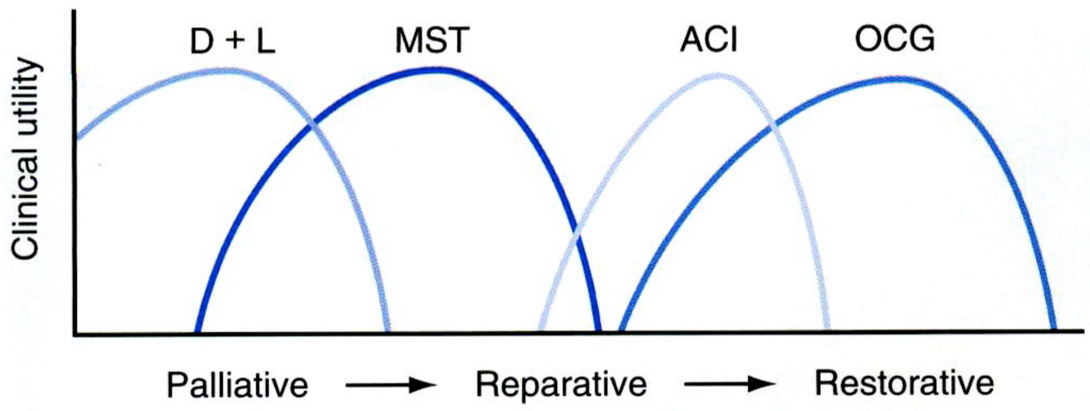

Figure 49-1 Treatment options for articular cartilage lesions overlap and range from palliative to reparative to restorative procedures. Maximal clinical utility for each should be recognized within its range. ACI, autologous chondrocyte implantation; D + L, dèbridement and lavage; MST, marrow stimulation techniques; OCG, osteochondral grafting.

Surgery

There are essentially four distinct surgical procedures used to treat chondral or osteochondral lesions in the knee. These include microfracture, osteochondral autograft, osteochondral allograft, and ACI. We conceptualize the treatment possibilities in categories depending on the clinical scenario. The categories range from palliative (débridement/lavage), intended to reduce mechanical irritation and inflammatory mediators, to reparative (microfracture, a marrow stimulation technique), designed to release pluripotential cells from the bone marrow that proliferate as fibrocartilage repair cells in the defect, to restorative (osteochondral grafting, either autograft or allograft), which replaces the articular cartilage and its subchondral bone. ACI bridges the boundary between a reparative technique and a restorative one (Fig. 49-1). The common goal to each of these procedures is to provide the patient with symptom reduction and a return to a high level of function while postponing, if not eliminating, the need for arthroplasty. Each recommended procedure should theoretically allow additional opportunity for cartilage restoration should the initial treatment fail.

Treatment Algorithm

Surgical treatment of a focal chondral defect is based on the characteristics of the lesion, local comorbidities, and the age and activity level of the patient. Important characteristics of the lesion include its size and depth, degree of containment, and location. For patellofemoral lesions, an anteromedialization osteotomy of the tibial tubercle is generally recommended to unload the repaired defect. For femoral condyle lesions, an intact meniscus and a mechanical axis that does not pass through the affected compartment will provide the ideal environment for healing and the greatest chance for symptom relief.

Typically, arthroscopic débridement with marrow stimulation is a reasonable first-line treatment, especially if performed during the initial evaluation of a defect. The intention is to reduce symptoms and provide long-term relief without eliminating options for further restorative or reparative procedures if needed. Secondary treatment for smaller lesions (i.e., 2 to 4 cm^2) includes revision with osteochondral autograft transplantation. Larger lesions may be amenable to ACI as ACI is best used in younger patients with contained shallow lesions that are 2 to 10 cm^2. Deeper lesions that are larger may be best treated with fresh osteochondral allograft transplantation. Figure 49-2 illustrates a typical treatment algorithm that considers lesion location, size, and the patient's level of physical demand.[8]

Surgical Techniques

Microfracture

Microfracture is a marrow-stimulating technique designed to allow fibrocartilage reparative tissue to form in a contained articular chondral lesion. This technique, performed arthroscopically,

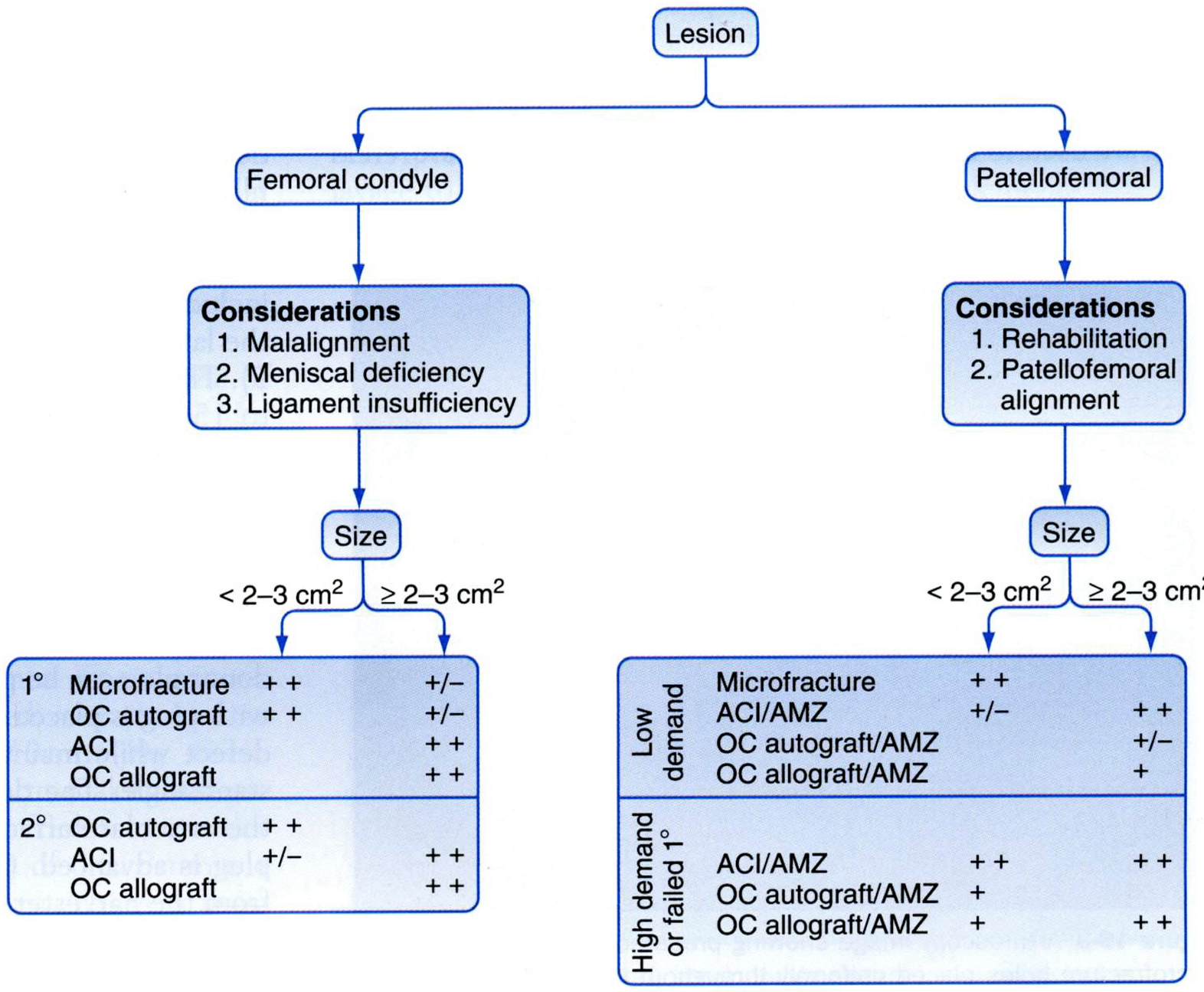

Figure 49-2 Treatment algorithm for focal chondral defects of the femoral condyle or patellofemoral joint. For femoral condyle lesions, assessment must first be made regarding malalignment, meniscus status, and ligamentous stability as these comorbidities must be corrected. For trochlear and patellar lesions, patellofemoral alignment must be assessed and anteromedialization considered. High-demand individuals are more likely to require a secondary line of treatment. ACI, autologous chondrocyte implantation; AMZ, anteromedialization; OC, osteochondral.

involves the creation of perforations through the subchondral bone that allow the release of blood and mesenchymal cells that form a clot in the lesion and proliferate and differentiate into a fibrocartilage repair tissue.[9]

The optimal patient for microfracture is the young, compliant patient with a focal grade III or IV articular cartilage lesion surrounded by normal cartilage without bone loss. Contraindications include significant bone loss, malalignment, or an opposing "kissing" lesion. The main advantages of this procedure are its low cost and relatively low technical difficulty. In addition, it is a procedure that does not "burn bridges" for future treatment options (i.e., it does not preclude subsequent restorative techniques if necessary). The major drawback of the procedure is that the repair tissue that forms is composed primarily of type I collagen, which is a fibrocartilage that has inferior biomechanical properties to normal hyaline cartilage and may not withstand prolonged high levels of activity with excessive biomechanical forces across a surface with reparative tissue.

The first step in microfracture is to prepare the lesion by removing all damaged cartilage, leaving a perpendicular edge of healthy articular cartilage that results in a "well-shouldered" lesion to contain the clot and reduce shear and compression of the lesion. The calcified layer of bone should then be removed with a curet. An awl is used to create holes in the lesion 2 to 3 mm apart and approximately 2 to 4 mm deep.[10] Begin by placing holes in the periphery of the lesion and work centrally until the entire surface of the lesion has been uniformly covered (Fig. 49-3). It is important to avoid subchondral bone collapse that can result from the creation of converging holes or holes placed too close together. The final step is to clamp the arthroscopy fluid inflow and confirm that blood and fat droplets emerge from each hole (Fig. 49-4). This ensures that the microfracture awl penetrated the underlying cancellous bone and that a clot is likely to form in the defect.

Osteochondral Autograft

During an osteochondral autograft procedure, a healthy intact osteochondral plug is transferred from a low weight-bearing area to the damaged lesion that is removed as a plug of matching size. Mosaicplasty is the term for this technique when multiple small plugs are used to fill a larger area. Osteochondral autograft refers to the osteochondral articular transfer system devised and marketed by Arthrex Inc. (Naples, FL). This technique is limited by the amount of donor tissue that can be used.

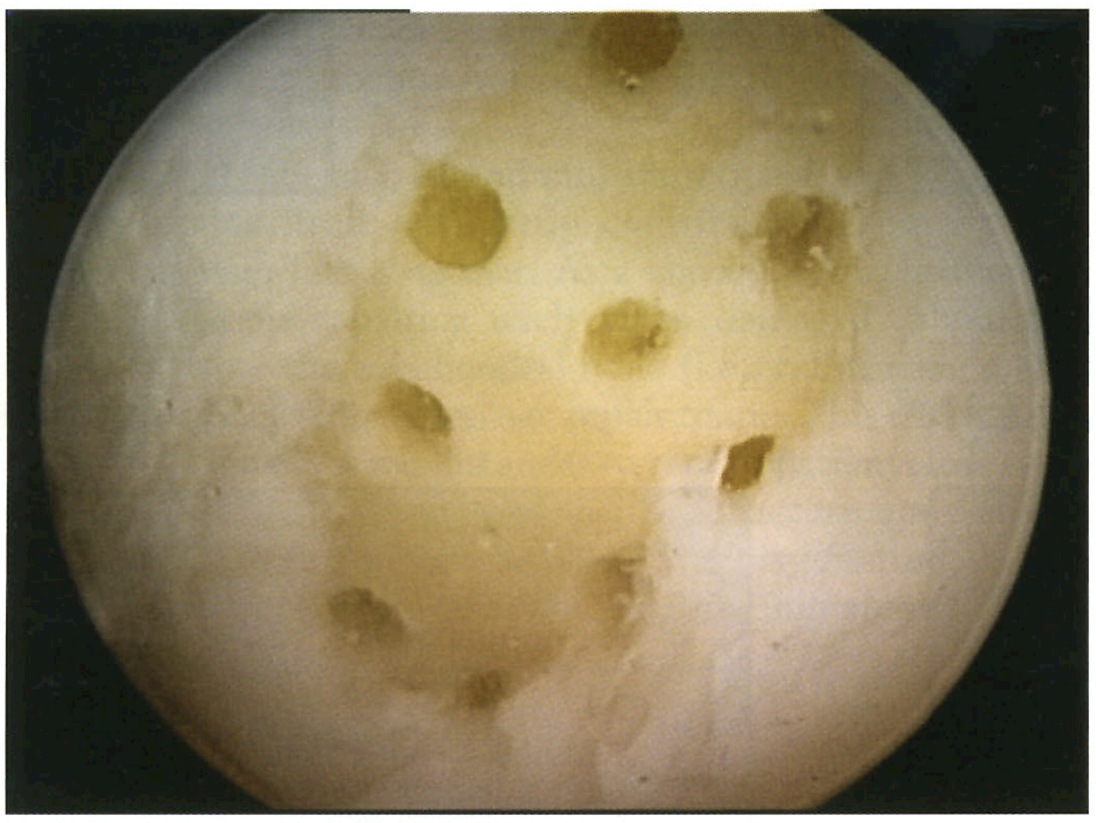

Figure 49-3 Arthroscopy image showing prepared lesion with microfracture holes placed uniformly throughout lesion 3 to 4 mm apart.

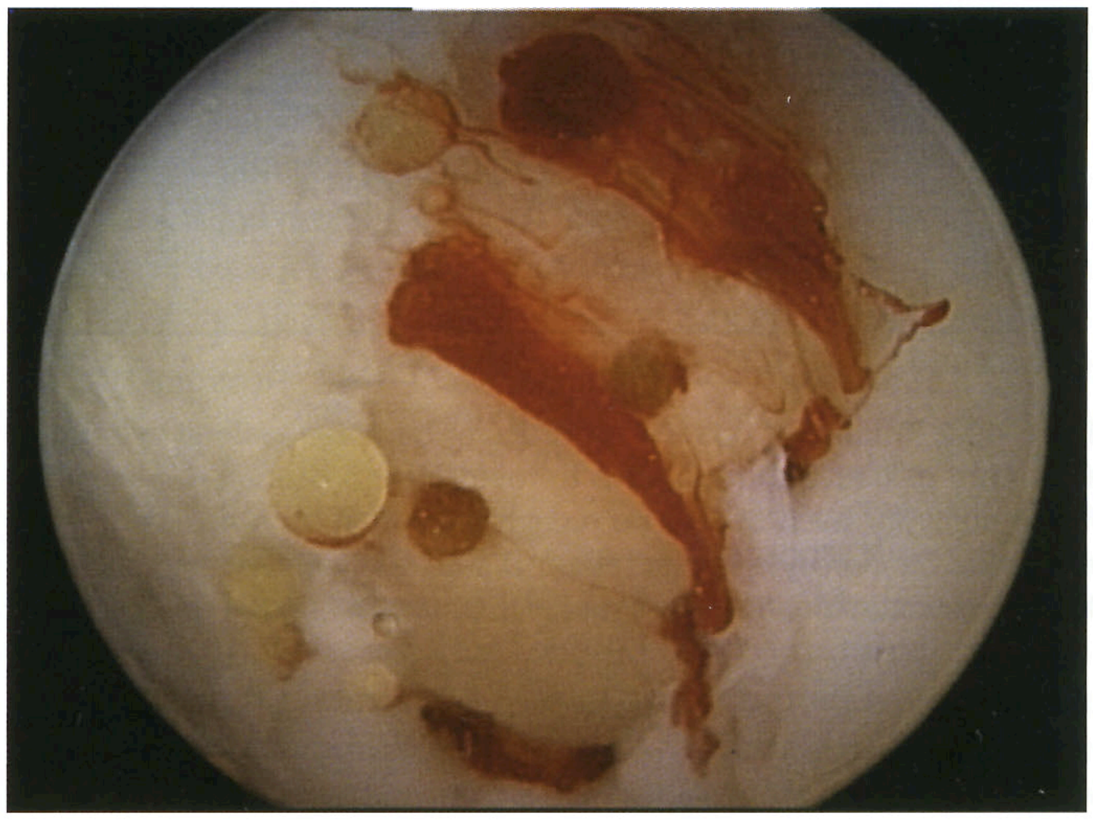

Figure 49-4 Arthroscopy image depicting adequate penetration into bleeding subchondral bone.

The ideal lesion for this technique is a symptomatic distal femoral condyle defect in a knee with intact menisci and normal alignment. The senior author has the best success with lesions that are 1 to 2 cm in diameter, although larger lesions can also be treated. One disadvantage of the technique is the donor site morbidity, which increases as the size of the lesion treated increases. The major advantage of this procedure over osteochondral allograft is that the donor plug is the patient's own, so there is no infectious or immunologic risk from the transplant.

The entire procedure can be performed arthroscopically or through a small arthrotomy, depending on the size and location of the defect. The senior author uses the osteochondral autograft system (Arthrex Inc.); however, there are many commercially available systems. The first step is to use a sizer to determine the number and size of grafts that will be required to fill the area of the lesion. The graft harvester of appropriate size is then introduced perpendicular to the donor site typically through a small parapatellar arthrotomy. The typical donor sites include the femoral intercondylar notch and the periphery of the lateral femur just proximal to the sulcus terminalis (Fig. 49-5). The harvester is then tapped into the bone to a depth of 12 to 15 mm, twisted sharply 90 degrees clockwise and counterclockwise, and removed with a parallel pull. The donor plug is removed from the harvester with a plunger that will push the donor plug into the recipient hole once this has been prepared.

The recipient hole is prepared to an equal depth and extracted in an identical manner. A constant knee flexion angle is required during this portion of the procedure, so that the donor plug can be placed at the same angle. The donor harvester with plug is placed over the recipient site and advanced into the defect while maintaining perpendicular orientation and a constant angle. The donor harvester has a tendency to "back off" the articular surface and should be held securely as the donor plug is advanced. Once the donor plug has been fully released from the harvester, the plug will typically rest a few millimeters proud. The final seating of the plug is performed with an oversized tamp using a gentle tapping technique to minimize damage

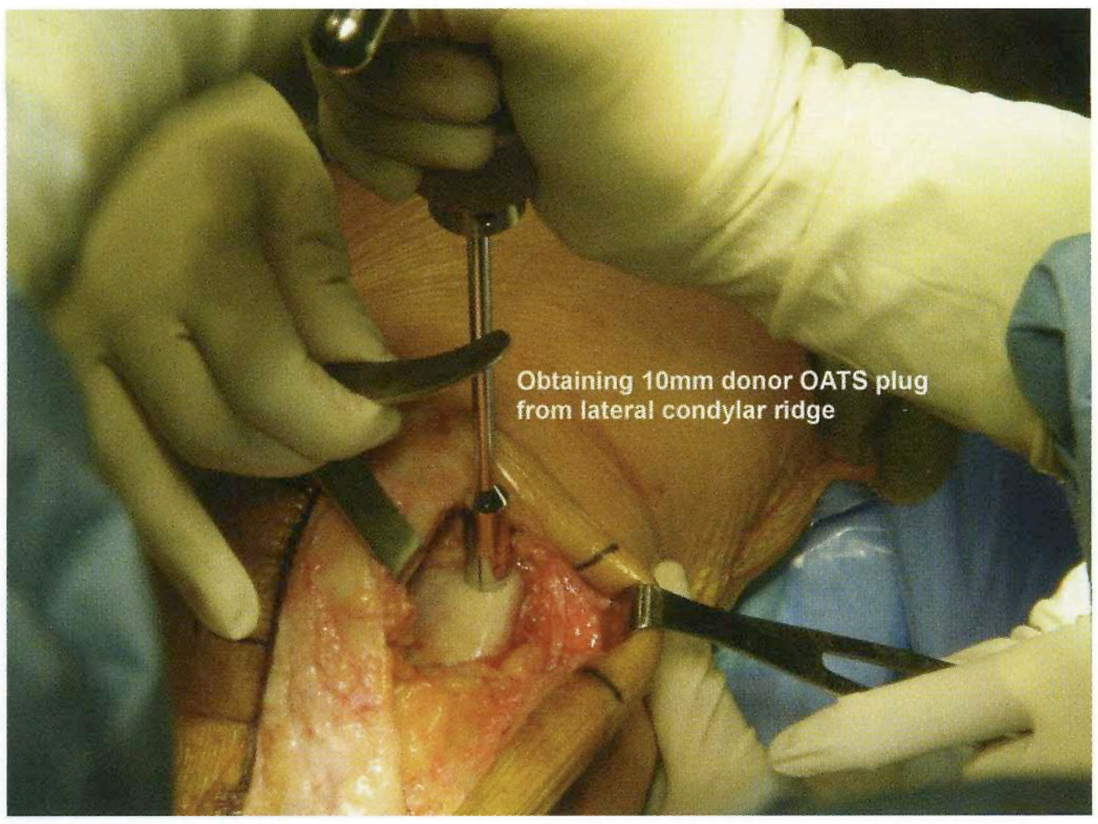

Figure 49-5 Typical harvest site for osteochondral autografts (OATS).

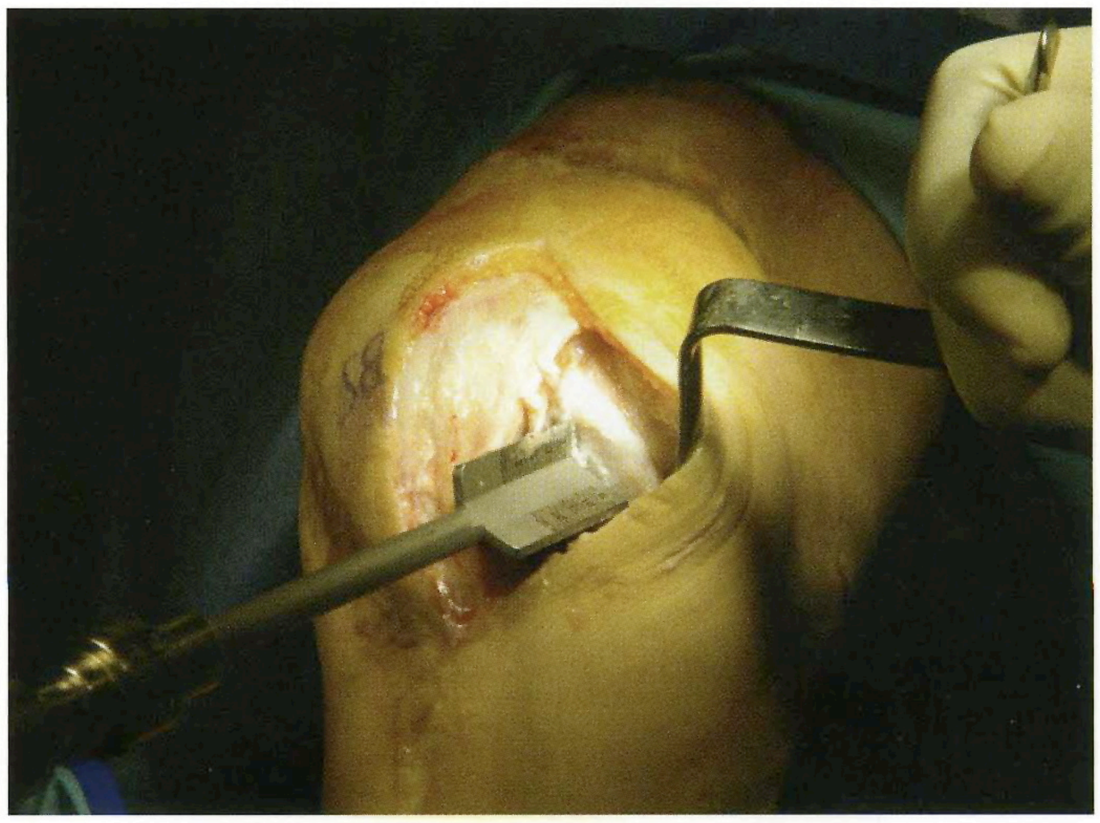

Figure 49-6 Boring the defect to create cylinder recipient site for osteochondral allograft.

to the articular cartilage. The plug should be seated flush with the surrounding cartilage.

If a mosaicplasty technique is being performed, all plugs (size and depth) should be carefully planned before placing the first one. The difficulty in using multiple smaller plugs is in creating a convexity to match the surrounding articular surface. In addition, the senior author has seen a number of patients whose smaller plugs have delaminated over relatively short periods of time postoperatively and therefore chooses to use the smallest number of larger diameter plugs possible (i.e., 10-mm diameter).

Osteochondral Allograft

This technique is employed to treat larger lesions or lesions with significant bone loss. As a salvage restorative technique, osteochondral allografts have the advantage of providing fully formed articular cartilage without limitation on size and without donor harvest morbidity. Unfortunately, a small but not negligible risk still remains with allograft tissue with respect to disease transmission and immunogenicity. In addition, the problem of cell viability at the time of implantation remains. Currently, most osteochondral allografts are transplanted as prolonged-fresh grafts stored at 4°C for between 14 and 28 days to maximally preserve cell viability, which directly correlates with the success of implantation.[11]

A parapatellar mini-arthrotomy is performed on the side of the lesion. The lesion is carefully evaluated to determine the graft shape required to best fit the defect. We use an instrumentation system (Arthrex Inc.) to size and harvest a cylindrical plug from the allograft. After matching the defect diameter to the sizing cylinder that best covers the defect, the osteochondral allograft plug is obtained. The sizing cylinder is placed perpendicular to the defect and a guide pin is drilled in the center of the lesion to a depth of 20 to 30 mm. The appropriately sized cannulated counter bore is drilled over the pin to create a cylindrical defect to a depth of 8 to 10 mm (Fig. 49-6). A small drill or Kirschner wire is then used to make multiple small perforations in the bottom of the prepared defect in order to create vascular access channels. The depth of 6 to 8 mm is a compromise between having sufficient bone to achieve a press fit and minimizing the amount of immunogenic bone implanted. The 12-o'clock position of the defect is marked with a sterile marking pen to help with orientation of the donor plug. Each of the quadrants in the defect is measured with a depth gauge and used to tailor the exact depth of final cut of the donor allograft plug.

Attention is then turned to the allograft preparation. A flat surface must be cut first in the allograft, which makes securing the graft in the workstation easier (Fig. 49-7). The bushing on the workstation is then secured over the allograft so that the harvested plug will have a contour that best matches the defect site. With smaller defects ($<2\,cm^2$), nearly any portion of a hemicondyle allograft will closely match the defect curvature. The 12-o'clock position on the allograft is marked so that it can be easily lined up with the same position previously marked at the defect. The donor graft is then drilled through its entire depth with a harvester, and the graft is removed (Fig. 49-8). The depth of each of the four quadrants previously measured at the donor site is marked on the allograft plug, and a final cut is made with an oscillating saw (Fig. 49-9). The edge of the allograft can be slightly beveled to facilitate insertion. Prior to insertion, the bony portion of the allograft should be irrigated with a pulse lavage to remove any residual bone marrow elements that may initiate an immune response.

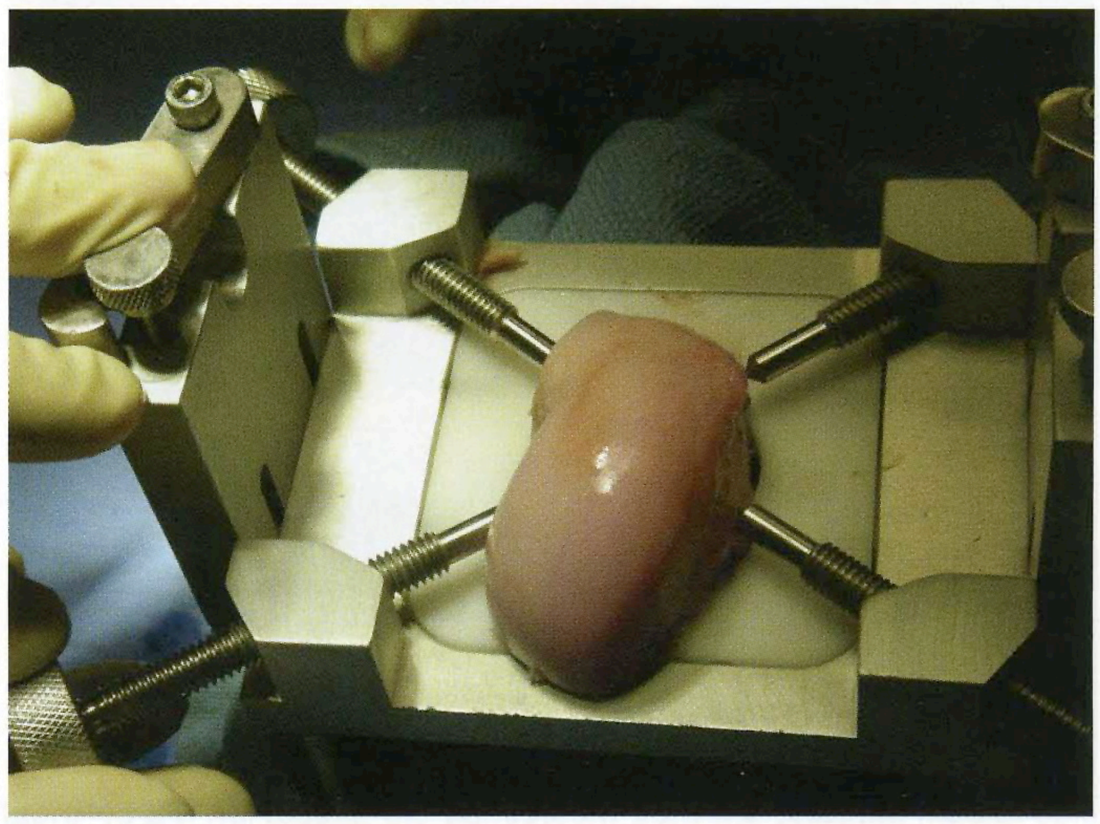

Figure 49-7 Allograft hemicondyle secured in a workstation.

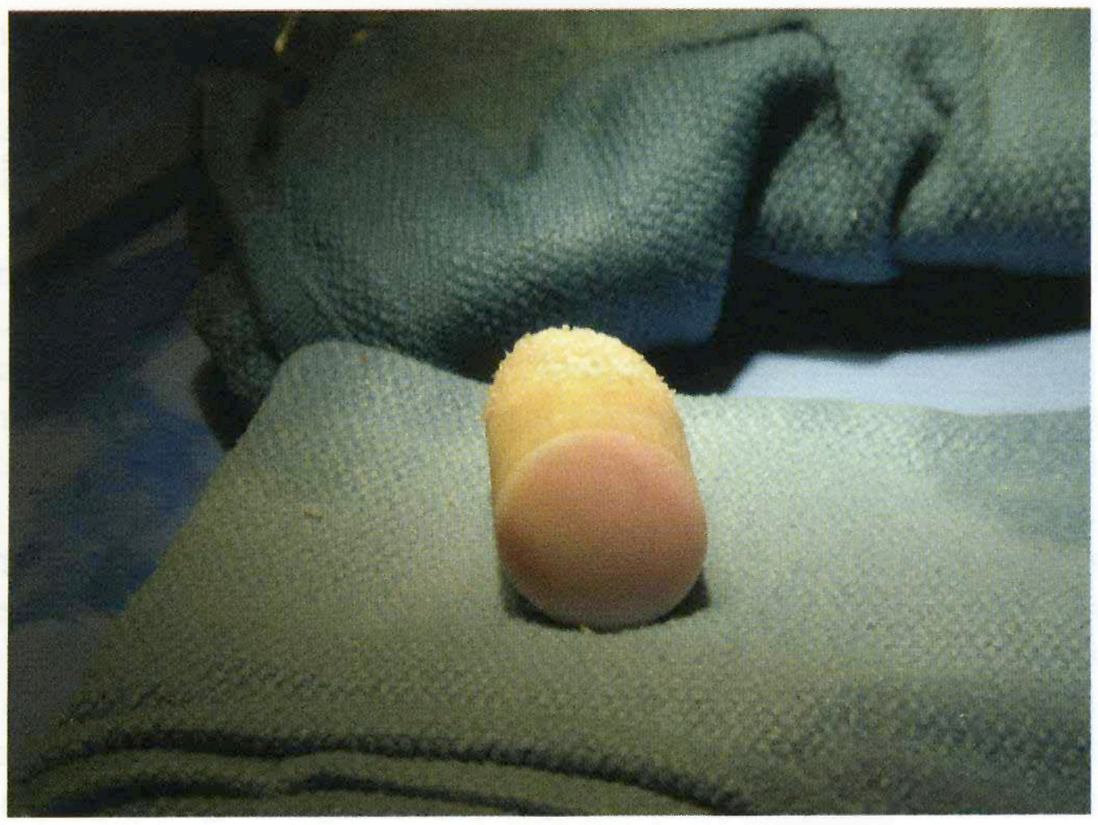

Figure 49-8 Initial allograft cylinder cut from hemicondyle.

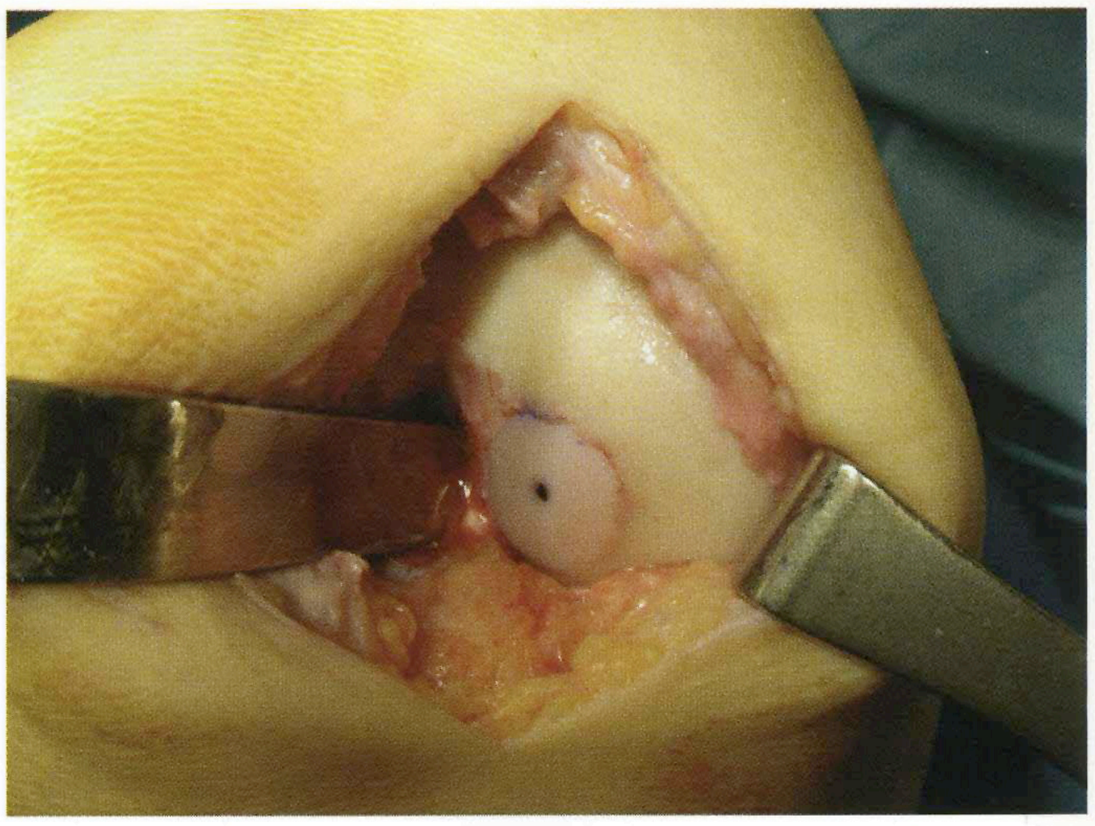

Figure 49-10 Completed osteochondral allograft.

The recipient socket is then dilated an additional 0.5 mm with a calibrated dilator and the graft is press fit into the socket by hand with the four quadrants in proper orientation. The graft can be gently impacted with an oversized tamp to ensure a flush fit, although we prefer to cycle the knee and load the ipsilateral compartment to terminally and atraumatically seat the graft. Fixation with bioabsorbable pins or a headless screw with differential thread pitch may be used to augment the press fit if needed for larger grafts (Fig. 49-10).

Autologous Chondrocyte Implantation

ACI is usually chosen to treat a defect after more traditional first-line treatments have failed. It involves the use of harvested and laboratory-grown autologous chondrocytes that are reimplanted in a defect under a watertight periosteal patch. Ideally, the patient has a symptomatic, unipolar, well-contained chondral defect in an otherwise normal knee. The defect size that can be treated with ACI ranges from 2 to 10 cm^2, although the senior author has experience in treating significantly larger lesions. The indications for use of ACI have expanded, and success has been reported with use in joints other than the knee. In addition, patellar and tibial lesions have been treated in addition to the classic femoral condyle or trochlea. As previously discussed, contraindications include untreated malalignment and ligament or meniscus insufficiency. While a relative contraindication, in selected cases, bipolar lesions can be treated effectively with ACI.

The ACI technique requires a minimum of two operations. The first involves arthroscopy to evaluate the lesion and to obtain a biopsy of articular cartilage. The lesion should be carefully measured and assessed for containment and depth. The site from which the senior author prefers to obtain the biopsy sample is the lateral edge of the intercondylar notch. A curved bone graft harvesting gouge is used to obtain approximately 200 to 300 mg or three "Tic Tac-sized" fragments of articular cartilage. The biopsy is placed in the collection vial and into a shipping container to be mailed for processing and cell growth.

After the requisite minimum of 6 weeks of cell growth, the second stage of implantation can be performed. This is an open procedure with exposure dependent on the location of the lesion. A femoral condyle lesion is exposed through a limited parapatellar arthrotomy on the side of the lesion. For medial femoral condyle lesions, we typically expose via a limited subvastus medialis approach, and for lateral condyle lesions, we perform a limited lateral retinacular release. Patellofemoral lesions are approached through a midline incision, which allows a tibial tubercle osteotomy to be performed simultaneously, followed by a lateral retinacular release without complete eversion of the patella (Fig. 49-11). The tibial tubercle osteotomy allows increased patellar mobility and easier access to the defect; however, we avoid complete elevation and eversion of the tubercle, which are disruptive to the fat pad and patellar tendon and a potential cause of postoperative stiffness. The incision is extended distally to harvest periosteum, or if a distal realignment is not performed, an additional incision located below the pes anserine tendons is required for the periosteal patch harvest on the anteromedial tibia.

Once adequate exposure is obtained, the defect is prepared. This involves removal of any fibrocartilage or loose cartilage flaps surrounding the lesion followed by the creation of stable vertical walls of healthy cartilage around the periphery of the lesion. A no. 15 scalpel is helpful to sharply incise the defect's border. Sharp-ring curets are also used to clear tissue from the lesion

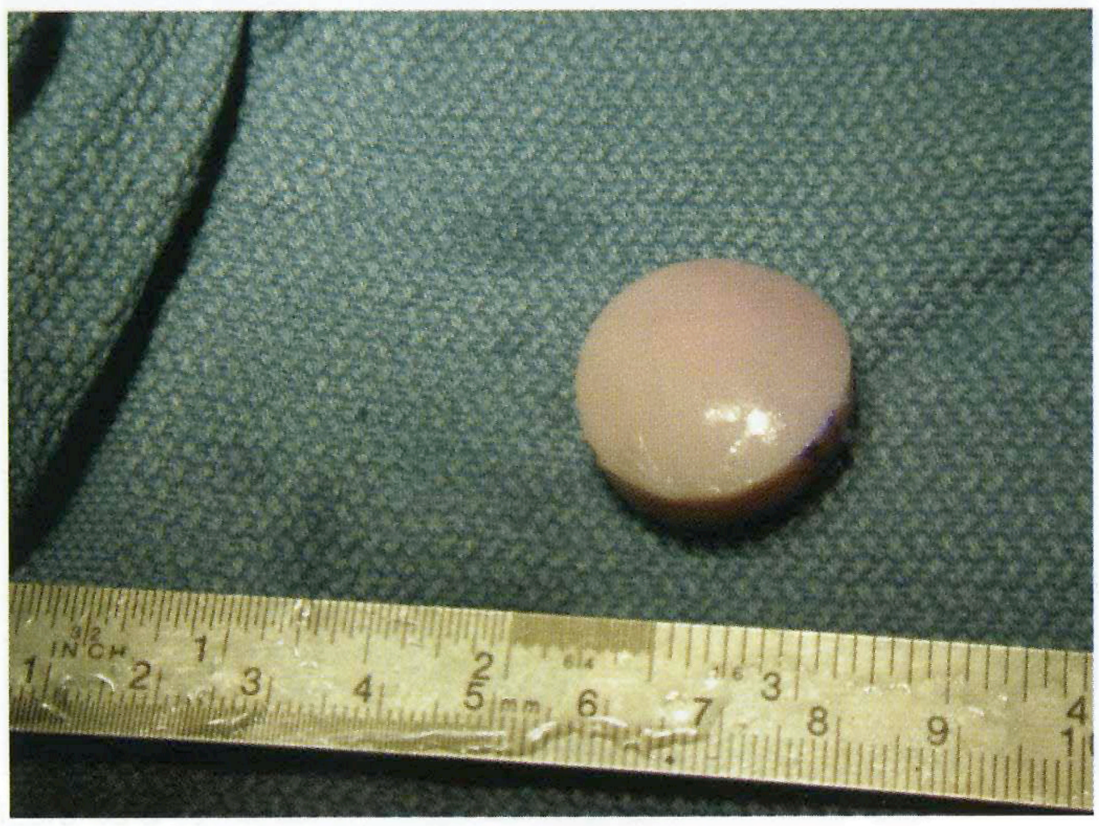

Figure 49-9 Final allograft plug to be placed in recipient bed.

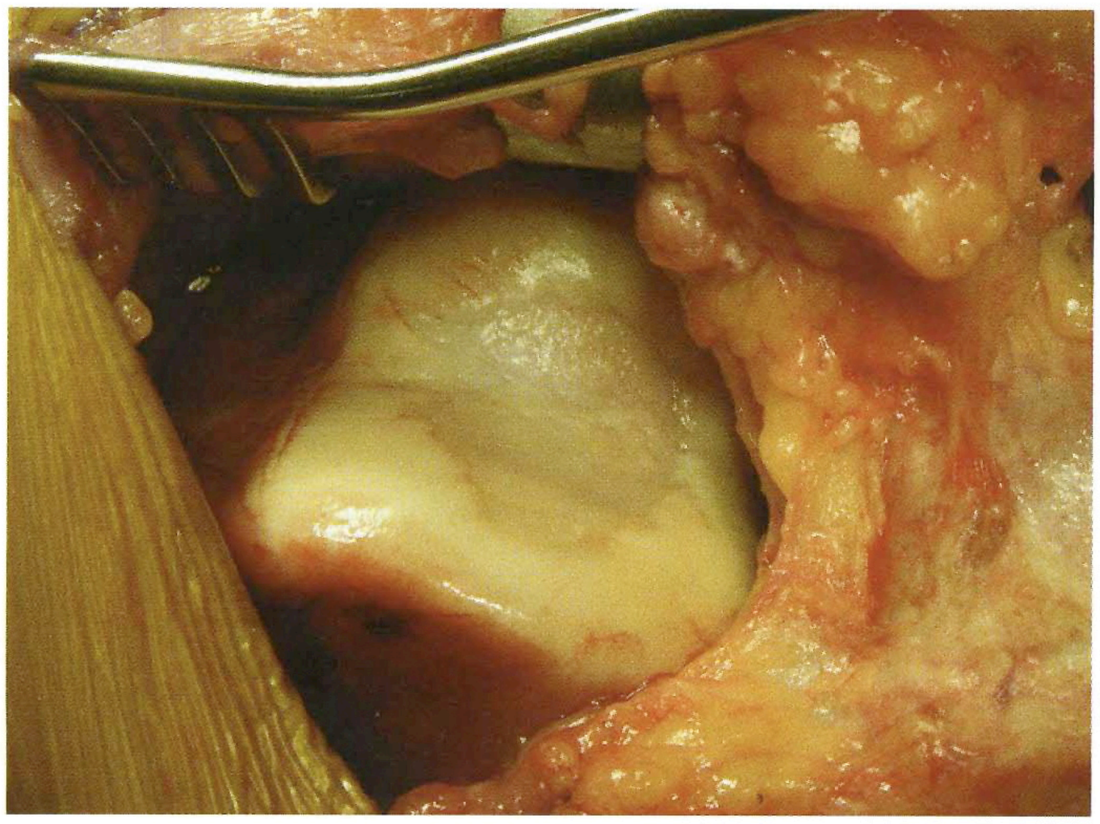

Figure 49-11 Large shallow trochlear lesion.

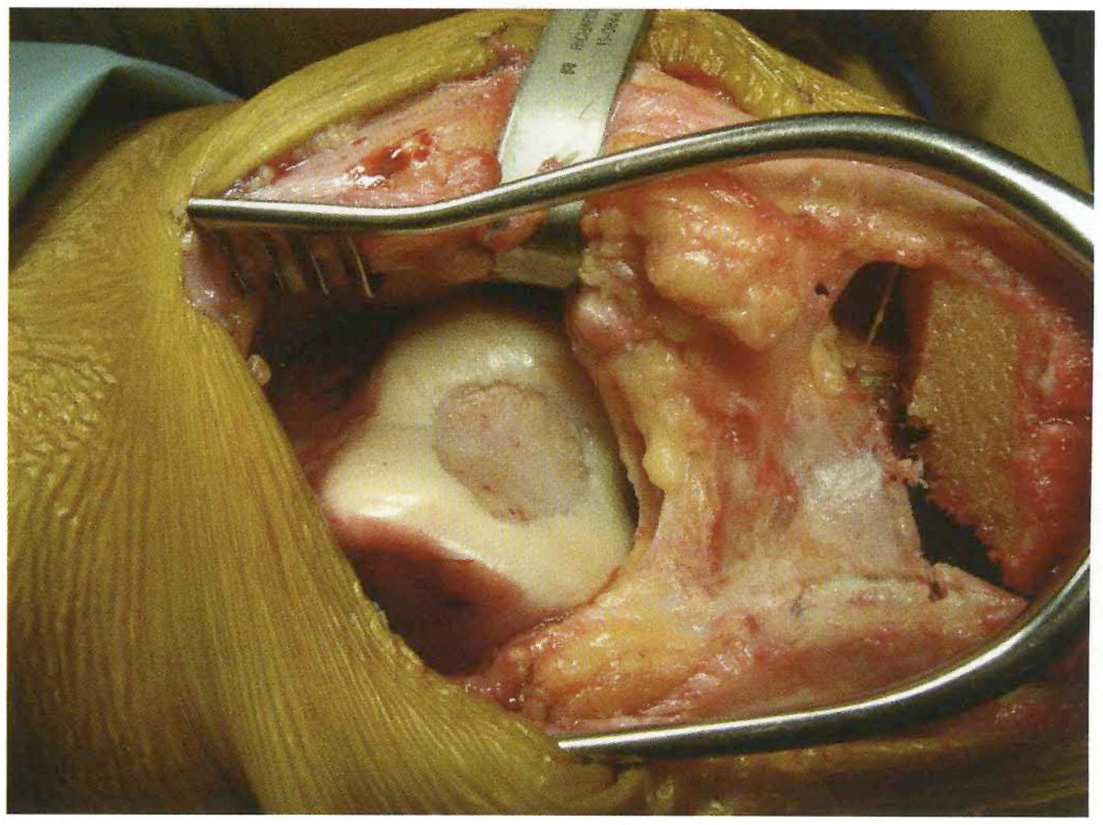

Figure 49-13 Final prepared trochlear lesion ready to be measured prior to periosteal harvest.

without penetrating the subchondral bone (Fig. 49-12). Finally, the tourniquet is deflated and neuropatties soaked in dilute 1:1000 epinephrine solution are held in the defect to achieve hemostasis. The final defect should be measured or traced so that an adequate patch of periosteum can be obtained (Fig. 49-13).

The next step is to obtain the periosteal patch through an additional incision over the anteromedial tibia 4 to 6 cm below the insertion of the hamstring tendons. Additional periosteum sites include the distal femur or contralateral tibia. Harvesting can be performed through a 3-cm longitudinal incision. Superficial subcutaneous fat and blood vessels should be carefully removed from the periosteum. This is more difficult in smokers who have more fragile periosteum and in the obese population who have greater amounts of overlying adipose tissue. Score the periosteum with a no. 15 scalpel, being sure to overestimate the required size by a few millimeters. The periosteum is elevated with a sharp, curved periosteal elevator while holding the leading edge with fine forceps (Fig. 49-14). Mark the outer surface with a sterile marking pen to distinguish it from the inner cambium layer.

The patch is then sewn onto the cartilage with the cambium layer facing down creating a taut surface. Absorbable 6-0 Vicryl sutures (Ethicon Inc, Johnson & Johnson, Somerville, NJ) on a P-1 cutting needle are used to sew the patch using sterile mineral oil so the suture passes with ease. The suture is passed first through the periosteum and then through the articular cartilage (Fig. 49-15). The knot is tied on the periosteum side, not over the healthy cartilage on the perimeter of the lesion. A small gap is left open in the patch superiorly to allow a test of watertightness and to implant the chondrocytes with an angiocatheter.

The patch is then tested for watertightness by using a saline-filled tuberculin syringe and an 18-gauge catheter. Additional sutures are placed as necessary after removal of all the water. The edges of the patch are then sealed with fibrin glue (Tisseel, Baxter Healthcare Corp., Glendale, CA) and a second water test is performed (Fig. 49-16).

Extraction of the chondrocytes from the vials is performed under sterile technique with an 18-gauge angiocatheter on a tuberculin syringe. The angiocatheter is placed in the vial (which should always remain vertical) so that the tip is submerged in the fluid above the pellet of cells at the bottom. Repetitive

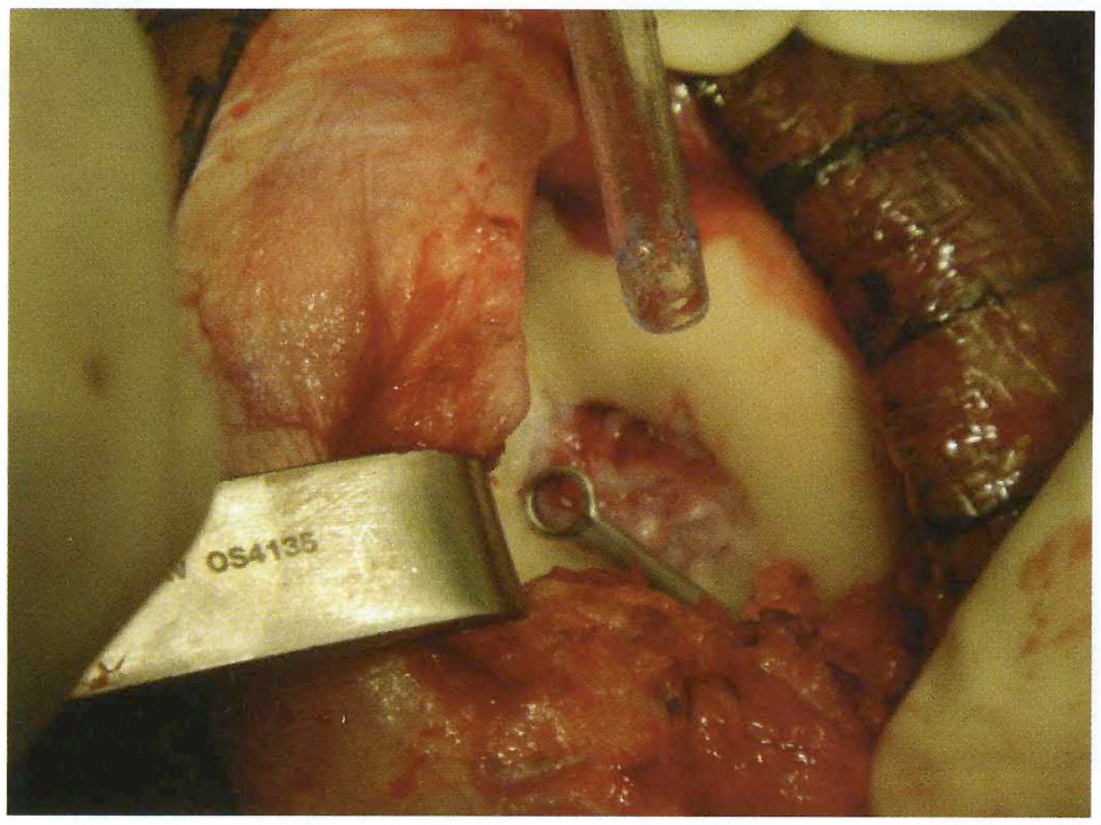

Figure 49-12 Preparing a trochlear lesion with a ring curet.

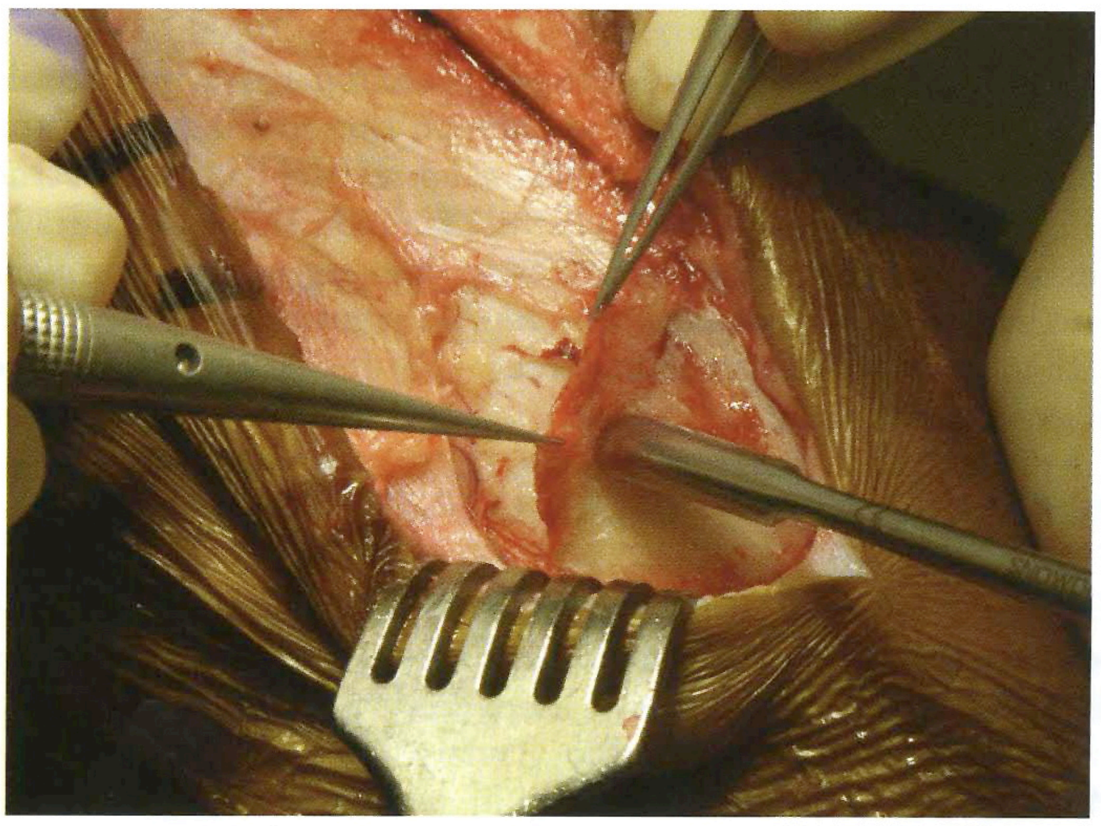

Figure 49-14 Harvesting the periosteum from the proximal medial tibia, below the medial collateral ligament insertion and Sartorius insertion.

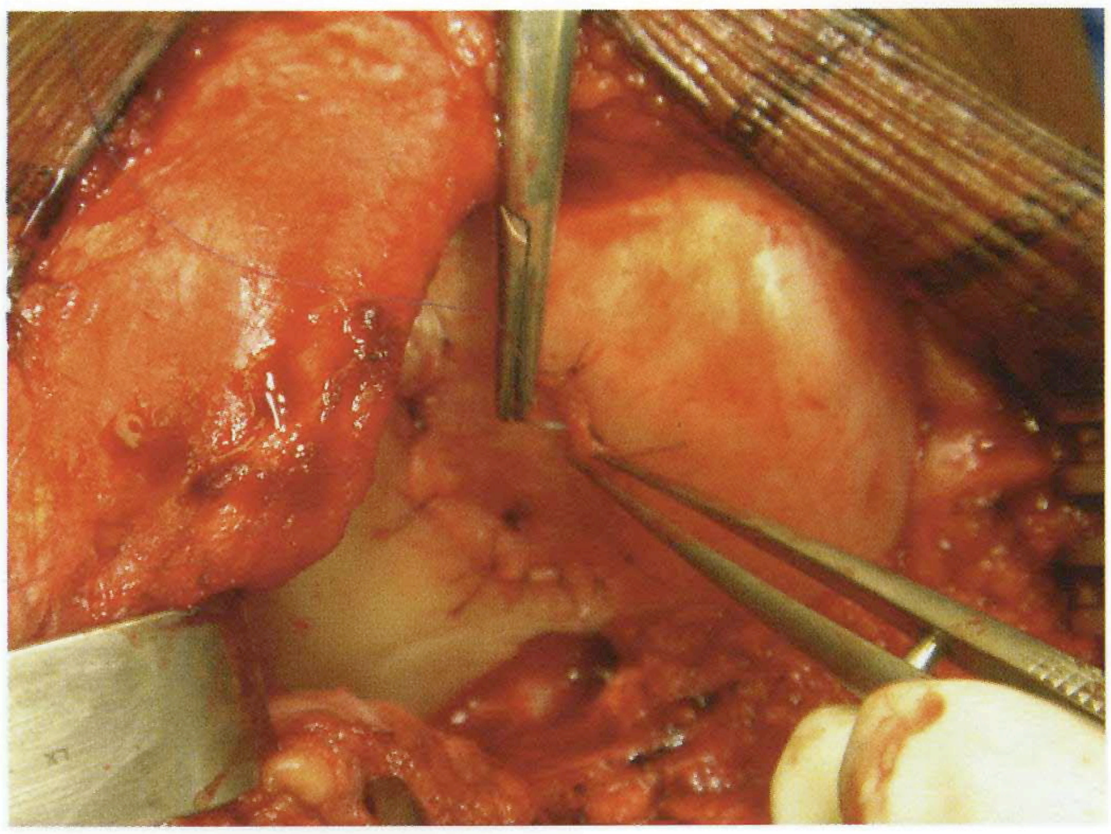

Figure 49-15 Sewing the periosteal patch in place with 6-0 colored Vicryl suture.

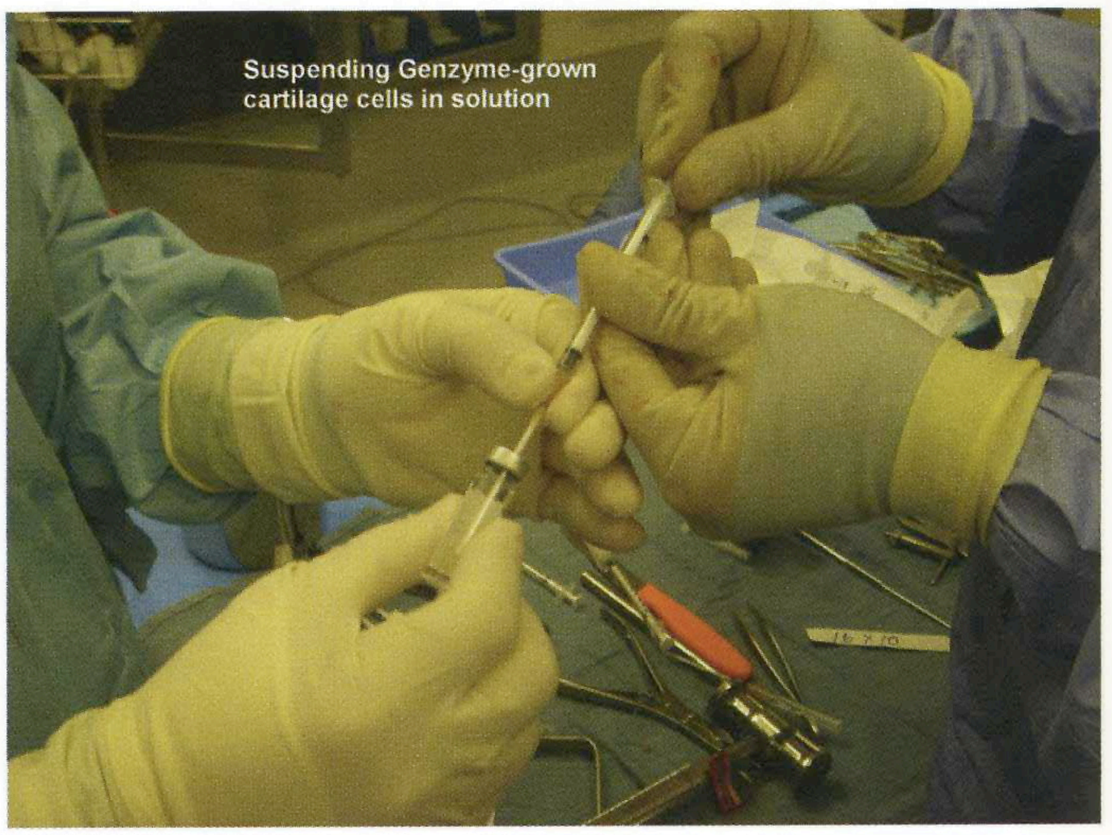

Figure 49-17 Extracting the chondrocytes for implantation.

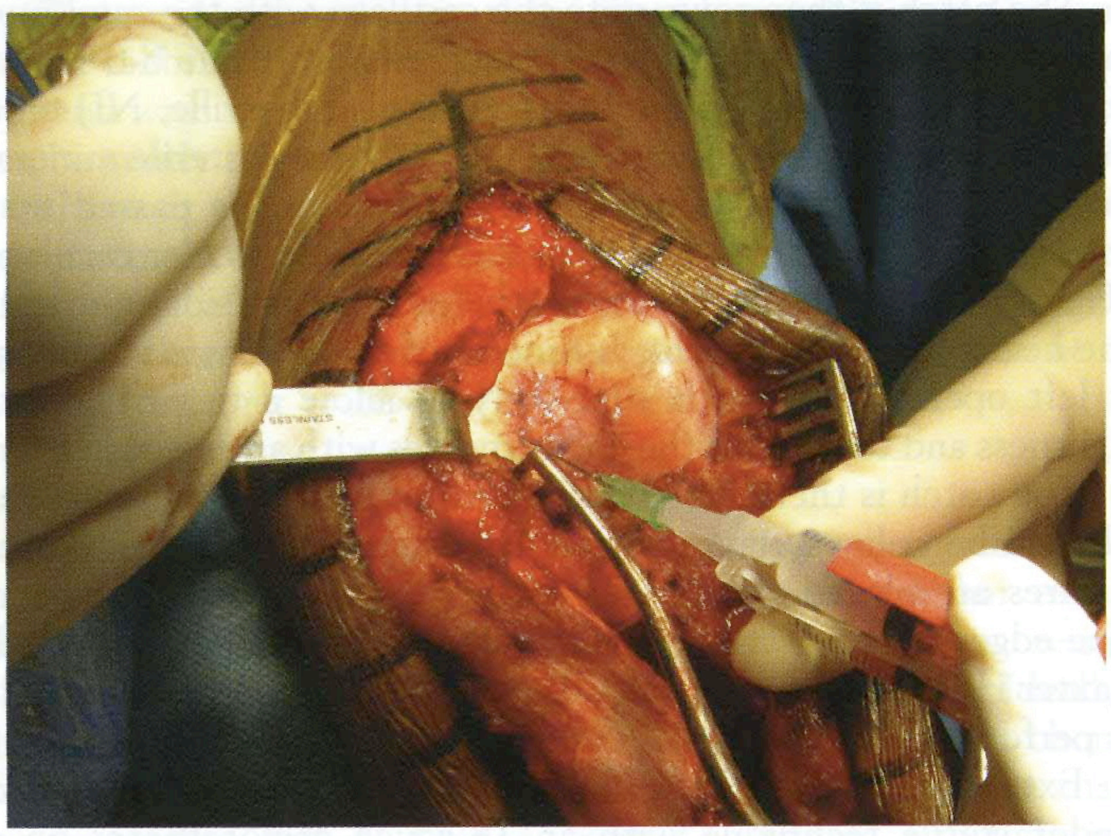

Figure 49-16 Sealing the periosteal patch with fibrin glue.

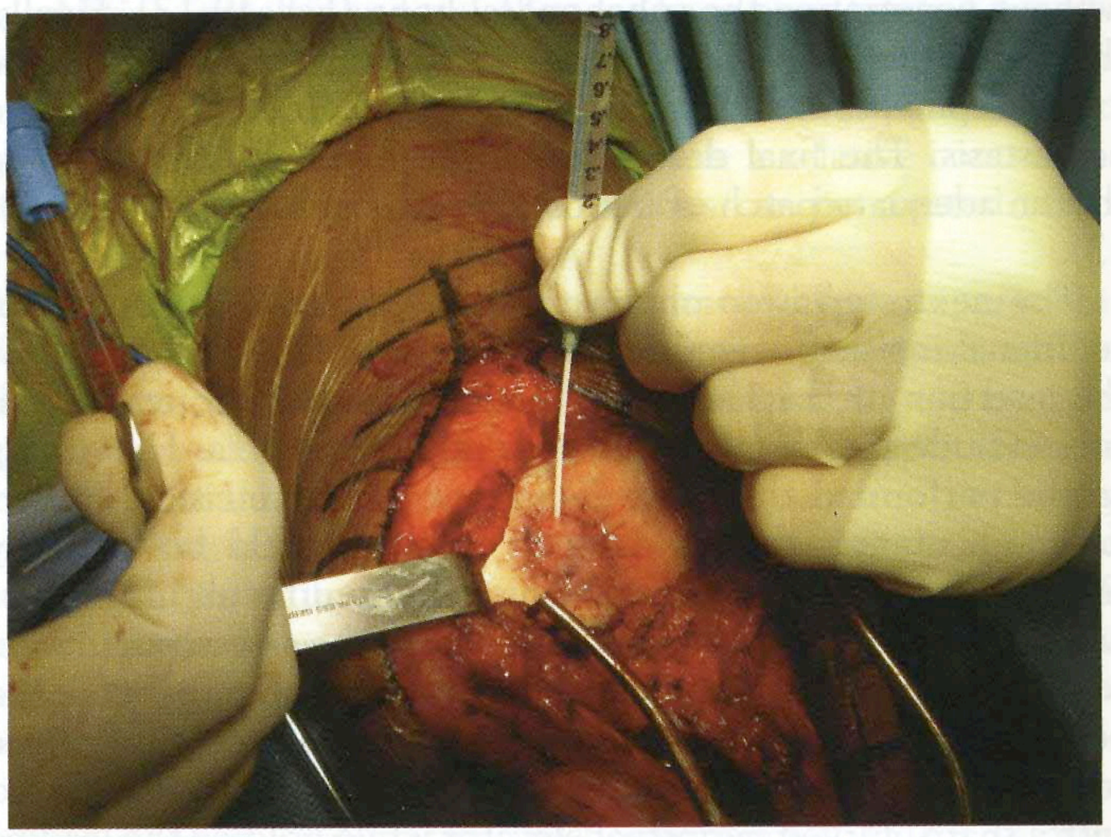

Figure 49-18 Implanting chondrocytes under the watertight periosteal patch.

gentle aspirations are the used to suspend the cells in solution. The entire volume is then aspirated and drawn into the syringe (Fig. 49-17).

To implant the cells under the periosteal patch, a new sterile angiocatheter should be placed through the opening at the top of the periosteal patch and advanced to the bottom of the defect. While injecting the cells, the surgeon slowly withdraws the angiocatheter tip to ensure even delivery of cells throughout the defect (Fig. 49-18). The remaining opening in the patch is then securely closed with additional sutures and fibrin glue (Fig. 49-19).

POSTOPERATIVE REHABILITATION

The success of all cartilage restoration techniques is highly dependent on the compliance and diligence of the patient during the rehabilitation process.

Microfracture

Following microfracture to lesions of the weight-bearing surfaces of the femoral condyle or tibial plateau, the patient is braced

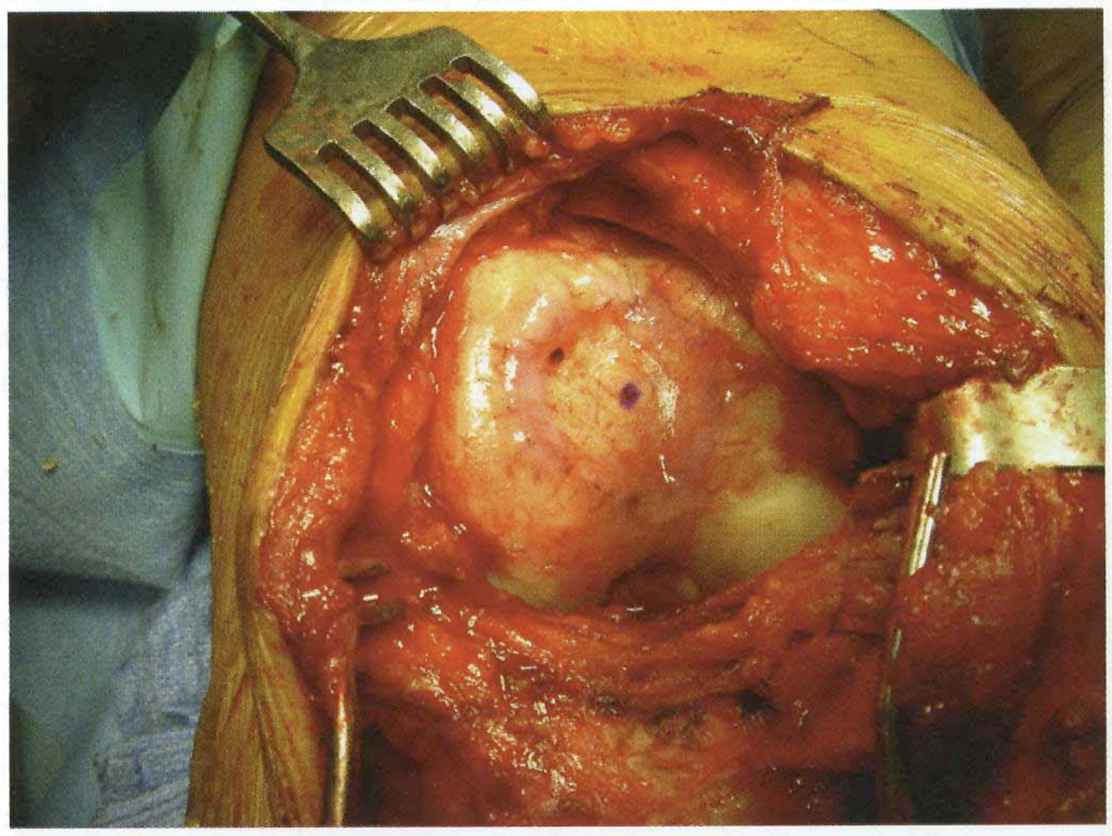

Figure 49-19 Final appearance of completed autologous chondrocyte implantation.

and remains non-weight bearing for 4 to 6 weeks with gradual advancement to full weight bearing for an additional 2 weeks. For lesions of the patellofemoral joint, the patient is braced with a flexion stop at 30 to 40 degrees in order to limit patellofemoral contact pressures but may bear weight in full extension. The brace is removed only for range-of-motion and strengthening exercises. Early passive motion is initiated, usually with a continual passive motion device immediately postoperatively used for a total of 6 hours each day for as long as 6 weeks. An alternative to continual passive motion device use is to perform 500 repetitions of knee flexion and extension three times daily.

Osteochondral Autograft

Similarly, both passive and active ranges of motion are encouraged after osteochondral autografting. Weight bearing is protected for up to 6 weeks. Once radiographic evidence of bone healing is noted at 6 to 8 weeks, the patient is advanced to full weight bearing as tolerated. Closed-chain strengthening exercises are begun after 3 months, running is usually possible at 6 months, and athletic activity involving higher shear forces can resume at 9 months.

Osteochondral Allograft

After osteochondral allografting, restricted weight bearing in a hinged knee brace is recommended for at least 8 weeks to protect the articular cartilage and to allow thorough incorporation via creeping substitution. The continual passive motion device is used for 6 to 8 hours per day at one cycle per minute for the first 4 to 6 weeks. Usually 4 to 6 months are required before return to light sporting activity. We recommend abstaining from high-impact activities after this procedure because of concern for graft collapse or deterioration of the chondral surface.

Autologous Chondrocyte Implantation

The rehabilitation following ACI involves early passive motion for 6 to 8 hours daily with the continual passive motion device. This is crucial as motion assists cellular orientation and prevents adhesions from developing. The graft is protected from overload by maintaining restricted weight bearing for 4 to 6 weeks in a hinged knee brace. Gradually impact-loading activities are phased in with increased strengthening. Full recovery and involvement in light sporting activity occurs between 4 and 6 months.

CRITERIA FOR RETURN TO SPORTS

Following all the procedures previously outlined, the general criteria for return to any sports activity include a normal gait pattern, a pain-free knee with normal or near-normal range of motion and strength, and no recurrent effusions. For patients who have undergone a microfracture, return to any sports activity is generally permitted after 16 weeks provided the preceding criteria are met. For osteochondral allograft procedures, there is the additional criterion of radiographic bony integration of the plug(s). Usually, return to lower impact sporting activities is permitted between 4 and 6 months. For autografts, return to sports involving high shear forces on the knee is delayed until approximately 6 months postoperatively. We advise our allograft patients against participating in high-impact cutting sports following an osteochondral graft procedure. Following ACI, return to light sporting activities such as jogging can usually resume by 6 to 9 months; however, high-impact activity resumes by 12 to 18 months.

RESULTS AND OUTCOMES

It is difficult to compare results for the various procedures described here. The patient population with articular cartilage defects is generally heterogeneous. Often, procedures are not performed in isolation but rather with the concomitant treatment of other comorbidities within the same knee.

Microfracture appears to have better outcomes in younger patients with smaller lesions, perhaps because the pluripotential cell count decreases with increasing age. One recent review demonstrated that 80% of patients reported themselves as improved, with patients younger than 35 showing the best outcomes.[5]

Overall, autologous osteochondral grafts perform better in isolated femoral condyle lesions (92% good or excellent) compared to tibial plateau lesions (87% good or excellent) or patellofemoral defects (79% good or excellent).[12]

Results following osteochondral allografting appear best (86% success at 7.5 years) if the lesion is the result of a purely traumatic event.[13] Bugbee[14] reported success rates of 93% for femoral lesions, 76% for patellofemoral grafts, and 65% for tibiofemoral bipolar defects at 4 years. In all studies, uncorrected mechanical limb malalignment or ligamentous instability was associated with worse outcomes.

Following ACI, results have been most favorable for femoral lesions and less favorable for patellar lesions. Peterson et al[15] reported 89% good to excellent results for femur lesions compared to 65% for the patella. As greater attention was paid to performing anteromedialization of the tibial tubercle, results after treating patellar lesions appear more promising and quite similar to femoral condyle lesions treated with ACI. We have presented 103 defects treated with ACI in 83 patients, with complete satisfaction reported in 79.3% of patients.[16]

In an attempt to compare microfracture with ACI in a similar patient population, Knutsen et al[17] randomized 80 patients with isolated focal chondral defects in stable knees with a normal mechanical axis to receive either ACI or microfracture as a first-line treatment. Both groups improved significantly; however, the microfracture group had statistically significantly greater improvement than the ACI group at 2 years.[17] Similarly, Horas et al[18] compared ACI to osteochondral autograft transplantation and noted improved symptoms in both groups but greater subjective improvement in the osteochondral autograft group.

COMPLICATIONS

Failure to recognize concomitant knee pathology is an avoidable cause of poor outcome with any cartilage restoration procedure. It is essential to have a clear understanding of the status of the knee in terms of its alignment, ligamentous integrity, and meniscal function prior to formulating a comprehensive surgical plan.

With complex or multiple procedures, stiffness is the most common complication, usually treated by arthroscopic releases and manipulation. With microfracture, overaggressive use of the awl by placing holes that are too deep or close together can lead to subchondral bone collapse. With osteochondral grafting, placement of plugs excessively proud may result in high shear forces and failure of the plug. Excessive impaction of osteochondral grafts may cause chondrocyte death. With ACI, graft overgrowth is the most common complication, which can

usually be resolved with arthroscopic débridement of the hypertrophic tissue.

CONCLUSIONS

The successful management of articular cartilage lesions is challenging for both the surgeon and patient. Surgeons are faced with complex decision making in addressing the defect as well as coexisting pathology of the knee. Additionally, each patient is unique and must be evaluated individually to determine the best course of treatment. Patients are charged with the responsibility of committing to a strict postoperative regimen on which the success of the operation depends. As further advances are made in this exciting area of orthopedics, promising new methods will evolve to improve the treatment of articular cartilage lesions and narrow the use of total joint arthroplasty.

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