Review Article

Fresh Osteochondral Allograft Transplantation for the Knee: Current Concepts

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Abstract

Fresh osteochondral allograft (OCA) transplantation has been used to manage a wide spectrum of chondral and osteochondral knee disorders. Basic science and clinical studies support the safety and efficacy of the procedure. Transplantation of viable, mature hyaline cartilage into the affected area is an advantage of the procedure, which can be used to restore bone stock in complex or salvage scenarios. Indications for OCA transplantation in the knee include primary management of large chondral or osteochondral defects and salvage of previously failed cartilage repair. The procedure also can be used for complex biologic knee reconstruction in the setting of osteonecrosis, fracture malunion, or posttraumatic arthritis. Challenges associated with OCA transplantation include allograft storage and size matching, tissue availability, chondrocyte viability, the possibility of immunologic graft response, and a demanding surgical technique. Future research should focus on optimizing allograft viability and healing and refining current surgical indications and techniques.

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Fresh osteochondral allograft (OCA) transplantation involves the transfer of size-matched allograft cartilage and subchondral bone into chondral or osteochondral defects of the knee. In addition to restoration of compromised or unavailable bone stock, OCAs can be used to transplant viable chondrocytes within mature hyaline cartilage. OCA has also been used in primary and salvage procedures to manage challenging lesions in other joints, including the shoulder and ankle.

Basic science and clinical studies have demonstrated that OCA is a safe and effective management option for a variety of complex knee pathologies, including large chondral or osteochondral lesions, focal osteonecrosis, and select cases of posttraumatic arthritis.[1-7] OCA transplantation offers distinct advantages over other cartilage repair techniques for management of wide or deep chondral or osteochondral lesions. Débridement, microfracture, and osteochondral autograft transplantation (OAT) are often ineffective or impractical for lesions >2 cm^2.[8-10] Staged cell-based cartilage repair (ie, autologous chondrocyte implantation [ACI]) remains a viable management option for large defects of the knee in young, active patients. However, OCA transplantation is a single-stage technique and may be preferable to other techniques, particularly in the setting of unshouldered lesions, extensive subchondral edema, or extensive bone loss that requires restoration.[11,12]

To prevent graft failure, concomitant pathology that involves the joint must be addressed during graft transplantation or with a staged procedure. Currently, OCA is the only available biologic option for salvage procedures following failed cell-based repair, prior OCA transplantation for large chondral or osteochondral defects, or failed fixation of large, deep osteochondritis dissecans (OCD) lesions.[11,13] Because this procedure is versatile, indications for OCA transplantation have been expanded to include biologic restoration of the knee joint.[4] The goal of surgery is restoration of a biologic joint; symptom relief; and functional improvement, with the possibility of delaying or eliminating the need for future arthroplasty.

Epidemiology

Articular cartilage lesions are prevalent in the knee joints of young, active persons (age range, 26 to 47 years).[14] These lesions have a limited ability to heal spontaneously.[15] In several large studies, the prevalence of chondral lesions found during arthroscopic knee joint evaluation ranged from 60% to 66%.[16-19] In a study of approximately 1,000 knee arthroscopies, 11% of knees had localized, full-thickness lesions suitable for a cartilage repair procedure.[16]

In young, active patients, traumatic or developmental etiologies such as OCD are predominant. Several large studies have found high-grade chondral lesions in 5% to 20% of all patients undergoing arthoscopic evaluation; 4% to 5% of these patients were younger than 40 years.[16-19] Most of these lesions are diagnosed following insidious onset of pain and swelling with athletic activity. Only 50% of patients with chondral lesions report a traumatic injury.[20] In young patients, large, symptomatic chondral or osteochondral lesions have been shown to have a devastating effect on quality of life, including the inability to return to sport and difficulty performing activities of daily living.[21] In this patient population, arthroplasty is a poor option in terms of patient satisfaction and lifetime risk of revision surgery.[22]

Basic Science

Allograft Harvest, Processing, and Storage

Tissue availability and the logistics of graft transplantation have limited the widespread use of fresh OCA in North America. Prior to 1998, only two institutions maintained systems for harvesting, processing, and storing tissues for their own clinical use.[23-25] In the late 1990s, OCAs became commercially available from tissue banks whose guidelines for sterile procurement and processing were established by the American Association of Tissue Banks, with oversight by the FDA.[26] Allograft tissue is harvested within 24 hours of donor death, ideally from donors aged 15 to 40 years with grossly healthy articular cartilage.[27,28]

Chondrocyte viability directly correlates with the clinical success of OCA transplantation.[29,30] If chondrocytes remain viable in storage, they maintain the extracellular matrix, thereby maintaining the material properties of the graft. In an in vivo study, Gross et al[31] demonstrated that long-term survival of OCAs depended on the presence of viable chondrocytes, intact extracellular matrix, and incorporation of host bone. Chondrocyte viability at the articular surface (superficial zone) is also important for long-term graft survival.[29] Several studies have found that, following transplantation, chondrocyte viability was preserved over time.[31-33] Studies of OCAs retrieved after revision procedures have shown that donor chondrocytes remain viable for many years after transplantation.[31,32]

OCA storage methods (eg, frozen, cryopreserved, fresh) have different effects on chondrocyte viability, immunogenicity, and time to transplantation. Biomechanical and biochemical composition of cartilage deteriorates with longer storage time, which correlates with decreased chondrocyte viability. In an animal model, mean chondrocyte viability

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decreased based on how long the graft was stored, decreasing from 100% on day 1 to 51.6% on day 60.[23]

Among the available storage options, fresh OCAs have been shown to have the highest level of chondrocyte viability.[34] In fresh OCAs stored hypothermically at 39.2°F (4°C), chondrocyte viability begins to decrease when the graft is stored longer than 14 days and the biomechanical properties of the graft deteriorate.[23,29,35] In general, the recommended maximal time from harvest to transplantation is 28 days. This correlates with chondrocyte viability of at least 70% at implantation when the graft is stored at 39.2°F (4°C).[1]

Pallante et al[36] found that fresh grafts stored for 28 days at 98.6°F (37°C) had increased chondrocyte viability throughout all zones compared with those stored at 39.2°F (4°C). The authors reported that, after 28 days of storage at 98.6°F (37°C), chondrocyte viability of the graft was 80% at the surface, 65% in the superficial zone, and 70% in the middle zone. This was a minimal decrease compared with the chondrocyte viability in fresh controls—100%, 85%, and 95%, respectively.[29] Other recent studies have supported these findings, demonstrating that storage at a physiologic temperature significantly improved the viability of OCAs.[36,37]

As a result of these findings, the length of graft storage before transplantation could be increased with no negative effect on viability. This longer time frame is especially important given that tissue banks currently retain OCA tissue until microbiologic and serologic testing is complete, which is often longer than 14 days.[27] Donors are screened for HIV, hepatitis B surface and core antigens, hepatitis C antibodies, human T-lymphotropic virus-I and -II antibodies, and syphilis. Bacterial cultures are also obtained, and tissue is discarded if it tests positive for *Clostridium* or *Streptococcus*.[26]

Immune Response

Langer and Gross[38] demonstrated that intact articular cartilage elicits no humoral immune response. Human studies of retrieved allografts consistently have shown that patients tolerate the OCA immunologically, with no histologic evidence of rejection despite the lack of human leukocyte antigen or blood-type matching.[39,40] The dense extracellular matrix of intact hyaline cartilage essentially hides chondrocytes, acting as immune-privileged tissue. The subchondral bone and marrow components of the graft elicit a strong immune response.[39] Larger grafts (>10 cm^2) tend to elicit a stronger, systemic immune response.[41]

Clinical Evaluation

History and Physical Examination

History should focus on the location, duration, and onset of symptoms (eg, femorotibial versus patellofemoral, acute versus chronic, traumatic versus insidious) and the presence or absence of knee swelling, mechanical symptoms, or concomitant instability. Focal cartilage defects may have as much of an effect on the patient's quality of life as osteoarthritis and more of an effect than anterior cruciate ligament deficiency of the knee.[21] Traumatic lesions may be seen in an athletic population or following high-energy trauma.[14] OCD may present with insidious localized pain and swelling in the skeletally immature patient with no history of prior injury. Lesion location should be correlated with specific symptoms because many chondral lesions are asymptomatic and may not be the source of the patient's chief complaint.[13] The patient's history should raise suspicion for concomitant pathology that requires management, including ligamentous instability, meniscal pathology, or malalignment. Prior nonsurgical management (eg, NSAIDS, injections, physical therapy) and surgical reports, including the number and type of previous procedures, should be documented and reviewed carefully. Patients should be asked about risk factors for osteonecrosis (eg, steroid intake) and relative contraindications to OCA, including inflammatory arthritis and smoking.

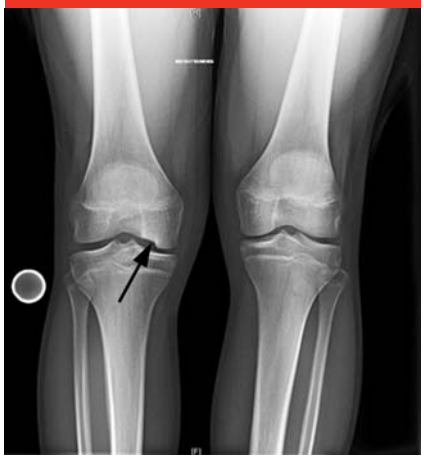
Physical examination should focus on knee alignment and gait. A dynamic strength assessment should be performed and the knee should be evaluated for effusion, tenderness to palpation, and ligamentous instability. Significant dynamic strength deficits of the quadriceps and core may warrant an attempt at rehabilitation before surgery is considered. Concomitant pathology, including ligament instability, limb malalignment, and/or meniscal deficiency, should be identified on physical examination and confirmed on imaging studies.

Imaging

Radiographic evaluation of chondral or osteochondral lesions of the knee includes bilateral weight-bearing AP and PA flexion, true lateral, and Merchant views. Radiographs of the lower extremities also should be obtained to assess the mechanical axis for significant varus or valgus malalignment; sizing markers can be used to calculate magnification on digital images.[29]

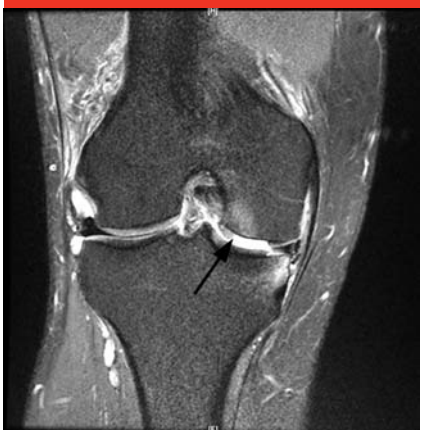
Tissue banks match allografts based on the size indicated on AP radiographs of the knee, which are provided by the surgeon[11] (Figure 1). Investigators have used the affected

Figure 1



Preoperative AP bilateral weight-bearing radiograph of the knees with a sizing marker demonstrating a large osteochondritis dissecans lesion (arrow) on the right medial femoral condyle. The radiograph is used to determine the size of the osteochondral allograft needed to manage the lesion.

Figure 2



Coronal T2-weighted magnetic resonance image of the knee joint demonstrating a large chondral defect (arrow) on the medial femoral condyle and subchondral edema.

condyle as a parameter for sizing, with an acceptable match being considered based on an overall condyle size within ±2 mm.[42] However, matching the condyle size does not take into account variable anatomy that exists secondary to pathology. For example, a condyle with an OCD lesion is often wider and flatter than a normal condyle, which necessitates a larger donor condyle.[11] Similarly, the width of the tibial plateau is measured from the medial to lateral cortex just distal to the articular surface; this measurement must match that of the donor tibial plateau.[43]

Alternatively, the size of the lesion can be measured on magnetic resonance images to determine the appropriate graft size.[13] However, studies have been shown that the size of the articular cartilage defect may be underestimated on MRI.[44,45] In a study of 38 patients with cartilage defects that were measured on preoperative magnetic resonance images, the mean final defect area was >60% larger than predicted on MRI.[45]

Advanced imaging studies are useful for evaluating osteochondral lesions. Cartilage-specific MRI sequences (eg, T1rho and T2 mapping, sodium MRI) permit detailed evaluation of a lesion's size and location and can be used to detect involvement of subchondral bone, subchondral edema, and concomitant ligamentous and meniscal pathology (Figure 2). CT may be useful for evaluating patellofemoral dysplasia or quantifying bone involvement and bone quality in patients with OCD lesions. In addition, bone scintigraphy can be used to evaluate for compartment overload in patients who have had prior menisectomy.

Patient Selection

Similar to other knee cartilage procedures, OCA transplantation should be performed in young, active patients with refractory symptoms following failure of nonsurgical treatment. In most patients, the main goal of surgery is to improve the overall quality of life and a return to pain-free performance of activities of daily living. In a young athletic population, goals may include return to the highest level of sport. In a study of 43 athletes with osteochondral defects of the knee treated with fresh-stored OCAs, Krych et al[2] demonstrated that 34 (79%) had a full return to sport at the preinjury level. Patient factors such as age, sex, body mass index, physical fitness, and emotional status (ie, expectations, motivations) are important prognostic indicators and can influence patient selection for cartilage procedures.[46]

In general, athletes younger than 25 years with symptoms lasting <1 year have better outcomes and a higher rate of return to sport following OCA transplantation than do other patient cohorts.[9] Similarly, young patients (aged <25 years) with posttraumatic or OCD lesions treated with OCA transplantation tend to return to higher activity levels following rehabilitation than do older patients.[2,43] Older patients with chronic focal lesions typically have lower demands and/or expectations, and the goal of treatment is to reduce pain associated with activities of daily living.[43]

Management of Chondral Lesions

In the cartilage treatment paradigm, OCA transplantation is one option available for management of idiopathic or traumatic focal chondral lesions. Other options include surgical débridement, microfracture, OAT, and ACI. Limited long-term success has been demonstrated with management of large, insidious or posttraumatic chondral lesions of the femoral condyles with surgical débridement or microfracture.[8-10] A meta-analysis of 11 studies on articu-

lar repair in athletes demonstrated that the results of microfracture deteriorate over time, particularly for defects >2 cm^2.[47] Although management of small chondral defects (<2 cm^2) with OAT may result in better outcomes than with microfracture, this technique is less suitable for management of larger lesions of the femoral condyle secondary to donor site availability and potential morbidity.[9,13,48]

Cell-based techniques such as ACI are a viable surgical option for large femoral condyle lesions. However, these techniques may be less suitable than OCA transplantation in the setting of deep lesions with violation of the subchondral plate and in cases of extensive subchondral edema.[11,12,49] OCA transplantation may be preferable to ACI because it is a single-stage procedure that transplants mature, viable hyaline cartilage, whereas ACI is a two-stage procedure that forms hyaline-like cartilage. In addition, OCA is currently the only biologic salvage option used following failure of cell-based procedures or prior OCA transplantation in the femoral condyles and patellofemoral joint.

OCA transplantation is indicated for primary management of large (>2 cm^2) chondral or osteochondral lesions of the knee and salvage procedures.[11,13,47] The indications for OCA transplantation are based on primary diagnosis (eg, idiopathic or posttraumatic, OCD, osteonecrosis, failed prior cartilage procedure); the presence of underlying subchondral edema; and lesion characteristics, including location (condyle, tibia, patellofemoral), size (>2 to <10 cm^2), and depth (ie, violation of subchondral plate).[27] Diagnostic arthroscopy may be used to evaluate lesion characteristics and develop a comprehensive staged surgical plan for biologic joint restoration in complex cases, such as persistent pain and/or biologic effusion after removal of loose bodies in patients with large, deep, unstable OCD lesions, and salvage scenarios following failed fixation of large, stable or unstable OCD lesions.

OCA transplantation also can be considered for management of focal osteonecrosis. Large lesions of the femoral condyles (>5 to ≤10 cm^2) and posterior condyle lesions are not contraindications because they may be treated with specific OCA transplantation techniques (snowman and shell, respectively). Indications for OCA transplantation have expanded to include resurfacing of the hemicondyle or whole condyle because the technique can provide nearly complete biologic joint restoration, especially in young patients with severe posttraumatic or degenerative lesions or in those who have undergone tumor resection.[1-7]

In general, management of defects of the patellofemoral compartment with allograft transplantation has resulted in poor outcomes.[50,51] ACI or other cell-based techniques have been used successfully in these cases, particularly for well-shouldered lesions. However, OCA transplantation is indicated for salvage of failed cell-based procedures in the patellofemoral joint. Primary management of these lesions with OCA may be considered in young patients with extensive chondral or osteochondral disease that requires near complete patella and/or trochlea biologic resurfacing. Improved storage and implantation techniques may make the use of OCA in the patellofemoral joint a more viable option.

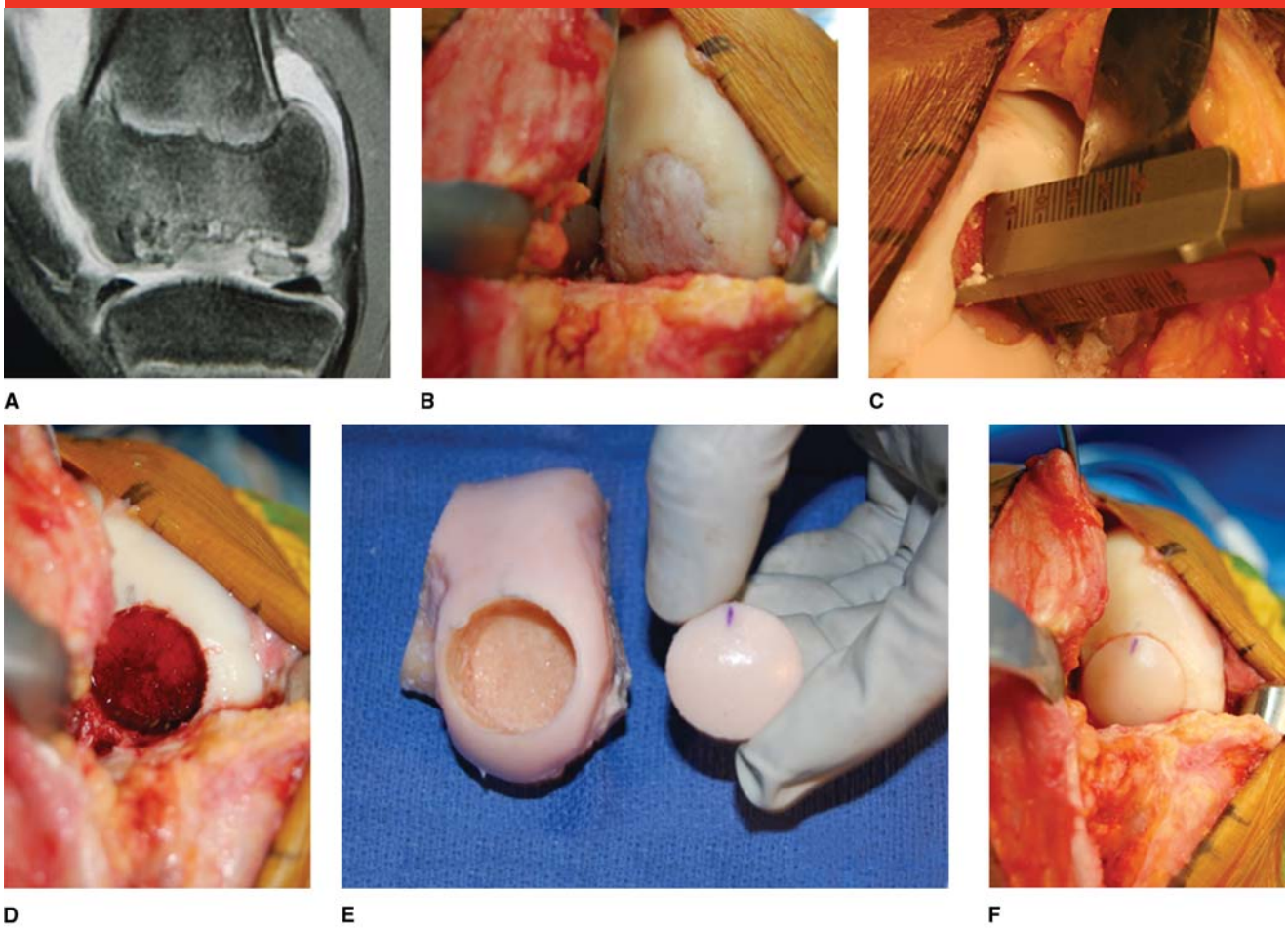
Currently, literature on management of tibial chondral lesions with OCA transplantation is lacking. Smaller lesions may be treated with benign neglect, débridement, microfracture, or salvage procedures such as retrograde OAT or cell-based techniques. In the setting of severe tibial chondral disease or failed prior cartilage and meniscal surgery, OCA transplantation of the entire tibial/meniscal surface may be considered.

OCA Transplantation Techniques

Selection of the appropriate OCA transplantation technique depends on the size and location of the chondral or osteochondral lesion. Typically, a midline skin incision is made, followed by either a medial or lateral parapatellar arthrotomy to expose the affected compartment. Care is taken to avoid damage to healthy chondral surfaces during deep dissection and transection of the anterior horn of the meniscus during capsulotomy.[27] For small or solitary defects, a quadriceps-sparing mini arthrotomy may be performed. A solitary plug technique is ideal for isolated defects if the affected area is well circumscribed in an easily accessible surface of the knee (eg, mid femoral condyle, mid patella, trochlea). The diameter of the plug can be matched precisely to the size of the lesion, providing complete coverage of the affected area and stable integration with the surrounding host bone and cartilage surfaces. This technique is demonstrated in Figure 3.

For large or multiple lesions, a standard arthrotomy is performed. Visualization of the entire zone of injury is critical to ensure that no damaged cartilage remains and that the OCA has healthy recipient cartilage along the periphery of the lesion.[52] The snowman technique is ideal for large or multiple lesions of the femoral condyle. This technique allows for coverage of a larger area of condyle than solitary plugs alone, particularly when lesion length (proximal to distal) is longer than lesion width (medial to lateral). This technique is

Figure 3



Femoral plug osteochondral allograft (OCA) transplantation technique. **A,** Sagittal T2-weighted magnetic resonance image of the knee demonstrating a large lesion of the medial femoral condyle. Intraoperative photographs demonstrating the recipient medial femoral condyle before (**B**), during (**C**), and after (**D**) reaming. The lesion is reamed with an appropriately sized reamer to a depth of 6 to 8 mm, using copious irrigation. **E,** Clinical photograph of size-matched allograft following harvest of the donor plug. The 12 o'clock position is marked for orientation. **F,** Intraoperative photograph of the recipient medial femoral condyle after the donor OCA is press fit into the reamed area.

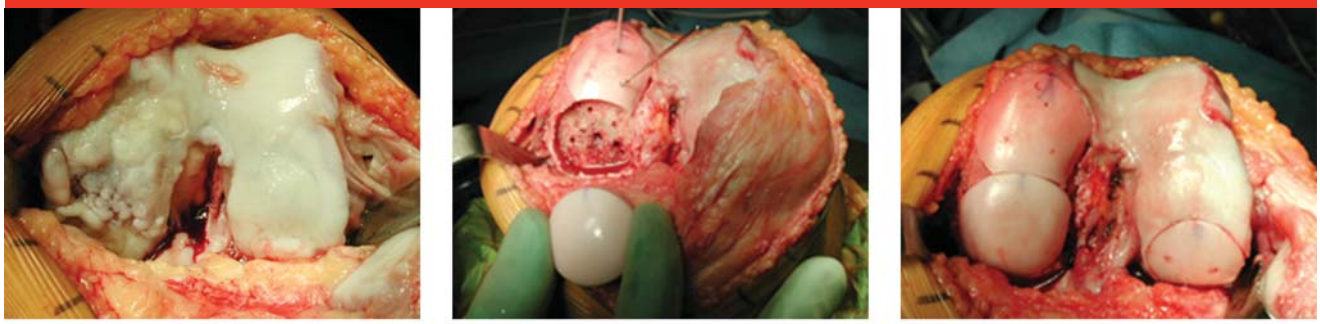
demonstrated in Figure 4. Care must be taken to avoid significant space between plugs because fibrocartilage may form and uneven cobblestoning may develop, affecting clinical outcomes.[53]

For asymmetric lesions (eg, whole patella/large trochlea) or for lesions in locations that are difficult to access (eg, posterior femoral condyles), the shell technique is useful. For posterior condyle lesions, the inability to obtain circumferential access to the lesion limits the surgeon's ability to perform plug or snowman techniques. For whole patella or trochlea OCA transplantation, the shell technique is preferred because it allows for anatomic restoration in the setting of asymmetric noncircular morphology. The surgical technique is demonstrated in Figure 5.

The small fragment allograft technique is indicated for posttraumatic complex lesions of the tibial plateau with concomitant meniscal deficiency. The surgical technique is demonstrated in Figure 6.

Current surgical techniques include meticulous washing of marrow elements and minimizing the width of underlying transplanted bone (6 to 8 mm) to decrease the risk of immune reaction. Because allograft bone heals by creeping substitution, it is beneficial to minimize the amount of bone transplanted. This decreases the time required for replacement by host bone and full osseous graft incorporation. Copious irrigation during graft harvest may also help to prevent thermal necrosis of donor chondrocytes.[11] Chondrocyte injury and subsequent death occurs during impaction insertion of grafts, thus

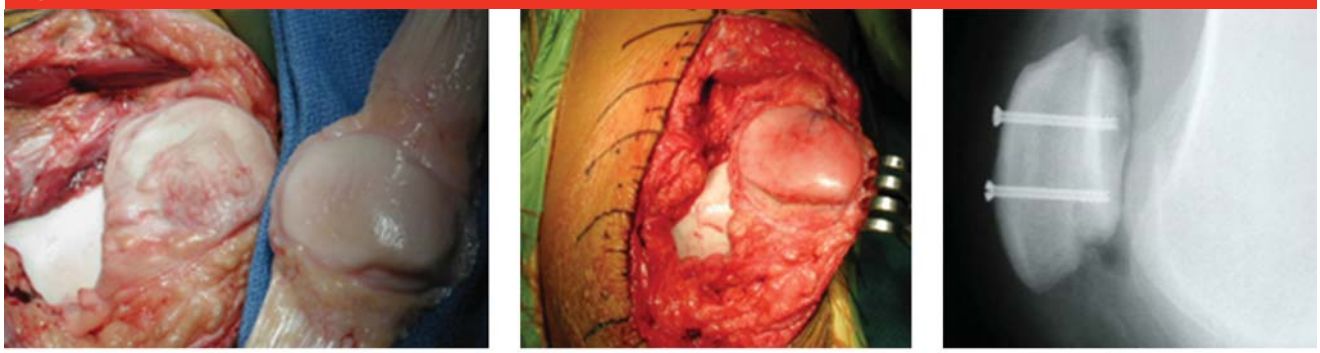
Figure 4



A B C

Osteochondral allograft (OCA) transplantation with the snowman technique. **A,** Intraoperative photograph of the femoral condyles demonstrating a large lesion of the medial femoral condyle and a solitary lesion of the lateral femoral condyle. **B,** The first OCA plug is placed in a fashion similar to that of the solitary plug technique. Provisional fixation of the first plug is performed with Kirschner wires prior to reaming for the second plug. The second site is reamed, with overlap at the inferior portion of the first plug. **C,** Intraoperative photograph taken following placement of the second OCA plug in the medial condyle and after a solitary plug was placed in the lateral femoral condyle.

Figure 5



A B C

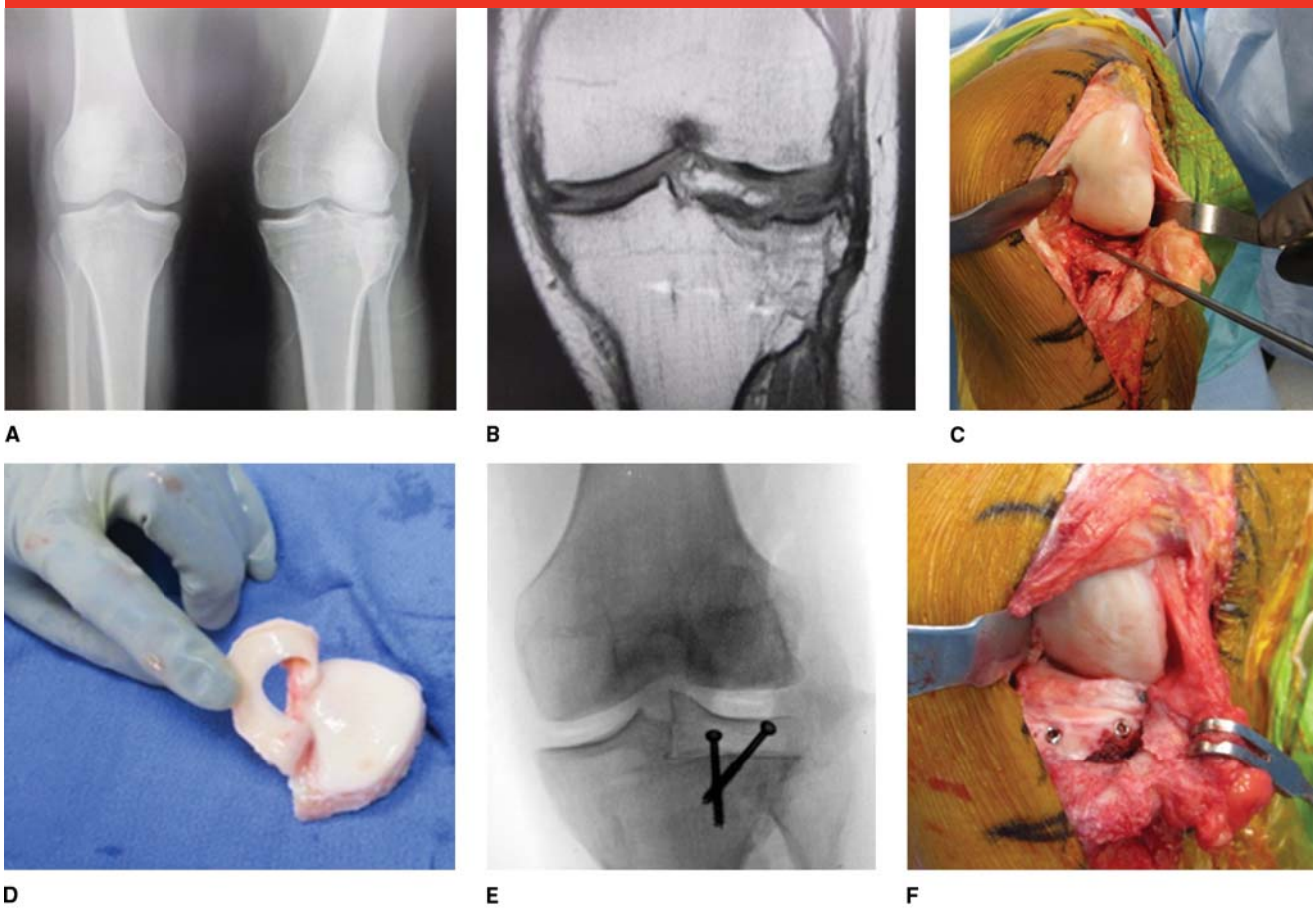
Shell technique for osteochondral allograft (OCA) transplantation. **A,** Intraoperative photograph of the patella demonstrating a large chondral lesion (left) adjacent to donor allograft (right). **B,** Intraoperative photograph of the patella following OCA transplantation. The entire chondral surface of the patella and adjacent subchondral bone was removed en bloc. The size-matched donor patella OCA was cut and contoured to fit the recipient patella. **C,** Postoperative lateral radiograph of the patella demonstrating screw fixation of the OCA.

minimizing the force of impact is crucial.[54] In most cases, the goal is to obtain a press fit. Fixation of contained allografts (ie, plug and snowman techniques) can be augmented with either bioabsorbable screws or chondral darts when necessary. Uncontained grafts (ie, shell and small fragment allograft techniques) require the use of either low profile interfragmentary screws or mini fragment plates for stable fixation.[13,27]

Management of Concomitant Pathology

Similar to other cartilage repair techniques, surgical success requires identification and management of concomitant pathology, including malalignment, ligament instability, and meniscal deficiency.[3,55] Concomitant pathology may be addressed in concert with OCA transplantation or in a staged fashion based on specific pathology and surgeon preference. Malalignment is evaluated during clinical examination and confirmed on a weight-bearing radiograph of the mechanical axis of the affected extremity. Realignment osteotomy is required when the weight-bearing axis falls through the affected area of articular cartilage. Biomechanical realignment decreases the load on the graft, increasing graft survival.[3] Gomoll[56] described the use of high tibial osteotomy as an adjunct to cartilage

Figure 6



Tibial meniscal allograft transplantation. **A,** Preoperative standing AP radiograph of the knee joints demonstrating isolated posttraumatic arthritis in the lateral compartment. **B,** Coronal T1-weighted magnetic resonance image of the knee joint demonstrating malunion of a lateral tibial plateau fracture with high-grade tibial cartilage loss, lateral meniscal deficiency, and relative preservation of the lateral femoral condyle. **C,** Intraoperative photograph of the knee following arthrotomy, confirming the presence of a meniscotibial injury appreciated on radiography and MRI. The damaged meniscotibial unit is resected en bloc. **D,** Size-matched fresh meniscotibial osteochondral allograft (OCA) is contoured to fit within the lateral compartment. The meniscotibial OCA is stabilized with screws and meniscal allograft repair. AP radiograph (**E**) and intraoperative photograph (**F**) of the knee joint demonstrating the final construct.

repair. The author's threshold for performing realignment osteotomy was 3° of varus or valgus malalignment, although this threshold and the degree of correction are typically based on surgeon preference. In general, opening wedge high tibial osteotomy is used to correct varus malalignment, and opening wedge lateral distal femoral osteotomy is used to correct valgus deformity. In the setting of patellofemoral chondral disease, tibial tubercle osteotomy (ie, anteriorization or anteromedialization of the tibial tubercle) may be performed along with cartilage procedures to transfer load from the damaged chondral surfaces to healthier parts of the joint or to correct maltracking (tibial tuberosity–trochlear groove distance >20 mm).[51]

Ligament injury is evaluated on clinical examination and confirmed on MRI. Restoration of rotational and translational stability is critical to the success of any cartilage procedure, allowing normalization of compartment contact stresses or shear forces that may damage the OCA over time.[57] Concomitant or staged ligament procedures include anterior and posterior cruciate ligament reconstruction as well as posteromedial and posterolateral corner repair or reconstruction. In the setting of patellar instability, medial patellofemoral ligament repair or reconstruction may be considered.

The meniscus plays a critical role in shock absorption, load distribution, and prevention of degenerative joint arthritis. OCA transplantation

is relatively contraindicated in the setting of meniscal deficiency. The surgeon must maintain a high index of suspicion for meniscal deficiency following failure of partial menisectomy. MRI or diagnostic arthroscopy can confirm meniscal deficiency. Successful repair of select peripheral meniscal tears may restore the functional properties of the meniscus to a near-normal state. In patients with meniscal deficiency, meniscal allograft transplantation is the preferred technique; several series have demonstrated improved graft survival in the setting of OCA transplantation with concomitant meniscal allograft transplantation.[3,55]

Postoperative Rehabilitation

Postoperative rehabilitation protocols for OCA are the same as those used following other cartilage procedures.[13] In the first phase of rehabilitation (0 to 6 weeks), the early goal is graft protection. Weight-bearing status varies based on lesion location, but the goal is to avoid placing shear or compressive stress on the transplanted area.

No consensus exists on the use of postoperative bracing following cartilage procedures. However, several authors recommend the use of a brace following surgery.[4,43] In general, weight bearing as tolerated is allowed with the brace locked in extension in patients treated for lesions of the patellofemoral joint.[43] Some authors recommend limited knee flexion (<45°) for the first 4 to 6 weeks in patients treated for patellar or trochlear lesions.[13,27] Patients treated for lesions of the femoral condyle or tibial plateau typically remain toe-touch weight bearing until early radiographic signs demonstrate graft incorporation. If a brace is used following management of these lesions, it is gradually opened in 20° increments as quadriceps control improves.[43] Non–weight-bearing status with early progressive range of motion (ROM) is encouraged, often with the use of a continuous passive motion machine. Weight bearing and ROM restrictions are modified based on the procedures performed for concomitant pathology (eg, osteotomy, ligament reconstruction, meniscal transplant or repair).

The goal of the second phase of rehabilitation (6 to 12 weeks) is for the patient to regain the ability to perform functional activities of daily life. Typically, braces are discontinued once the patient has adequate quadriceps control and can perform a straight leg raise without an extension lag.[43] Some authors recommend prolonged use of an unloader brace for 4 months postoperatively to offload the affected compartment.[4,27] This may be particularly useful in patients with bipolar lesions.[4,27] Patients progress toward full ROM, normalized gait, and initiation of closed-chain exercises and gentle strengthening.

The final phase of rehabilitation (>3 months) varies based on the goals and expectations of the patient. In the patient with a goal of performing activities of daily living without pain after salvage procedure, a transition is made to a maintenance home exercise program and gradual return to work. In the athlete, this phase focuses on advanced strengthening, core stabilization, proprioception, and gradual return to sport-specific training. Athletes should be cautioned against activities that produce excessive impact loading on the allograft, especially during the first year after surgery. If possible, high-loading activities should be avoided until 6 to 12 months postoperatively.[27] Athletes should have full ROM, ligamentous stability, no effusion, and excellent dynamic strength before considering the risks and benefits of returning to the highest level of activity. Return to play should follow a set of rigorous criteria, at the discretion of the treating surgeon.

Results

In general, studies of OCA transplantation for idiopathic focal chondral or osteochondral lesions of the femoral condyles have demonstrated good to excellent outcomes in terms of graft survival and patient function.[1-7,58-63] Table 1 summarizes recent study results of OCA transplantation for the knee joint. We found that recent literature on the subject primarily consists of the small case series, with a considerable lack of level I evidence. Although there are study limitations due to the small number of cases, graft survival rates ranging from 84.5% to 100% at 5 years, 71% to 89% at 10 years, 74% to 76% at up to 15 years, and 66% at up to 20 years have been reported.[3,6,7,63,64]

Favorable results were also reported for OCA transplantation used to manage OCD and steroid-associated osteonecrosis, with graft survival rates of 79% to 94% at up to 5 years postoperatively.[51,55,59,60] Poor results have been reported with bipolar, large (>10 cm^2), and chronic lesions; increasing patient age; uncorrected malalignment; and workers' compensation cases.[3,62,64]

With regard to OCA transplantation for posttraumatic or tibial malunion, a limited number of studies are available. In general, these small series have reported good to excellent outcomes, with graft survival rates of 95%, 71% to 80%, and 65% to 66% reported at 5, 10, and 15 to 20 years, respectively.[64,65] In the setting of osteoarthritis, the prognosis is less favorable, with a graft failure rate of up to 48% reported in one study.[66] Outcomes fol-

Table 1

Comparision of Osteochondral Allograft Outcomes

Study	Site of Lesion	Mean Follow-up (yr)	No. of Knees
LaPrade et al[1]	Femoral condyle	3	23
Krych et al[2]	Femoral condyle, trochlea, multiple locations	2.5	43
Gross et al[3]	Femoral condyle, tibial plateau	10	60
Williams et al[4]	Femoral condyle	4	19
McCulloch et al[5]	Femoral condyle	2.9	25
Görtz et al[6]	Femoral condyle	5.6	28
Levy et al[7]	Femoral condyle	13.5 (median)	129
Emmerson et al[63]	Femoral condyle	7.7	65

HSS = Hospital for Special Surgery, IKDC = International Knee Documentation Committee Subjective Knee Evaluation Form, KOOS = Knee Injury and Osteoarthritis Outcome Score, KOOS ADL = Knee Injury and Osteoarthritis Outcome Score Activity of Daily Living scale, OA = osteoarthritis, OCD = osteochondritis dissecans, SF-12 = 12 Item Short Form Health Survey, SF-36 = 36 Item Short Form Health Survey

lowing OCA transplantation for patellofemoral lesions remain poor; one series reported graft survival rates of 43% at 5 years and 29% at 10 years postoperatively, and another study reported a graft survival rate of 75% after an average follow-up of 8 years.[50,51]

Limited data are available on the use of OCA transplantation in an athletic population.[2] In a recent study of 43 athletes treated with fresh OCA transplantation, 38 (88%) had limited return to sport, and 34 (79%) returned to sport at the preinjury level.[2] Patients older than 25 years and those with symptoms lasting longer than 12 months were less likely to return to sport.

Summary

Fresh OCA transplantation is useful for management of large chondral and osteochondral lesions of the knee. The technique has the unique advantage of transplanting viable, mature hyaline cartilage into the affected area. In complex or salvage scenarios, OCA transplantation allows the surgeon to restore compromised or unavailable bone stock. Basic science studies continue to refine allograft processing and storage, allowing for safe and timely transplantation of aseptic tissue with minimal immune response and improved vitality. Patient selection relies on a thorough history and physical examination, followed by appropriate imaging studies. Management of concomitant limb malalignment, ligamentous stability, and meniscal deficiency is critical to the success of OCA transplantation. This procedure may be preferable over other cartilage procedures because it is single-stage technique that can be used for large chondral or OCD lesions of the condyles or in the setting of substantial subchondral edema or substantial violation of the subchondral plate. OCA is the only biologic option available following failed cell-based cartilage repair (ie, ACI) or prior failed OCA transplantation in the femorotibial or patellofemoral joint.

Indications for OCA transplanta-

Table 1 (continued)

Comparision of Osteochondral Allograft Outcomes

Diagnosis	Failure Rate (%)	Graft Survival (yr)	Postoperative Outcomes Scores (Preoperative Scores)
Idiopathic, OCD lesions >3 cm, trauma	0	100%	IKDC: 68.5 (52) Cincinnati knee: 69 (49.2)
Trauma, nontrauma, OCD	0	100%	Limited return to sport: 88%; return to sport at preinjury level: 79% IKDC: 79.29 ± 15 (46.27 ± 14.86) KOOS ADL: 82.82 ± 14 (62 ± 15.96) Marx activity: 8.35 ± 5.9 (5.49 ± 6.35)
OCD, posttraumatic arthritis, osteonecrosis	20	95% (5); 85% (10); 74% (15)	HSS knee: 83
Idiopathic, OCD lesions >2 cm, osteonecrosis	21	79%	SF-36: 66 ± 24 (51 ± 23) KOOS ADL: 70 ± 22 (56 ± 24)
OA, trauma, OCD lesions >2 cm, osteonecrosis	4	96%	Lysholm: 67 (39) IKDC: 58 (29) KOOS pain: 73 (43) SF-12: 40 (36)
Osteonecrosis	11	89%	Merle d'Aubigne and Postel: 15.8 (11.3) IKDC pain: 2.0 (7.1) IKDC function: 8.3 (3.5) Knee Society function: 85.7 (60)
OCD lesions >2 cm, trauma, osteonecrosis, OA	24	82% (10); 74% (15); 66% (20)	Merle d'Aubigne and Postel: 16 ± 2.2 (12.1 ± 12.1) IKDC pain: 3.8 ± 2.9 (7 ± 1.9) IKDC function: 7.2 ± 2 (3.4 ± 1.3) Knee Society function: 82.5 (65.6)
OCD lesion	15	91% (5); 76% (10); 76% (15)	Merle d'Aubigne and Postel: 13 ± 1.7 (16.4 ± 2.0)

HSS = Hospital for Special Surgery, IKDC = International Knee Documentation Committee Subjective Knee Evaluation Form, KOOS = Knee Injury and Osteoarthritis Outcome Score, KOOS ADL = Knee Injury and Osteoarthritis Outcome Score Activity of Daily Living scale, OA = osteoarthritis, OCD = osteochondritis dissecans, SF-12 = 12 Item Short Form Health Survey, SF-36 = 36 Item Short Form Health Survey

tion have expanded to include management of focal osteonecrosis, fracture malunion, joint restoration following tumor resection, and select cases of osteoarthritis. Surgical technique varies based on lesion size and location, with the plug technique used most often. Postoperative rehabilitation follows the principles of all cartilage procedures and may be modified based on management of concomitant pathology.

Mid- to long-term results of OCA transplantation are encouraging, with good to excellent subjective outcomes and graft survival reported in several large series. Worse results are seen in patients with chronic, large, or bipolar lesions; lesions of the patellofemoral joint; and increased age. Challenges to widespread use of OCA transplantation include graft availability, accurate size matching, and demanding surgical technique. Additional basic science and clinical research on optimizing graft viability and healing and refining current surgical indications and techniques is needed.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 8-10, 23, 29, 30, 35-38, and 52 are level I studies. References 1, 3, 12, 18, 31, 32, 39-42, 44, and 59 are level II studies. References 21 and 45 are level III studies. References 2, 4-7, 14, 16, 17, 19, 22, 46-48, 50, 51, 55, 57, 58, and 60-64 are level IV studies. References 11, 13, 15, 26, 27, 33, 34, 43, 49, 53, 54, 56, and 66 are level V expert opinion.

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