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The Four Most Common Types of Knee Cartilage Damage Encountered in Practice: How and Why Orthopaedic Surgeons Manage Them

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Abstract

Cartilage damage of the knee is common and may present in patients as a variety of symptoms. These conditions can be classified based on location, etiology, and/or pathophysiology. A systematic approach to the evaluation and classification of chondral injuries helps improve definitive management. The four most common types of knee cartilage damage are osteochondritis dissecans, incidental chondral defects, patellofemoral defects, and defects encountered after meniscectomy.

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The field of cartilage repair continues to evolve rapidly, with new products regularly introduced in clinical practice. Concurrently, established procedures for cartilage repair, such as autologous chondrocyte implantation (ACI) and osteochondral allograft transplantation, have undergone improvements in techniques and availability. Collectively, these changes help make cartilage repair accessible to a wide range of patients and surgeons for a variety of indications. Education on cartilage repair also has evolved to incorporate a more case-based approach. Surgeons should understand the epidemiology of as well as how to diagnose and manage the four most common types of knee cartilage damage encountered in clinical practice: incidental chondral defects, osteochondritis dissecans (OCD), patellofemoral defects, and defects encountered after meniscectomy.

Incidental Chondral Defects

Chondral or osteochondral lesions have been reported in as many as 61% to 66% of patients who undergo knee arthroscopy.[1-3] Chondral and osteochondral lesions may be traumatic, idiopathic, or associated with repetitive microtrauma. Cartilage damage often is associated with injuries to other anatomic knee structures and may be observed in conjunction with malalignment. Meniscal derangement and acute anterior cruciate ligament (ACL) tears are highly correlated with chondral lesions.[4,5] Compressive and shear forces at the time of injury can lead to disruption of the osteochondral unit. In addition, chronic ligamentous instability or meniscal derangement can alter knee biomechanics and increase joint contact forces, which may result in damage to chondral surfaces and the underlying subchondral bone.

In a recent systematic review, Brophy et al[4] reported a 16% to 46% incidence of severe articular cartilage injury in patients who had acute ACL tears. Studies have reported a higher incidence

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of chondral and osteochondral injury with increasing time from ACL injury.[4,6-12] Sometimes the treating surgeon may be aware of a chondral defect based on preoperative imaging; at other times, a chondral defect may be unexpectedly discovered during arthroscopy that is performed to manage other ligamentous or meniscal injuries. The natural history of articular cartilage defects is not completely understood; however, full-thickness chondral defects are known to lack the ability to spontaneously heal.[13-15] If left untreated, chondral defects can lead to progressive joint degeneration and eventual osteoarthritis.[16,17] Because of poor understanding of the independent variables associated with defect progression, close monitoring of asymptomatic defects, rather than surgery, often is selected as a management strategy. Patients who have a suspected genetic predisposition to chondral or osteochondral lesions (parent who underwent arthroplasty in their 40s or 50s) as well as patients with marked malalignment or meniscal deficiency warrant closer monitoring.

Clinical Evaluation

Patients with symptomatic chondral defects typically have nonspecific knee pain and swelling. Mechanical symptoms, such as catching and locking, as well as instability may be present. Traumatic etiologies often are associated with a specific event, such as a fall or a twisting injury while playing sports. Conversely, idiopathic lesions and lesions associated with repetitive microtrauma may have more of an insidious onset, without a specific event that the patient can recall. After a detailed history with regard to the onset of symptoms is obtained, a comprehensive physical examination should be performed. The physical examination begins with a gait analysis followed by an assessment for effusion, deformity, contracture, malalignment, and patellar maltracking, paying close attention for possible mechanical blockage or crepitus. Unfortunately, neither a patient's history nor physical examination are sensitive or specific for cartilage defects versus other intra-articular derangements.

Imaging

Radiographic studies include standing AP, lateral, Merchant, and 45° flexion PA views. Full limb-length radiographs may help determine mechanical alignment in select patients or in patients with known chondral defects. MRI can help effectively evaluate for articular cartilage and subchondral edema. Although determining the size of a lesion on imaging is helpful for prognostic purposes and can help guide surgical management, MRI frequently underestimates lesion size by as much as 60%.[18] Ligamentous and meniscal structures should be assessed for any evidence of injury.

Treatment

Nonsurgical Treatment

Initial management for most articular cartilage lesions consists of activity modification, anti-inflammatory medications, injections, bracing, and physical therapy. Patients who continue to be symptomatic despite nonsurgical treatment should be evaluated for possible surgical treatment. Age, activity level, patient expectations, defect size, and associated injuries are important factors in the determination of whether a patient is a surgical candidate. Patients who are considered surgical candidates must understand that most cartilage-restoring procedures require extensive rehabilitation and that they will be unable to return to activities for an extended period of time. In addition, patients should understand that high-impact activities, such as running

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and basketball, are discouraged, but not necessarily contraindicated, postoperatively depending on the surgical procedure selected and the outcome desired.

Surgical Treatment

The goal of surgical treatment for patients who have symptomatic chondral defects is to restore the osteochondral unit in an anatomic fashion with maintenance of the supporting subchondral bone and repair tissue that closely resembles native articular cartilage. However, if a chondral lesion is incidentally found at the time of ACL reconstruction or meniscal surgery, the symptomatology is less clear. In general, the lesion should be documented and possibly managed with chondroplasty based on its appearance. National Football League players who underwent microfracture for the management of articular cartilage lesions were 4.4 times less likely to return to professional football compared with National Football League players who underwent chondroplasty alone.[19] Acute cartilage repair is discouraged because it is unknown whether a particular lesion is or will be symptomatic. Furthermore, most cartilage repair rehabilitation protocols differ from those of the primary procedure, especially a simple meniscectomy. A patient who is faced with drastically and unexpectedly different postoperative weight-bearing restrictions will, most likely, be unhappy. Postoperatively, the patient and the family should be counseled on the surgical findings and instructed on when to seek a reevaluation (eg, if persistent pain and swelling occur). A scheduled follow-up, with or without repeat MRI, is advised in certain high-risk patients, such as younger patients with a lateral meniscal deficiency or a large lateral femoral condyle OCD lesion.

Arthroscopic Débridement and Chondroplasty

Arthroscopy can be used for both diagnostic and therapeutic purposes. Direct visualization via arthroscopy can help a surgeon determine the exact size and location of a defect, which provides the surgeon with a guide for definitive cartilage repair treatment options if they are necessary in the future. Arthroscopy is particularly helpful because MRI frequently underestimates lesion size.[18] During arthroscopy, a surgeon may be tempted to débride lesions in the patellofemoral joint despite a patient being clinically asymptomatic. In these patients, the surgeon is advised to document the damage but refrain from débridement because it can convert an asymptomatic lesion into a clinically symptomatic lesion. Although arthroscopic débridement and chondroplasty can help improve a patient's clinical symptoms, it is not curative.

Arthroscopic débridement and chondroplasty also can be a useful procedure for patients who may not be good candidates for cartilage restoration (based on age, advanced degenerative changes, body mass index, and participation in athletics) or patients who are unwilling to adhere to a strict postoperative rehabilitation protocol; however, data on the long-term efficacy of arthroscopic débridement and chondroplasty are lacking.

Marrow Stimulation (Microfracture)

Marrow stimulation in the form of drilling or microfracture can be used to treat patients who have small chondral defects (<2 cm^2) of the knee. The ideal patient for marrow stimulation is younger than 40 years and has a focal chondral defect of the medial or lateral femoral condyle. In a study of 72 patients with chondral defects of the knee who underwent microfracture, Steadman et al[20] reported significant improvements in mean Tegner activity and Lysholm Knee Scale scores as well as good to excellent Medical Outcomes Study 36-Item Short Form (SF-36) and Western Ontario and McMaster Universities Osteoarthritis Index scores at a mean follow-up of 11 years. In a study of 109 patients with chondral defects of the knee who underwent microfracture, Gobbi et al[21] reported that, at a mean follow-up of 6 years, mean Lysholm Knee Scale scores improved and International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form scores were normal or near normal in 70% of the patients who had a mean defect size of 4 cm^2. After further analysis, the authors reported that a lesion size less than 2 cm^2 and an age younger than 40 years were associated with a better rate of return to high-impact sports.

Many other studies have reported good short-term results after microfracture; however, the recent literature suggests that outcomes after microfracture may deteriorate with time. Goyal et al[22] reported that microfracture resulted in good short-term outcomes in low-demand patients who had small lesions; however, the authors reported that failure could be expected 5 years after microfracture regardless of lesion size. Gobbi et al[23] reported good short- and long-term clinical results in patients with small lesions who underwent microfracture but acknowledged that deterioration of clinical outcomes should be expected 2 to 5 years postoperatively. A systematic review of 3,000 patients reported improved knee function 24 months after microfracture; however, data on outcomes more than 24 months after microfracture were

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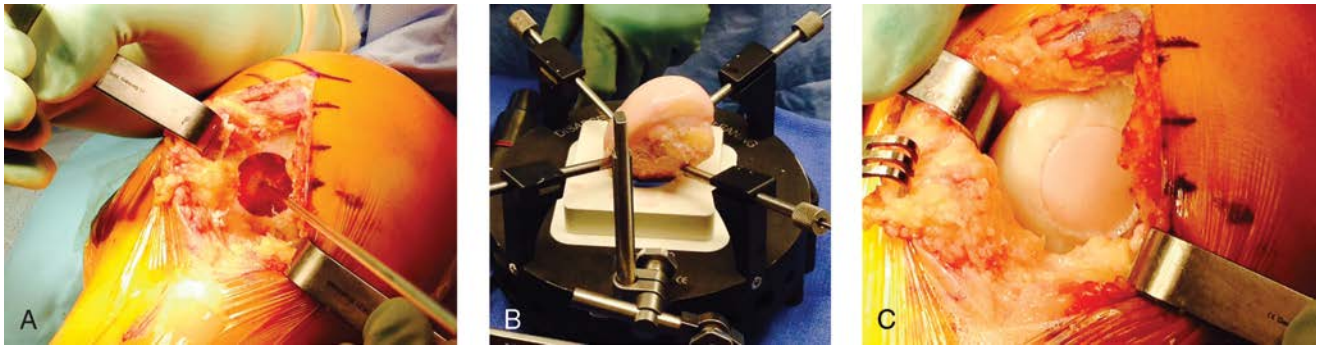

Figure 1 Photographs of a knee with an osteochondral defect that was treated with osteochondral allograft transplantation. **A,** Intraoperative photograph taken after preparation of the osteochondral defect shows removal of unhealthy cartilage and the underlying subchondral bone. **B,** Clinical photograph shows a fresh femoral hemicondyle that was used to obtain an osteochondral allograft cylinder. **C,** Intraoperative photograph taken after osteochondral allograft transplantation that was performed with the use of the press-fit technique. (Reproduced from Gomoll AH, Chilelli BJ: Articular cartilage of the knee, in Miller MD, ed: *Orthopaedic Knowledge Update: Sports Medicine*, ed 5. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2016, 221-236.)

insufficient.[24] Modifications to the microfracture technique, such as the creation of smaller holes via nanofracture or the augmentation of microfracture with a dehydrated micronized articular cartilage allograft scaffold combined with platelet rich plasma, are currently being investigated.[25,26]

Osteochondral Autograft Transfer/Mosaicplasty

Osteochondral autograft transfer (OAT) is best suited for patients who have small chondral or osteochondral lesions (<2 to 3 cm^2) of the femoral condyles. OAT addresses abnormal or deficient subchondral bone and restores mature hyaline cartilage. Multiple osteochondral cylinders are transferred via mosaicplasty for patients who have lesions larger than 1 cm^2.

In a study of athletes who underwent OAT, Hangody et al[27] reported good to excellent outcomes at a mean follow-up of 9.6 years in 91% of patients who were treated for femoral condyle lesions, 86% of patients who were treated for tibial lesions, and 74% of patients who were treated for patellofemoral lesions. In a study of 73 patients who underwent OAT, Solheim et al[28] reported that, at a mean follow-up of 7 years, 88% of the patients said that they would undergo the procedure again; however, the authors reported a deterioration of results from 1 year postoperatively to 5 to 9 years postoperatively. In a long-term outcomes study of 73 patients who underwent OAT, Solheim et al[29] reported poor outcomes in 40% of the patients at a long-term follow-up that ranged from 10 to 14 years. A further analysis revealed that the poor outcomes were associated with patients who were older than 40 years (59%), were women (61%), and had defects larger than 3 cm^2 (57%). Conversely, patients who were younger than 40 years and had a defect smaller than 3 cm^2 had a failure rate of only 12.5% and a mean Lysholm Knee Scale score of 82. Long-term donor site morbidity after graft harvest has been reported to be approximately 3%.[30]

Osteochondral Allograft Transplantation

Osteochondral allograft transplantation is ideal for patients who have large chondral or osteochondral lesions (>2 to 4 cm^2; **Figure 1**). Osteochondral allograft transplantation can be performed to treat patients who have uncontained defects and used as a salvage option in patients in whom other cartilage repair procedures fail. Similar to OAT, osteochondral allograft transplantation addresses subchondral bone abnormalities and restores mature articular cartilage.

In a recent long-term outcomes study of 58 patients who underwent fresh osteochondral allograft transplantation, Raz et al[31] reported that graft survival was 91%, 84%, 69%, and 59% at 10, 15, 20, and 25 years postoperatively, respectively. The mean modified Hospital for Special Surgery score was 86 for patients who had a surviving graft 15 years postoperatively. In a systematic review of 19 studies, which included 644 knees that were managed with osteochondral allograft transplantation, Chahal et al[32] reported an overall satisfaction rate of 86% at a mean follow-up of 58 months, with little to no arthritis reported in 65% of the patients at final follow-up. The mean age of the patients across all of the studies

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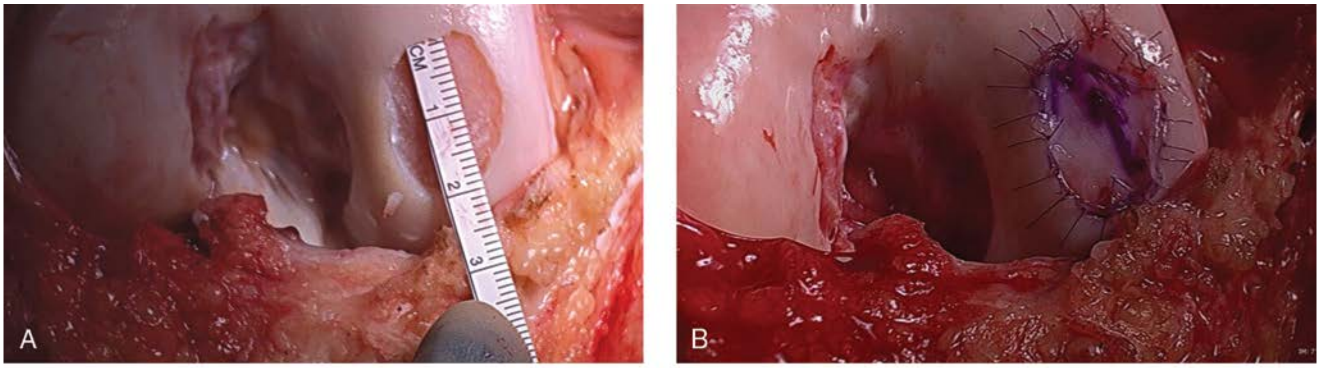

Figure 2 Images of a knee with a chondral defect that was treated with autologous chondrocyte implantation (ACI). **A,** Intraoperative photograph shows a chondral defect of the medial femoral condyle that has been prepared for ACI. **B,** Intraoperative photograph shows that autologous chondrocytes have been injected beneath a type I/III collagen membrane and sealed with 6-0 absorbable braided suture and fibrin glue. **C,** Arthroscopic image shows the medial femoral condyle 10 months after ACI.

that were included was 37 years, and the mean defect size across all of the studies that were included was 6.3 cm^2.

Video 42.1: Autologous Chondrocyte Implantation. Jack Farr, MD (3 min)

Autologous Chondrocyte Implantation

ACI is an articular cartilage-restoring procedure that is used to treat patients who have medium to large full-thickness chondral defects (>2 to 4 cm^2) of the knee (**Figure 2**). The size of a defect being managed with ACI is not limited; however, contained defects rather than uncontained defects are preferred. Since ACI was originally described in 1994, newer second- and third-generation ACI techniques have been routinely used in the United States and Europe.[33-36]

Saris et al[37] conducted a randomized controlled trial of 144 patients with a mean lesion size of 4.8 cm^2 who underwent either matrix-applied ACI or microfracture. The authors reported that the patients who underwent matrix-applied ACI had significant improvements in mean Knee Injury and Osteoarthritis Outcome Scores (KOOS) and knee-related quality of life scores 2 years postoperatively. The authors reported that management with matrix-applied ACI for cartilage defects larger than 3 cm^2 was both statistically and clinically better and had similar structural repair tissue and safety compared with microfracture. Several other studies have reported favorable midterm results after ACI.[38-40] In a long-term study of 224 patients who underwent ACI, Peterson et al[41] reported that, at a mean follow-up of 12.8 years, 74% of the patients described their postoperative status as better or the same as that in previous years, and 92% of the patients stated that they were satisfied and would undergo ACI again. In a study of 210 patients with a mean defect size of 8.4 cm^2 who underwent ACI, Minas et al[42] reported that, at 10 years postoperatively, survivorship was 71%, and 75% of the patients had improved function.

Particulated Juvenile Articular Cartilage

Particulated juvenile articular cartilage (PJAC) for the management of chondral defects of the knee has recently gained popularity and consists of small, minced pieces of juvenile articular cartilage allograft that were obtained from donors aged 13 years or younger. PJAC is applied to a prepared defect in a monolayer and attached with a fibrin sealant.[43] Although outcome studies on the use of PJAC are limited, short-term results are encouraging.

In the largest outcomes study to date, Farr et al[44] followed 29 defects (11 trochlear defects and 18 femoral

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condyle defects; mean defect size, 2.7 cm²) in 25 patients who underwent treatment with PJAC. The authors reported statistically significant increases in mean IKDC Subjective Knee Evaluation Form scores as well as KOOS pain, symptoms, activities of daily living, and sports and recreation subscale scores at 24 months postoperatively. Postoperative biopsy samples obtained from eight patients revealed a mixture of hyaline and fibrocartilage; however, immunohistologic results confirmed a higher percentage of hyaline cartilage with excellent integration of the PJAC in the surrounding native cartilage. The advantages of PJAC include the lack of donor site morbidity, the ability to perform a one-stage procedure, and the likely increased chondrocytic differentiation potential of the juvenile tissue.[45,46] Further studies are necessary to determine the long-term efficacy and durability of PJAC. Additional treatment options that use a cryopreserved three-dimensional sheet of meshed allograft cartilage are currently being investigated as an alternative to PJAC.

Osteochondritis Dissecans

OCD is an idiopathic condition that primarily affects subchondral bone and has the potential to disrupt overlying articular cartilage. Pain and dysfunction can result from OCD. OCD most often occurs in the skeletally immature population and the young adult population. The exact prevalence of OCD is unknown; however, estimates between 15 and 29 per 100,000 individuals have been reported.[47,48] The incidence of OCD is higher in males compared with females, with male-to-female ratios ranging from 2:1 to 4:1.[49-52] The most common site of OCD in the knee is the medial femoral condyle (60% to 80%), followed by the lateral femoral condyle (15% to 32.5%) and the patella (5% to 10%).[48,52,53]

OCD is divided into juvenile (open physes) and adult (closed physes) forms; this distinction is important because patients with juvenile OCD have a higher likelihood to spontaneously heal with nonsurgical treatment, whereas patients with adult OCD often follow a progressive disease course that results in fragment detachment.[54] Despite several theories on the etiology of OCD, the exact cause of OCD is unknown. The term "osteochondritis" was initially selected to describe an inflammatory condition, but this has since been deemed unlikely. Various theories on the pathophysiology of OCD include endocrine disorders, abnormal ossification, vascular insufficiency, repetitive microtrauma, and genetic predisposition.[48,55-57] Several studies have attempted to relate sports activity to OCD, which would suggest repetitive microtrauma as a potential cause;[48,58,59] however, inconsistent histologic analyses have resulted in a lack of consensus on the exact etiology of OCD.[60]

Clinical Evaluation

Typically, patients with OCD have an insidious onset of nonspecific pain that often is exacerbated by activity and may be accompanied by effusions. Mechanical symptoms, such as catching and locking, may occur, especially in patients who have unstable OCD lesions. Some patients may have an antalgic gait or an obligate external rotation gait, both of which are used to avoid tibial spine impingement on the medial femoral condyle defect.[61] The physical examination should focus on an assessment of the knee for effusion, mechanical blockage, associated ligamentous laxity, and tenderness to palpation.

Imaging

Initial imaging studies include weight-bearing AP, lateral, and Merchant radiographs. In addition, 45° flexion PA radiographs are particularly helpful to evaluate OCD lesions along the posterior femoral condyles.[62] Contralateral knee radiographs can be considered given the high incidence of bilateral involvement.[59] The radiographs should be scrutinized for radiolucencies, subchondral cysts, sclerosis, fragmentation, loose bodies, joint space narrowing, and physeal status. If an OCD lesion is suspected, MRI can help in diagnosis and characterization of the defect.[63-65] The size, location, and depth of the OCD lesion can be determined with MRI. The articular surface overlying abnormal subchondral bone is analyzed for any evidence of disruption. MRI classification systems have been proposed to help predict the stability of OCD lesions;[66,67] however, the appearance of OCD lesions on MRI is often inconsistent with clinical symptoms and arthroscopic findings.[65,68,69] Anatomic detail of the subchondral bone can be difficult to assess on MRI in patients who have diffuse subchondral edema; therefore, CT or CT arthrography can be used to assess the fine anatomy of subchondral bone. In patients in whom nonsurgical treatment fails, full limb-length radiographs can help determine mechanical alignment and aid in surgical decision making.

Treatment

Nonsurgical Treatment

The goal of nonsurgical treatment for patients who have an OCD lesion is

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to attain healing, which is most often observed in patients who have juvenile OCD.[53,70,71] Nonsurgical treatment consists of activity modification, limited weight bearing, immobilization, physical therapy, and anti-inflammatory medications. Running, jumping, sports, and physical education class activities should be restricted. No studies have reported that one form of nonsurgical treatment is better than another, and no data support a specific duration of nonsurgical treatment.[72] The authors of this chapter restrict activity and consider limited weight bearing with crutches but without immobilization. Crutches should not be used longer than 12 to 16 weeks because of the potential for atrophy and weakness. Physical therapy is initiated to maintain motion and facilitate quadriceps and hamstring strengthening. Radiographs should be obtained at 3 and 6 months to assess for lesion healing. If healing is observed, patients are allowed to gradually return to activities.

In a study of 42 skeletally immature patients with stable OCD lesions who underwent 6 months of nonsurgical treatment, Wall et al[70] reported progressive healing in two-thirds of the patients. The authors reported that large OCD lesions, swelling, and/or mechanical symptoms were poor prognostic factors for healing. Similarly, Hefti et al[59] reported a better prognosis, no effusion, and a classic lesion location (lateral aspect of the medial femoral condyle) in younger patients with small OCD lesions (<2 cm^2) who underwent nonsurgical treatment; however, the authors reported that unstable OCD lesions were best managed with surgery. Sales de Gauzy et al[71] reported complete radiographic healing in 30 of 31 OCD lesions in 24 children (mean age, 11 years 4 months) who underwent a nonsurgical treatment regimen of activity restriction alone. Other studies have reported successful healing in only 50% of patients who were treated nonsurgically.[53,73,74] Surgical treatment should be considered in patients who remain symptomatic despite 6 months of nonsurgical treatment and in patients who have unstable OCD lesions that are unlikely to heal. However, patients who have mechanical symptoms as a result of displaced or grossly unstable OCD lesions often are indicated for immediate surgical treatment.

Surgical Treatment

Surgical treatment should be considered in patients in whom nonsurgical treatment fails and in patients who have unstable OCD lesions, especially in the setting of mechanical symptoms. Surgical options for the management of OCD lesions include arthroscopic fragment excision and débridement, drilling, arthroscopic/open reduction and internal fixation, microfracture, OAT, osteochondral allograft transplantation, and ACI; however, no consensus on the preferred surgical option exists. Factors such as patient age, mechanical alignment, and lesion characteristics (size, location, depth, and stability) should be considered in the development of the surgical plan. In addition, the treating surgeon should approach abnormal subchondral bone and the overlying articular surface as an intimately related osteochondral unit. The goal of reparative and restorative procedures is to reestablish the osteochondral unit in an anatomic fashion and, thus, restore joint congruity and normal kinematics of the knee.

Arthroscopic Fragment Excision and Débridement

Arthroscopy can be used for diagnostic, palliative, and reparative purposes. For patients who have unstable OCD lesions with evidence of a loose fragment that has little capacity to heal with osteosynthesis or drilling, arthroscopic fragment excision and débridement can provide short-term relief of pain and mechanical symptoms. However, some long-term studies have reported a high rate of progressive radiographic degeneration in patients with large OCD lesions (>2 cm^2) who underwent arthroscopic fragment excision and débridement.[75-77] Based on the available literature, débridement alone in younger patients is not considered an ideal long-term treatment. Close postoperative observation with the potential for early cartilage restoration may be considered, especially in younger patients who have lateral femoral condyle lesions.

Drilling

Arthroscopic or arthroscopic-aided drilling can be effective for the management of OCD lesions, especially in children with OCD lesions who have open growth plates and an intact chondral surface.[78-81] Drilling can be performed via an anterograde (transarticular) approach with penetration of intact articular cartilage or via a retrograde (extra-articular) approach with preservation of intact articular cartilage. The goal of drilling is to promote subchondral healing by creating vascular channels from the underlying marrow. No current evidence supports one drilling approach over another. Anterograde drilling is less technically challenging but disrupts an intact chondral surface. Retrograde drilling is more technically challenging but avoids articular

Figure 3 Images of the knee of a skeletally immature patient with an osteochondritis dissecans (OCD) lesion who underwent arthroscopic drilling. **A,** AP radiograph demonstrates an OCD lesion on the lateral aspect of the medial femoral condyle. Sagittal T1-weighted proton-density (**B**) and sagittal T2-weighted fat-saturated (**C**) MRIs confirm abnormal subchondral bone with an intact chondral surface. **D,** AP radiograph taken 3 months after retrograde drilling demonstrates complete healing of the OCD lesion.

cartilage penetration. The authors of this chapter prefer to perform retrograde drilling in skeletally immature patients who have an intact articular surface with no arthroscopic evidence of fragment instability (**Figure 3**). The use of fluoroscopy is encouraged because of the risk for physeal injury with a retrograde approach.

Arthroscopic/Open Reduction and Internal Fixation

Partially detached or hinged fragments can be reduced and fixed to intact underlying subchondral bone via an arthroscopic or open approach.[82] The fixation of loose osteochondral fragments also can be considered based on the intraoperative appearance of the fragment. Partially detached chondral or osteochondral flaps are hinged open, after which débridement, curettage, and microfracture or drilling of the subchondral bone is performed. Substantial subchondral bone deficiency or cysts should be addressed with local autograft bone that is harvested from the intercondylar notch or the ipsilateral proximal tibia, being mindful of potentially open physes. Fixation devices include cannulated metal headless compression screws and bioabsorbable screws or pins. Headless, cannulated, titanium, variably pitched implants allow for excellent compression and placement below the articular surface, which helps avoid prominent hardware and potential third-body wear (**Figure 4**). Screws should be removed after healing of the defect at 6 to 12 weeks postoperatively. Bioabsorbable implants have shown promise; however, questions remain with regard to their compression strength and enzymatic breakdown, which can lead to large subchondral cysts in some patients.[83-87] In addition, complete resorption may take years, during which time the implant can become prominent if the OCD lesion fails to heal and disintegrates around the implant, risking injury to the opposing articular surface. Therefore, the authors of this chapter prefer to use headless metal compression screws for fixation, which are then removed at 6 to 12 weeks postoperatively.

Implant removal is performed to assess lesion healing and remove unstable fragments. After implant removal, 8 additional weeks of postoperative full weight bearing are recommended to prepare the patient for return to higher level activities and avoid concern for damage that could be caused by a prominent screw that may be associated with fragment settling. In a study on the outcomes of patients with OCD lesions who underwent various surgical treatments, Pascual-Garrido et al[88] reported that patients who underwent arthroscopic internal fixation had a greater improvement in outcome scores compared with those who underwent osteochondral allograft transplantation.

Marrow Stimulation (Microfracture)

Marrow stimulation can be performed in patients who have an unstable OCD lesion if the osteochondral fragment is considered unsalvageable. Marrow stimulation involves penetration of the subchondral bone to liberate mesenchymal stem cells from the trabecular bone. These mesenchymal stem cells flow into the OCD lesion and biologically induce the formation of fibrocartilage repair tissue.

Although several studies have reported good outcomes after marrow stimulation, the long-term durability of the procedure has been questioned. Gudas et al[89] randomized 50 children (aged 18 years or younger) with OCD

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lesions to either a microfracture group or an OAT group. After 1 year, both groups had significant clinical improvement, with good to excellent results reported in 23 of 25 patients (92%) in the OAT group and 19 of 22 patients (86%) in the microfracture group. Although outcomes were stable in the OAT group at a follow-up of 4.2 years (19 of 23 patients [83%] had good to excellent results), only 12 of 19 patients (63%) in the microfracture group had similar results. In addition, microfracture failed in 9 patients (41%). Patients with OCD lesions that were larger than 3 cm^2 who underwent microfracture had worse outcomes compared with patients with OCD lesions that were less than 3 cm^2 who underwent microfracture. Microfracture is a viable option for patients who have small defects (<2 to 3 cm^2) without substantial subchondral bone deficiency (<6 mm). Postoperative rehabilitation that includes protected weight bearing and immediate range of motion is critical to enhance surgical outcomes.

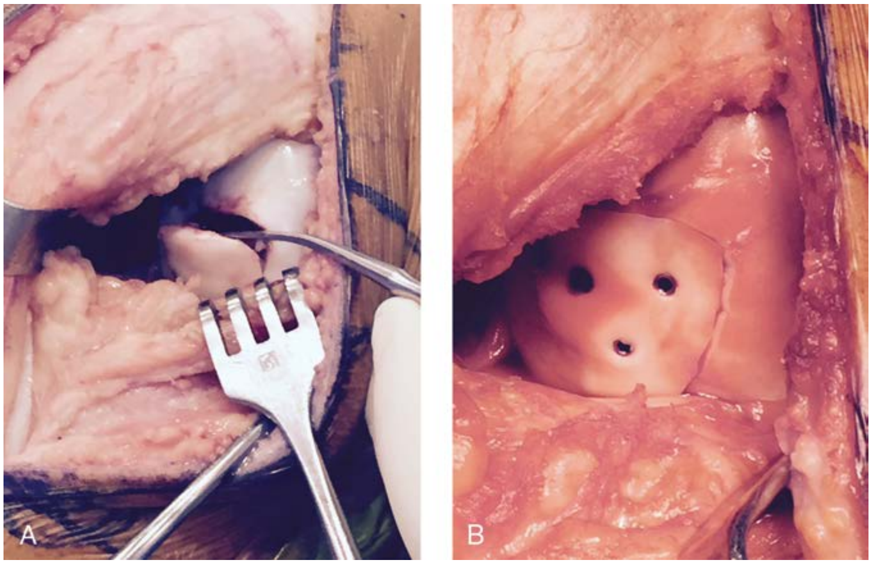

Figure 4 Intraoperative photographs of a knee with an osteochondritis dissecans (OCD) lesion that was treated with open reduction and internal fixation. **A,** Photograph shows a hinged OCD lesion on the lateral femoral condyle. **B,** Photograph shows open reduction and internal fixation of the OCD lesion with the use of headless, cannulated, titanium, variably pitched screws.

OAT/Mosaicplasty

OAT may be considered in patients who have subchondral bone deficiency and a disrupted articular surface. OAT is most effective for patients who have small OCD lesions (<2 to 3 cm^2). OAT involves preparation of the osteochondral defect and transfer of an osteochondral cylinder from a low–weight-bearing region of the knee (such as the intercondylar notch or the periphery of the trochlea) to the OCD lesion. OCD lesions larger than 1 cm^2 require the use of multiple plugs, which is referred to as mosaicplasty. Because of the potential donor site morbidity that is associated with the use of multiple plugs, the authors of this chapter prefer to perform mosaicplasty only in patients who have small OCD lesions.

OAT also can be used as an alternate form of fixation in lieu of screws. Miniaci and Tytherleigh-Strong[90] performed OAT mosaicplasty in 20 patients to secure OCD fragments. The harvested osteochondral cylinders were placed through the central aspect of the OCD fragment and, occasionally, along the periphery of the OCD fragment to create a biologic splint. At a follow-up of 18 months, all of the patients had normal IKDC Subjective Knee Evaluation Form scores. In addition, MRI demonstrated bone healing and cartilage healing at 6 months and 9 months postoperatively, respectively.

Osteochondral Allograft Transplantation

Patients who have large OCD lesions (>2 to 4 cm^2) may be treated with osteochondral allograft transplantation. Osteochondral allograft transplantation is ideal for patients who have OCD defects with subchondral bone deficiency (>8 to 10 mm) because it restores the entire osteochondral unit. Osteochondral allograft transplantation also can be used as a salvage procedure in patients in whom other cartilage repair procedures fail.

In a study of 64 patients with OCD lesions who underwent fresh osteochondral allograft transplantation, Emmerson et al[91] reported good to excellent results in 72% of the patients at a mean follow-up of 7.7 years. All of the patients underwent previous surgical procedures before osteochondral allograft transplantation. In a more recent study of 39 patients (43 knees) who underwent fresh osteochondral allograft transplantation, Murphy et al[92] reported that, at a follow-up of 10 years, graft survivorship was 90%, and 88% of the knees in which the grafts were in situ were rated good to excellent. The cohort consisted of 26 pediatric and adolescent knees in which an OCD lesion was the underlying cause of the defect.

Autologous Chondrocyte Implantation

Similar to osteochondral allograft transplantation, ACI can be performed in patients who have large OCD lesions (>2 to 4 cm^2) and used as a salvage option in patients in whom other cartilage repair procedures fail. Modifications to ACI have been described for patients with more than 8 to 10 mm of subchondral bone loss. This modified ACI technique, which has been referred to as the sandwich technique, involves autologous bone grafting of the subchondral defect followed by the application of a collagen membrane on which ACI is performed.[93,94]

In a study of 58 patients with OCD lesions who underwent ACI, Peterson et al[93] reported successful clinical results in more than 90% of the patients at a mean follow-up of 5.6 years. Mean Wallgren-Tegner activity scale, Lysholm Knee Scale, and visual analog scale scores improved, and 93% of the patients reported improvement on a patient self-assessment questionnaire. Forty-eight of the patients underwent a mean of 2.1 surgical procedures before ACI, and the mean duration of symptoms was 7.8 years. The sandwich technique was performed in seven patients who had a defect depth greater than 10 mm. In a study of 32 patients with OCD lesions who underwent ACI for the management of at least one failed non-ACI procedure, Cole et al[95] reported successful results in 85% of the patients at a follow-up of 48 months. The authors performed ACI with the use of a traditional single-layer technique rather than the sandwich technique.

Patellofemoral Defects

Patellofemoral pain is one of the most common musculoskeletal conditions, with etiologies including acute trauma, overuse, chronic patellar maltracking, and patellar instability. Patellofemoral chondral defects can result from these etiologies or may be idiopathic. In a systematic review of 11 studies that included 931 athletes, Flanigan et al[96] reported patellofemoral chondral defects in 37% of the athletes. Retrospective studies that were based on a large number of consecutive knee arthroscopies have reported that, after the medial femoral condyle, the patella is the second most common site for chondral defects.[1,97] Numerous studies have reported that chondral and osteochondral lesions are observed in as many as 95% of patients who sustain a patellar dislocation.[98-101] The inferior aspect of the medial patellar facet is the most common defect site after patellar dislocation.[98] Although a large percentage of patients who have patellofemoral chondral lesions respond favorably to nonsurgical treatment, surgical treatment should be considered in the subset of patients who remain symptomatic despite nonsurgical treatment. Successful management of patellofemoral chondral lesions can be challenging because of the complex biomechanical environment of the patellofemoral joint. Therefore, a careful evaluation of the underlying pathomechanics of the patellofemoral joint is necessary to ensure a successful surgical outcome.

Clinical Evaluation

Typically, patients with patellofemoral cartilage injuries have anterior knee pain that is worse with activity. Activities that involve loaded knee flexion, such as squatting, kneeling, and the use of stairs, often elicit pain. Intermittent swelling is common, and catching or locking can result from an unstable chondral flap. Some patients may have patellar instability (acute or chronic) and recall a specific event associated with their dislocation or subluxation. The physical examination should focus on an assessment of the knee for effusion, patellar mobility, and tracking with range of motion. Generalized ligamentous laxity, lower extremity alignment and rotation (femoral neck anteversion and tibial torsion), hip strength, and core strength should be evaluated.

Imaging

Routine radiographs, including standing AP, lateral, Merchant, and 45° flexion PA views, should be obtained. The radiographs are evaluated for fractures, loose bodies, joint space narrowing, osteophytes, patella alta, patellar tilt, and patellar subluxation. MRI is particularly useful to help diagnose and characterize chondral and osteochondral defects of the patellofemoral joint. In addition, MRI helps evaluate the integrity of the medial patellofemoral ligament (MPFL) and the tibial tubercle-trochlear groove (TT-TG) as well as assess the TT-TG distance, the TT-posterior cruciate ligament (PCL) distance, patellar height, and the presence of trochlear dysplasia. The TT-TG distance is a measure of tibial tubercle lateralization, which is calculated by measuring the medial to lateral distance between the center of the trochlear groove and the center of the tibial tubercle. The TT-PCL distance is measured from the medial aspect of the PCL, close to its tibial insertion, to the center of the tibial tubercle. Both MRI and CT can help calculate the TT-TG distance in patients who have patellar instability; however, recent data suggest that MRI may underestimate this distance.[102-104] The TT-TG distance often is misleading for a variety of reasons and should not be used in isolation. Measurement of the TT-PCL distance helps resolve underestimated TT-TG.[105] Given the high incidence of chondral and osteochondral injuries after patellar dislocation, many surgeons routinely obtain MRI after patellar dislocation, even after a primary dislocation, because, often, substantial chondral or osteochondral avulsions may be missed on radiographs. The medial patella and the lateral femoral condyle are the most commonly injured sites after patellar dislocation. The lateral femoral condyle can be particularly difficult to evaluate. Edema is commonly observed; however, because of the convexity of the mostly peripherally located defect zone, actual cartilage damage can easily be missed.

Treatment

Nonsurgical Treatment

Initial management for most patellofemoral chondral defects should consist of nonsurgical measures, with attention to the core-to-floor approach. The exception to nonsurgical management includes patients who have mechanical symptoms resulting from a displaced chondral flap or an osteochondral fragment. A detailed discussion on the management of acute patellar dislocations is beyond the scope of this chapter. Nonsurgical treatment focuses on activity modification, anti-inflammatory medications, physical therapy, bracing, and intra-articular injections (cortisone or viscosupplementation). Physical therapy focuses on patellar stabilization; functional pelvic, valgus, and rotational control; and core, hip, and lower extremity strengthening. Physical therapy effectively alleviates patellofemoral pain by reducing mechanical stress in the joint and improving patellar tracking.[106,107] Nonsurgical treatment should be attempted for 6 weeks to 6 months, depending on a patient's progress.

Surgical Treatment

Patients in whom nonsurgical treatment fails or patients who have displaced chondral or osteochondral injuries should be considered for surgical treatment. Surgical treatment is individualized based on defect characteristics (size, location, stability, and status of the subchondral bone) and associated conditions, such as malalignment and instability. Other factors that should be considered in the development of the surgical plan include patient age, activity level, goals, and expectations, as well as a willingness to participate in postoperative rehabilitation. Surgical options for the management of patellofemoral defects include open reduction and internal fixation of the chondral/osteochondral fragment, microfracture with or without augments, OAT, osteochondral allograft transplantation, ACI, PJAC, realignment procedures (tibial tubercle osteotomy [TTO], lateral release/lengthening, and MPFL reconstruction), tibial and femoral rotational osteotomies, and patellofemoral arthroplasty.

Loose Body Repair, Removal, and/or Chondroplasty

Small chondral or osteochondral loose bodies that result from patellar dislocation can be removed arthroscopically. The removal of these fragments helps eliminate mechanical symptoms and prevents third-body wear. Associated patellofemoral defects can be further evaluated and addressed with open reduction and internal fixation if the fragment is amenable and in an age-appropriate patient. Alternatively, stabilization chondroplasty can be performed to address loose chondral flaps. If large osteochondral fragments are suspected preoperatively or encountered during arthroscopy, primary in situ fixation with metal screws or bioabsorbable implants should be considered. Small partial- or full-thickness chondral lesions (<1 cm^2) may require only chondroplasty, especially if they are located at the inferior aspect of the medial patellar facet, which experiences limited loading.

The anterior lateral femoral condyle is the second most common defect site after patellar dislocation; however, it is difficult to visualize through the standard lateral arthroscopic viewing portal. Frequently, the defect bed is covered with early repair tissue that is similar to that observed after marrow stimulation, particularly in patients who have an osteochondral defect. Large acute defects observed within 6 weeks of injury can be managed with a marrow-stimulation rehabilitation protocol to maximize the healing potential of this regenerative tissue.

Marrow Stimulation (Microfracture)

Microfracture can be used to treat patients who have small full-thickness chondral defects (<2 cm^2) of the patella or trochlea. Performing patellar microfracture via an arthroscopic approach is technically challenging because it is difficult to position the instruments perpendicular to the defect. Unfortunately, few outcome studies have evaluated patellofemoral defects in isolation; most studies combine data on femoral condyle defects with that of patellofemoral defects.

Kreuz et al[108] followed 70 patients who underwent microfracture for the management of full-thickness chondral defects that involved various compartments of the knee. Thirty-two patients had femoral condyle defects, 11 patients had tibial defects, 16 patients had trochlear defects, and 11 patients had patellar defects. The authors reported good results in all of the patients at 6 months and 18 months postoperatively but reported deteriorating outcome scores and MRI defect filling at 36 months postoperatively. In addition, greater deterioration was reported in the patients who had trochlear and patellar defects compared with the patients who had femoral condyle defects; this is a concern given the known long-term deterioration that occurs after microfracture in other areas of the knee. Therefore, microfracture should be reserved only for patients who have small lesions, most of which are located in the inferior pole or the lateral patellar facet.

OAT/Mosaicplasty

OAT may be considered in patients who have small full-thickness chondral or osteochondral defects (<2 cm^2) of the patella or the trochlea. OAT restores the osteochondral unit with hyaline cartilage and native bone. OAT is a viable option for patients who have patellofemoral defects; however, the procedure is more complicated in these patients because it requires the complex contour of the patella and trochlea to be matched with donor cylinders that commonly lack the same thickness of native patellofemoral cartilage.[109]

In a study of 10 consecutive patients with patellar defects (mean defect size, 1.2 cm^2) who underwent OAT, Figueroa et al[110] reported improved mean Lysholm Knee Scale scores (73.8 to 95) and no complications at a mean follow-up of 37.3 months. Follow-up MRI obtained at 8 months postoperatively were favorable, with all of the grafts being flush to the adjacent cartilage and, in most patients, no fissures in the graft-receptor interface. In a study of 22 patients with patellar defects (mean defect size, 1.65 cm^2) who underwent OAT, Nho et al[111] reported improved mean IKDC Subjective Knee Evaluation Form (47.2 to 74.4), Activities of Daily Living Scale of the Knee Outcome Survey (60.1 to 84.7), and SF-36 (64.0 to 79.4) scores at a mean follow-up of 28.7 months. Similarly, in a study of 33 patients with symptomatic patellar defects (1 to 2.5 cm^2) who underwent OAT, Astur et al[112] reported statistically significant improvements in mean Lysholm Knee Scale, Kujala Anterior Knee Pain Scale, Fulkerson Knee Instability Scale, and SF-36 scores 2 years postoperatively. The authors reported that MRI obtained 2 years postoperatively revealed full graft integration in all patients.

Conversely, Bentley et al[113] reported a high failure rate in patients with patellar chondral lesions who underwent mosaicplasty. The authors conducted a prospective randomized study of 100 patients with osteochondral defects who underwent either ACI or mosaicplasty. Of the 100 patients, 5 underwent mosaicplasty for the management of patellar defects. All of the patellar mosaicplasty procedures had failed at a mean follow-up of 1.7 years. Therefore, OAT may be considered in patients who have small lesions (<2 cm^2); however, higher failure rates should be expected in patients with larger defects that require more donor cylinders.

Patellar cartilage is approximately twice as thick as medial or lateral trochlear cartilage (the usual donor site). This difference in cartilage thickness will lead to subchondral bone mismatch and may be a stress riser. In addition, many patients with patellar lesions have patellar instability or malalignment, in which the lateral trochlea, in particular, is overloaded. The selection of the donor site in these patients is difficult and may be impossible without causing further damage to the patellofemoral joint.

Osteochondral Allograft Transplantation

Osteochondral allograft transplantation restores the entire osteochondral unit and is ideal for patients who have large defects (>2 to 4 cm^2). Similar to OAT, osteochondral allograft transplantation is a technically demanding procedure because of the concave and convex contour of the patella and trochlea. In a retrospective study of 14 fresh patellofemoral allografts that were implanted in the knees of 11 patients, Torga Spak and Teitge[114] reported that eight grafts were in place at final follow-up (mean, 10 years; range, 2.6 to 17.5 years), four of which were in place for more than 10 years and two of which were in place for more than 5 years. Of the nonsurviving allografts, three were in place for more than 10 years. Ten of the 11 patients in the study said that they would undergo the procedure again.

In a study of 20 fresh osteochondral allografts that were used to manage patellofemoral lesions in the knees of 18 patients, Jamali et al[115] reported a failure rate of 25% and a revision surgery rate of 53%. In a recent prospective study of 27 patients (28 knees) with isolated full-thickness patellar injuries who underwent osteochondral allograft transplantation, Gracitelli

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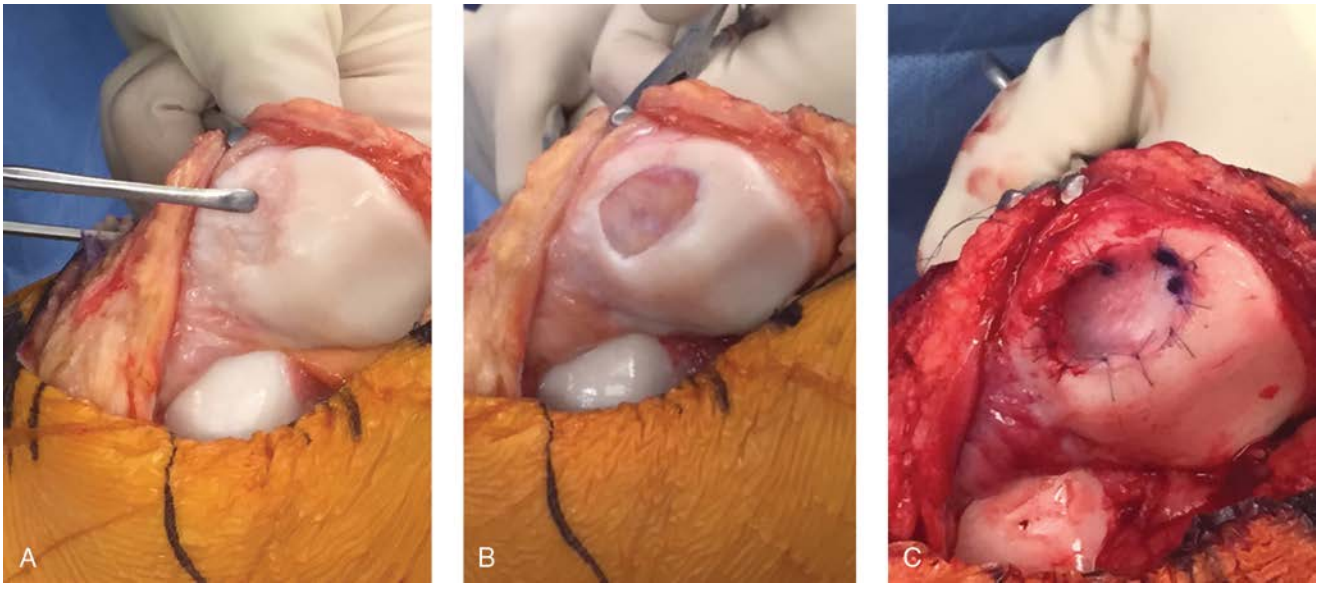

Figure 5 Intraoperative photographs of a knee with a patellofemoral defect that was treated with autologous chondrocyte implantation (ACI). **A,** Photograph shows a large chondral defect of the medial patellar facet. **B,** Photograph shows the removal of unhealthy articular cartilage from the medial patellar facet before ACI. **C,** Photograph shows the medial patellar facet after ACI.

et al[116] reported that survivorship was 78.1% at 5 and 10 years postoperatively and 55.8% at 15 years postoperatively. Seventeen of the 28 knees (60.7%) underwent additional surgery after osteochondral allograft transplantation, and osteochondral allograft transplantation failed in 8 of the 28 knees (28.6%). Despite the high revision surgery rate, 89% of the patients in whom osteochondral allograft transplantation was successful said that they were extremely satisfied or satisfied with the results of the procedure. The authors reported that the outcomes of their study were inferior compared with the published outcomes of osteochondral allograft transplantation for the management of femoral condyle injuries. Chahal et al[32] discovered a similar trend in a systematic review of 19 studies of 644 knees that were managed with osteochondral allograft transplantation and reported that osteochondral allograft transplantation results in inferior outcomes in patients who have patellofemoral defects compared with patients who have tibial and femoral condyle lesions.

Autologous Chondrocyte Implantation

ACI is a surgical option for patients who have medium to large chondral defects (>2 to 4 cm^2) of the patellofemoral joint (**Figure 5**). Compared with OAT and osteochondral allograft transplantation, matching the contour of the native morphology of the patellofemoral chondral surfaces is technically easier with ACI (**Figure 6**). In a large multicenter study of 110 patients with patellar cartilage defects who underwent ACI, Gomoll et al[117] reported statistically significant and clinically important improvements in all physical outcome scale scores at a minimum follow-up of 4 years. The authors reported that mean IKDC Subjective Knee Evaluation Form scores improved from 40.2 to 69.4, mean modified Cincinnati Knee Rating Scale scores improved from 3.2 to 6.2, and mean Western Ontario and McMaster Universities Osteoarthritis Index scores improved from 50.4 to 28.6. The authors noted that 92% of the patients said that they would undergo the procedure again, and 86% of the patients rated their knees as good or excellent at final follow-up.

Particulated Juvenile Articular Cartilage

PJAC is a surgical option for the treatment of patients who have patellofemoral defects of any size. Similar to ACI, matching the contour of the native patellofemoral surface is technically easier with PJAC compared with OAT or osteochondral allograft transplantation. PJAC is particularly useful for the management of patellofemoral lesions in patients in whom concomitant osteochondral allograft transplantation is necessary to manage femoral condyle defects because PJAC can be ordered on short notice after an osteochondral allograft has been matched (**Figure 7**). In

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Figure 6 Arthroscopic image of a knee taken 10 months after autologous chondrocyte implantation for the management of a chondral lesion of the femoral trochlea shows that the anatomic contour of the trochlea was restored.

a study of 13 patients (15 knees) with patellar chondral defects who underwent treatment with PJAC, Tompkins et al[118] reported that, at a mean follow-up of 28.8 months, mean IKDC Subjective Knee Evaluation Form, visual analog scale, and KOOS scores were favorable, and the mean fill of the defect based on MRI was 89%. The authors reported that two patients required knee manipulation under anesthesia for arthrofibrosis, and three patients required revision surgery for symptomatic grafts.

Video 42.2: Anteromedialization. Jack Farr, MD (2 min)

Video 42.3: Lateral Lengthening. Jack Farr, MD (2 min)

Video 42.4: Medial Patellofemoral Ligament Reconstruction. Jack Farr, MD (4 min)

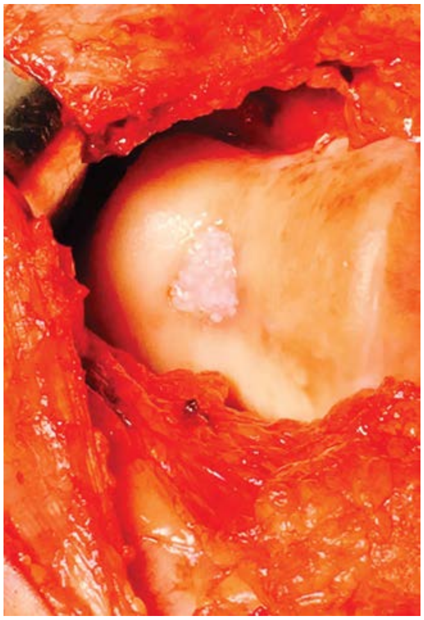

Figure 7 Intraoperative photograph of the knee of a patient shows a femoral trochlear defect that was managed with particulated juvenile articular cartilage at the same time that a lateral femoral condyle osteochondral defect was managed with osteochondral allograft transplantation.

Osteotomy

TTO for the treatment of patients who have patellar instability or patellofemoral disease has been extensively studied. TTO typically involves anteromedialization of the tibial tubercle.[119,120] Decreased lateral patellofemoral contact pressures have been demonstrated in biomechanical models after TTO.[121,122] Therefore, patients who have defects of the lateral patella or the trochlea are ideal candidates for and have the greatest potential to benefit from TTO.

Studies on the use of TTO in conjunction with cartilage repair have been recently published in the literature. Peterson et al[39] reported disappointing early results in patients with patellar defects who underwent ACI, with good to excellent results reported in only two of seven patients (29%). The authors performed realignment procedures, if they were necessary, in the latter 14 patients in the study, which resulted in good to excellent results in 11 of the 14 patients (79%). In a study that compared the outcomes of patients who underwent patellar ACI with or without concomitant extensor realignment, Henderson et al[123] reported superior mean modified Cincinnati Knee Rating Scale scores, function, mean SF-36 scores, and IKDC Subjective Knee Evaluation Form scores in the patients who underwent ACI in conjunction with extensor realignment compared with those who underwent ACI without extensor realignment. The authors reported that an unloading osteotomy may improve the outcomes of select patients who have normal patellofemoral biomechanics; however, both of the groups in the study included a substantial number of patients who had lateral patellar facet defects, which would be expected to respond positively to an unloading osteotomy, thus amplifying the differences the authors reported between the groups.

Pascual-Garrido et al[88] reported that ACI in conjunction with anteromedialization resulted in improved outcomes compared with ACI alone. Gillogly et al[124] reported good to excellent results at a mean follow-up of 7.6 years in 83% of patients who underwent ACI in conjunction with TTO. The authors reported that ACI in conjunction with TTO failed in only one patient, who subsequently underwent patellofemoral arthroplasty 5.9 years after the index procedure. A recent systematic review reported significantly greater improvements in multiple clinical outcomes in patients with patellofemoral chondral defects who underwent ACI in

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combination with osteotomy compared with those with patellofemoral chondral defects who underwent ACI alone.[125]

Conversely, a recent, large, multicenter study reported no significant difference between patients who underwent patellofemoral ACI with or without concomitant TTO.[117] However, the authors noted that most of the patients in the study (70%) had panpatellar defects, which would be expected to improve less after ACI with concomitant TTO, and, overall, the rate of ACI in conjunction with TTO was quite high (68%). The authors stressed that TTO is indicated in patients who have an abnormal biomechanical environment, and reported that the outcomes of patients who underwent patellar ACI in conjunction with TTO were similar compared with those of patients who underwent femoral condyle ACI.

Patellar instability must be addressed in patients with patellofemoral chondral defects who undergo cartilage restoration. Therefore, TTO should be considered in patients who have an elevated TT-TG distance (>15 mm) and patellar instability. Lateral retinacular lengthening typically is performed in combination with TTO. MPFL reconstruction can be performed in combination with TTO in select patients, most of whom typically have an acute or chronically disrupted MPFL and intraoperative evidence of continued lateral maltracking or instability despite distal realignment and lateral retinacular lengthening.

Video 42.5: Patellofemoral Arthroplasty. Jack Farr, MD (9 min)

Patellofemoral Arthroplasty

Patellofemoral arthroplasty is a primary surgical option for the treatment of patients who have advanced diffuse patellofemoral degeneration and is a salvage option in patients in whom cartilage procedures fail. Historically, a high failure rate and mediocre results were associated with patellofemoral arthroplasty; however, newer implant designs and techniques have substantially improved patient outcomes and implant survivorship.[126]

The Meniscectomized Knee

Meniscus tears are one of the most common knee injuries and frequently require surgical management. The meniscus is a critically important structure that minimizes joint contact stresses by providing maximum contact area. The meniscus also has a crucial role in proprioception and knee stability. In a loaded knee, the medial meniscus transmits 50% of the medial compartment load, and the lateral meniscus transmits 70% of the lateral compartment load.[127] Medial meniscus tears are twice as likely to occur compared with lateral meniscus tears. Meniscal surgery is performed in approximately 35 to 61 per 100,000 individuals.[128-130]

Biomechanical studies have reported that meniscectomy results in higher contact forces and lower contact areas compared with meniscal repair;[131] however, because of patient factors and tear characteristics, meniscal tears are not always amenable to repair. Contact forces have been reported to increase by as much as 65% after partial meniscectomy and 235% after total meniscectomy.[131] A change in contact forces may cause medial and/or lateral knee pain secondary to compartment overload, which may lead to progressive articular cartilage degeneration. In a prospective 40-year follow-up study of 53 patients who underwent total meniscectomy as adolescents, Pengas et al[132] reported that meniscectomy led to symptomatic knee osteoarthritis later in all of the patients, with a 132-fold increase in the rate of total knee replacement compared with that of age-matched control patients. Roos et al[133] reported that patients who underwent meniscectomy had a 14.0 relative risk for advanced osteoarthritis compared with age- and sex-matched control patients. Many other studies have reported a strong association between meniscectomy and radiographic and symptomatic osteoarthritis.[134-136]

Clinical Evaluation

Patients who are symptomatic and have undergone meniscectomy may have a wide variety of complaints; however, localized joint line pain or focal pain in the medial or lateral compartment are common. The surgeon should obtain a thorough history, including the time from previous surgery, the duration of current symptoms, and the activities or factors that precipitate pain. Some patients experience pain only with high-impact activities; other patients may experience pain with normal weight-bearing activities. The physical examination begins with a gait analysis followed by an assessment for effusion, deformity, contracture, ligamentous instability, malalignment, and patellar maltracking.

Imaging

Routine radiographs, including standing AP, lateral, Merchant, and 45° flexion PA views, should be obtained. The radiographs are evaluated for fractures, loose bodies, osteophytes, and joint space narrowing. Full limb-length

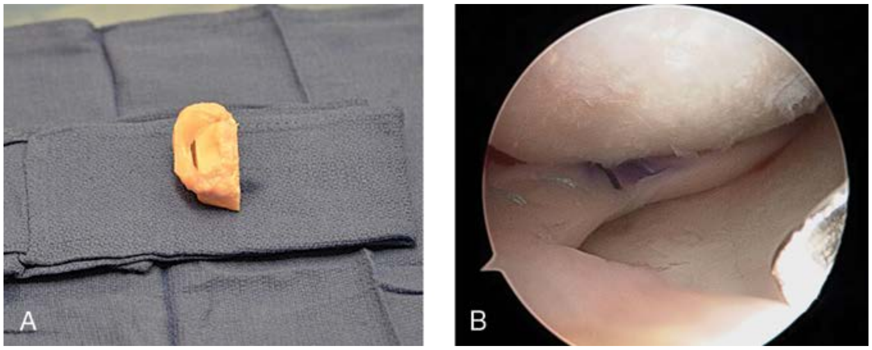

Figure 8 Images show meniscal allograft transplantation. **A,** Clinical photograph shows a meniscal allograft before transplantation. **B,** Arthroscopic image of a knee taken after suture fixation of the meniscal allograft.

radiographs may help determine mechanical alignment. MRI is used to evaluate for meniscal insufficiency and associated relevant chondral or osteochondral defects.

Treatment

Nonsurgical Treatment

Initial management should consist of nonsurgical treatment, including anti-inflammatory medications, activity modification, physical therapy, and injections (cortisone or viscosupplementation). An unloader brace can be effective in patients who have unilateral compartment overload as a result of malalignment or meniscal deficiency. Nonsurgical treatment may help alleviate symptoms; however, in many patients, nonsurgical treatment is only palliative in nature. Younger patients, especially those younger than 30 years, who have meniscal deficiency should be monitored closely because joint degeneration can occur quickly, especially after lateral meniscectomy.[136] A short period of time in which surgical intervention can be attempted to provide pain relief and potentially alter the progression of degenerative disease may exist.

Surgical Treatment

Surgical treatment should be considered in patients who are symptomatic and in patients in whom nonsurgical treatment fails, especially younger patients who have a high risk for rapid joint deterioration. Surgical options include meniscal allograft transplantation (MAT), osteotomy, cartilage repair, unicompartmental knee arthroplasty (UKA), and total knee arthroplasty (TKA). Factors such as patient age, goals, and activity level as well as the extent of the disease process should be considered in the development of the surgical plan.

Meniscal Allograft Transplantation

MAT may be considered in younger patients who have meniscal deficiency (**Figure 8**). The first human MAT was performed in 1984; since then, physicians' understanding of MAT has evolved.[137] Biomechanical studies report improved intra-articular contact area and pressures in patients who undergo MAT.[138,139] The primary indication for MAT is a symptomatic knee compartment in a patient with a history of total or subtotal meniscectomy.[140] No consensus on the upper age limit for MAT exists; however, 50 to 55 years is typically used as a cutoff. Controversy on the amount of acceptable chondral loss for MAT exists; however, ideally, articular cartilage defects that are greater than International Cartilage Repair Society grade III should be focal and small so that they can be addressed in conjunction with cartilage repair.[141] Contraindications to MAT include obesity, ligamentous instability (unless it is addressed before or in conjunction with MAT), previous joint infection, and squaring of the femoral condyles.[142,143] Patients who have more than 3° of varus or valgus malalignment should be considered for a concurrent osteotomy (high tibial osteotomy or distal femoral osteotomy).

Isolated MAT is an appropriate treatment option for younger patients who have meniscal deficiency, neutral alignment, and no chondral damage. Conversely, younger patients who have medial meniscal deficiency, varus malalignment, and a medial chondral defect may benefit from medial MAT, high tibial osteotomy, and cartilage repair. In a study of 18 patients who underwent MAT, osteotomy, and cartilage repair, Harris et al[144] reported statistically significant improvements in mean IKDC Subjective Knee Evaluation Form scores; mean Lysholm Knee Scale scores; and KOOS pain, activities of daily living, sports and recreation, and quality of life subscale scores at a mean follow-up of 6.5 years. Thirteen revision surgeries were performed in 10 patients (55.5% reoperation rate); however, only one patient (5.6%) was converted to TKA.

Overall, survival rates and patient satisfaction have been positive after MAT. In a study of 172 patients who underwent MAT, McCormick et al[145] reported a 95% survival rate

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at a mean follow-up of 5 years. In a study of 30 patients who underwent MAT, Vundelinckx et al[146] reported that, at a mean follow-up of 12 years 8 months, 90% of the patients said that they were very satisfied or satisfied with the procedure and would undergo MAT again. In a systematic review of 55 studies on MAT, Rosso et al[147] reported that MAT provides good clinical results at short-term and midterm follow-up, with improvement in knee function and acceptable failure and complication rates. Although MAT has been associated with favorable outcomes, treating surgeons must carefully identify proper candidates for MAT. Younger patients who have realistic expectations and are willing to comply with a rigorous postoperative rehabilitation are ideal. If multiple procedures are indicated, a staged procedure in which extra-articular and intra-articular procedures are grouped together based on surgeon comfort level may be considered.

Video 42.6: High Tibial Valgus Osteotomy. Jack Farr, MD (7 min)

Osteotomy

An osteotomy (distal femoral or proximal tibial) is a joint-preserving procedure that can be used to treat patients younger than 50 years who have early compartment osteoarthritis. A varus-producing distal femoral osteotomy is indicated in patients who have lateral compartment disease, and a valgus-producing proximal tibial osteotomy is indicated in patients who have medial compartment disease (**Figure 9**). Osteotomy is advantageous for younger patients because long-term activities are not restricted, and the need for joint arthroplasty may be delayed or prevented.

Opening and closing wedge osteotomies have been described in the literature; however, a paucity of studies support one technique over another.[148,149] As a result of improved plating technology and various bone graft substitutes, opening wedge osteotomy has become the preferred technique.[150,151] In a study of 47 consecutive adults (younger than 55 years) who underwent proximal tibial opening wedge osteotomy for the management of medial compartment osteoarthritis and genu varus alignment, LaPrade et al[152] reported that, at a mean follow-up of 3.6 years, mean modified Cincinnati Knee Rating Scale scores improved from 42.9 to 65.1, and only three patients (6%) required revision osteotomy or conversion to TKA. In a recent systematic review of 21 studies, which included 1,065 patients who were treated for unicompartmental knee osteoarthritis, Brouwer et al[153] reported that valgus high tibial osteotomy reduced pain and improved knee function in patients who had medial compartment knee osteoarthritis.

Although less commonly used, varus-producing distal femoral osteotomy has resulted in encouraging outcomes in patients who have lateral compartment disease and genu valgus alignment.[154-156] The authors of this chapter prefer to perform osteotomy in patients with malalignment and isolated medial or lateral compartment disease who are younger than 55 years because they tend to be more active and may not be willing to comply with the postoperative activity restrictions associated with UKA. Conversely, UKA is a good option for less active patients aged 55 to 70 years who have isolated unicompartmental disease.

Figure 9 AP radiograph of the knee of a patient who was treated with a medial high tibial opening wedge osteotomy.

Cartilage Repair

Younger patients who have focal chondral defects as well as meniscal deficiency and/or malalignment may benefit from cartilage repair surgery in conjunction with other procedures, such as osteotomy or MAT. Cartilage repair options include microfracture, OAT, PJAC, ACI, and osteochondral allograft transplantation. The decision on which repair technique to use depends on both patient factors and the characteristics of the chondral lesion. Small lesions (<2 to 3 cm^2) are best managed with microfracture, OAT, or PJAC. Large lesions (>2 to 3 cm^2) are best managed with ACI or osteochondral allograft transplantation. If abnormal or deficient subchondral bone is present, OAT or osteochondral allograft transplantation should be considered to restore the entire osteochondral unit. The authors of this chapter recommend that additional patellofemoral or tibial defects be managed with ACI or PJAC (the use of ACI is off-label in the patella and tibia).

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In a study of 30 patients who underwent 31 combined MAT and cartilage restoration procedures, Rue et al[157] reported statistically significant improvements in mean Lysholm Knee Scale and IKDC Subjective Knee Evaluation Form scores at a mean follow-up of 3.1 years. The cartilage restoration procedures in the study included ACI and osteochondral allograft transplantation. In a case series of 36 patients who underwent MAT in combination with ACI, Farr et al[158] reported statistically significant improvement in standardized outcome survey, visual analog pain scale, and satisfaction scores at a minimum follow-up of 2 years. The authors reported that, before the 2-year follow-up, the procedure failed in four patients, all of whom required revision surgery. In a study of 48 patients who underwent MAT in combination with osteochondral allograft transplantation, Getgood et al[159] reported that, at a mean follow-up of 6.8 years, revision surgery was required in 26 of the 48 patients (54.2%), but the procedure failed in only 11 patients (22.9%). The authors reported statistically significant improvements in all outcome scores of the patients who had grafts that were still in place at the last follow-up. In addition, 90% of the patients said that they would undergo the procedure again, and 78% of the patients were extremely satisfied or satisfied with their outcomes.

Arthroplasty

UKA and TKA are treatment options for patients who have advanced degeneration of the knee. Because of the more limited life span of implants in younger patients, arthroplasty, especially TKA, should be reserved for patients older than 55 years who have lower physical demands. UKA and TKA also can be used as a salvage option for patients in whom cartilage surgery fails. Patients who have isolated unicompartmental disease can be successfully treated with UKA, whereas patients who have more diffuse disease that involves more than one compartment are better treated with TKA. In a study of 54 consecutive patients who underwent lateral UKA, Lustig et al[160] reported that implant survival was 94.4% at 10 years postoperatively and 91.4% at 15 years postoperatively. The authors reported that the most common reason for revision surgery to TKA was progression of medial compartment osteoarthritis. Similarly, implant survival rates as high as 94% to 100% have been reported 10 years after medial compartment arthroplasty.[161-163]

Summary

The evaluation and treatment decision-making process for patients who have articular cartilage injuries will continue to evolve in conjunction with advances made in cartilage repair surgery. A systematic approach to the evaluation and classification of chondral lesions is of the utmost importance in the development of treatment algorithms. Treatment algorithms should be tailored based on patient factors, lesion characteristics, and associated injuries. Patients with an asymptomatic chondral or osteochondral defect should be observed rather than considered for surgical treatment.

Nonsurgical management is the mainstay of initial treatment for most patients who have symptomatic articular cartilage injuries. Nonsurgical treatment has proved successful, especially in patients who have juvenile OCD, incidental chondral defects, and certain patellofemoral defects that are associated with patellar instability or maltracking. Surgical treatment is reserved for patients in whom nonsurgical treatment fails, patients who have mechanical symptoms, and patients who have a high risk of rapid joint degeneration. Incidental chondral defects that are found at the time of arthroscopy should be documented and, possibly, managed with chondroplasty; more advanced cartilage repair techniques should not be attempted acutely for many reasons.

Cartilage repair surgery may be considered in patients who have symptomatic chondral defects and meet surgical indications. A preoperative discussion is important to establish realistic postoperative expectations and discuss possible postoperative complications. First-line surgical treatment options include arthroscopic débridement and chondroplasty, marrow stimulation (microfracture), drilling, arthroscopic/open reduction and internal fixation, OAT, osteochondral allograft transplantation, ACI, and PJAC. Careful attention should be paid to articular cartilage and underlying subchondral bone in the decision of which surgical technique should be used to reestablish the osteochondral unit. Cartilage repair surgery can be combined with other procedures, such as osteotomy and MAT, in select patients. Multiple procedures can be performed concomitantly or in a staged fashion based on a surgeon's comfort level. Salvage options for patients in whom cartilage surgery fails include osteochondral allograft transplantation, ACI, sandwich bone graft techniques, partial joint arthroplasty, and total joint arthroplasty.

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