Joint Preservation Techniques in Orthopaedic Surgery

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Context: With increasing life expectancy, there is growing demand for preservation of native articular cartilage to delay joint arthroplasties, especially in younger, active patients. Damage to the hyaline cartilage of a joint has a limited intrinsic capacity to heal. This can lead to accelerated degeneration of the joint and early-onset osteoarthritis. Treatment in the past was limited, however, and surgical treatment options continue to evolve that may allow restoration of the natural biology of the articular cartilage. This article reviews the most current literature with regard to indications, techniques, and outcomes of these restorative procedures.

Evidence Acquisition: MEDLINE and PubMed searches relevant to the topic were performed for articles published between 1995 and 2016. Older articles were used for historical reference. This paper places emphasis on evidence published within the past 5 years.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: Autologous chondrocyte implantation and osteochondral allografts (OCAs) for the treatment of articular cartilage injury allow restoration of hyaline cartilage to the joint surface, which is advantageous over options such as microfracture, which heal with less favorable fibrocartilage. Studies show that these techniques are useful for larger chondral defects where there is no alternative. Additionally, meniscal transplantation can be a valuable isolated or adjunctive procedure to prolong the health of the articular surface.

Conclusion: Newer techniques such as autologous chondrocyte implantation and OCAs may safely produce encouraging outcomes in joint preservation.

Keywords: articular cartilage; autologous chondrocyte implantation; osteochondral allograft; meniscal transplantation

Traumatic chondral damage can have deleterious effects in any joint. Given the limited intrinsic healing capacity of articular cartilage, this can ultimately lead to arthritis and limb deformity. A variety of surgical techniques have been developed to address these defects such as arthroscopic debridement, mesenchymal stimulation (Figure 1), autologous osteochondral transplantation (OATS/mosiacplasty), autologous chondrocyte implantation (ACI), or the use of osteochondral allografts (OCAs). Most of these methods result in tissue repair that predominantly consists of fibrocartilage, with limited durability and inferior biomechanical properties to native hyaline cartilage. As a result, there has been a push to develop techniques that result in true hyaline cartilage repair.

Articular cartilage is an avascular milieu composed mostly of extracellular matrix (water, type II collagen, and proteoglycans). This matrix is sparsely interdigitated, with the chondrocytes being responsible for maintaining the balanced environment within joints. Proteoglycans bind water, and the resultant osmotic swelling pressure provides the compressive stiffness that allows cartilage to function in load transmission. Large proteoglycan aggregates, or aggrecans, bind to hyaluronic acid molecules, whereas nonaggregated proteoglycans interact with collagen. Changes in the proteoglycan composition, whether by aging, trauma, or inflammation, result in a loss of matrix infrastructure. This results in alterations of the mechanical properties of cartilage and, ultimately, the joint.[17] As the active

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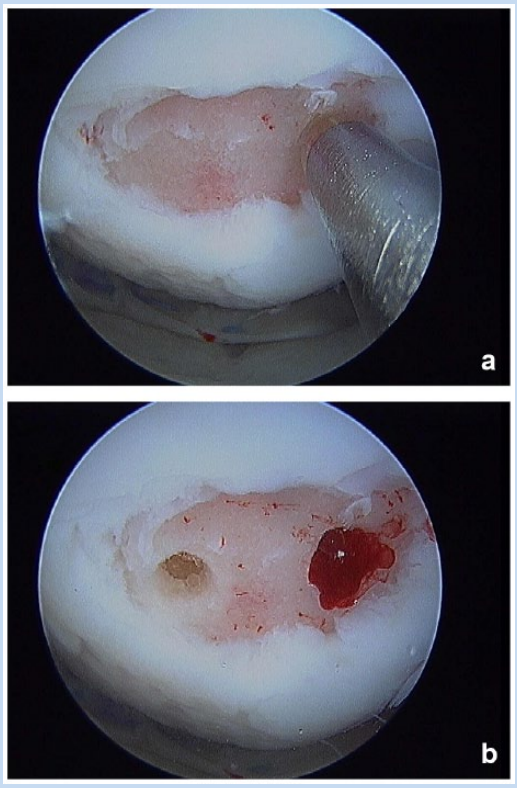

Figure 1. (a) Chondral lesion in the distal femur postdebridement with microfracture awl in place. (b) Postmicrofracture with bleeding subchondral bone.

cells in mature cartilage are differentiated chondrocytes, once damaged, the surface is ultimately unable to repair itself.

In a prospective study of 1000 consecutive arthroscopies performed on patients with symptomatic knees, 61% had some form of chondral lesion. Using the International Cartilage Repair Society (ICRS) criteria, these lesions were classified as osteoarthritis, ostechondritis dissecans, chondromalacia patellae, or focal lesions. Of patients with chondral damage, 28% were classified as focal chondral lesions. Of note, 61% endorsed a specific traumatic event.[27] A retrospective study of 25,124 arthroscopies showed similar findings, with 60% of patients having focal lesions; of those, 24% to 36% accounted for Outerbridge grade III or higher.[70]

The purpose of this review is to describe several techniques available for joint preservation, from cartilage repair techniques to alignment-altering procedures. These techniques are evolving and expanding the surgical options in the treatment of carefully selected patients with focal chondral lesions.

MARROW-STIMULATION TECHNIQUES

Several procedures have been adapted to release mesenchymal stem cells from bone to promote healing of articular cartilage defects.[25] These include microfracture, abrasion arthroplasty, and subchondral drilling. The theory behind these techniques is to create bleeding into the defect, which will form a blood clot and eventually transition into fibrocartilage.[25] While this is not a reparative process that re-creates normal hyaline cartilage, it intends to fill the defect and eliminate the source of pain.[40]

These techniques are typically performed arthroscopically and may be used as an adjuvant to other biological or anatomical procedures discussed later. First, the defect should be debrided of all damaged or loose cartilage. The periphery of the defect should be prepared into perpendicular walls, allowing a rim for the blood to pool. It is imperative to remove the calcified layer of cartilage prior to performing the marrow-stimulation technique as this allows an environment for the clot to adhere. Microfracture is typically carried out using a narrow awl, creating holes 2 to 4 mm deep and 3 to 4 mm apart.[41,62] Drilling is similar but uses a narrow drill instead of an awl. There is concern of thermal necrosis from the drill that may be detrimental to cartilage repair.[63] Abrasion arthroplasty is done by removing subchondral bone (1-2 mm) in the cartilage defect to expose intraosseous vessels, which leads to bleeding.[29]

Rehabilitation after microfracture techniques varies.[15] Patients are typically kept nonweightbearing, but range of motion is encouraged up to a certain degree. Some advocate for the use of continuous passive motion in the early postoperative period; however, high-quality evidence is lacking.[16,55]

Histologic analysis after microfracture showed greater amounts of fibrocartilage and low concentrations of type II collagen.[3] Outcomes show that microfracture is better used as a primary treatment for younger patients with smaller lesions (<2 cm^2).[3,23,40,58] Significant improvements have been seen with regard to pain and activities of daily living; however, there is a decrease in return to prior level of athletic participation.[3,23] A recent review showed variable rates of failure and revision surgery ranging from 2% to 31%.[40,41] This is thought to be a result of deterioration of the fibrocartilage layer deposited by infiltrating fibroblasts. Abrasion arthroplasty has shown poor outcomes.[29,53]

AUTOLOGOUS CHONDROCYTE IMPLANTATION

While marrow-stimulation techniques have had success in addressing isolated chondral defects, these procedures are limited by the durability of fibrocartilage deposition and lack of growth containment. Attempts to restore the joint surface with native hyaline cartilage while reliably addressing large (>4 cm) defects led to the transplantation of autologous-isolated chondrocytes in animals and, eventually, in human study participants. Chesterman and Smith[11] provided proof of the concept by harvesting, storing, and implanting isolated chondrocytes in rabbit animal models. In addition, they tracked the progression of freshly implanted chondrocytes, showing invasion into subchondral bone at 12 weeks and new matrix formation by 26 weeks.[18]

The first iteration of ACI (P-ACI) in 1987 by Brittberg involved chondrocytes implanted under a harvested periosteal membrane

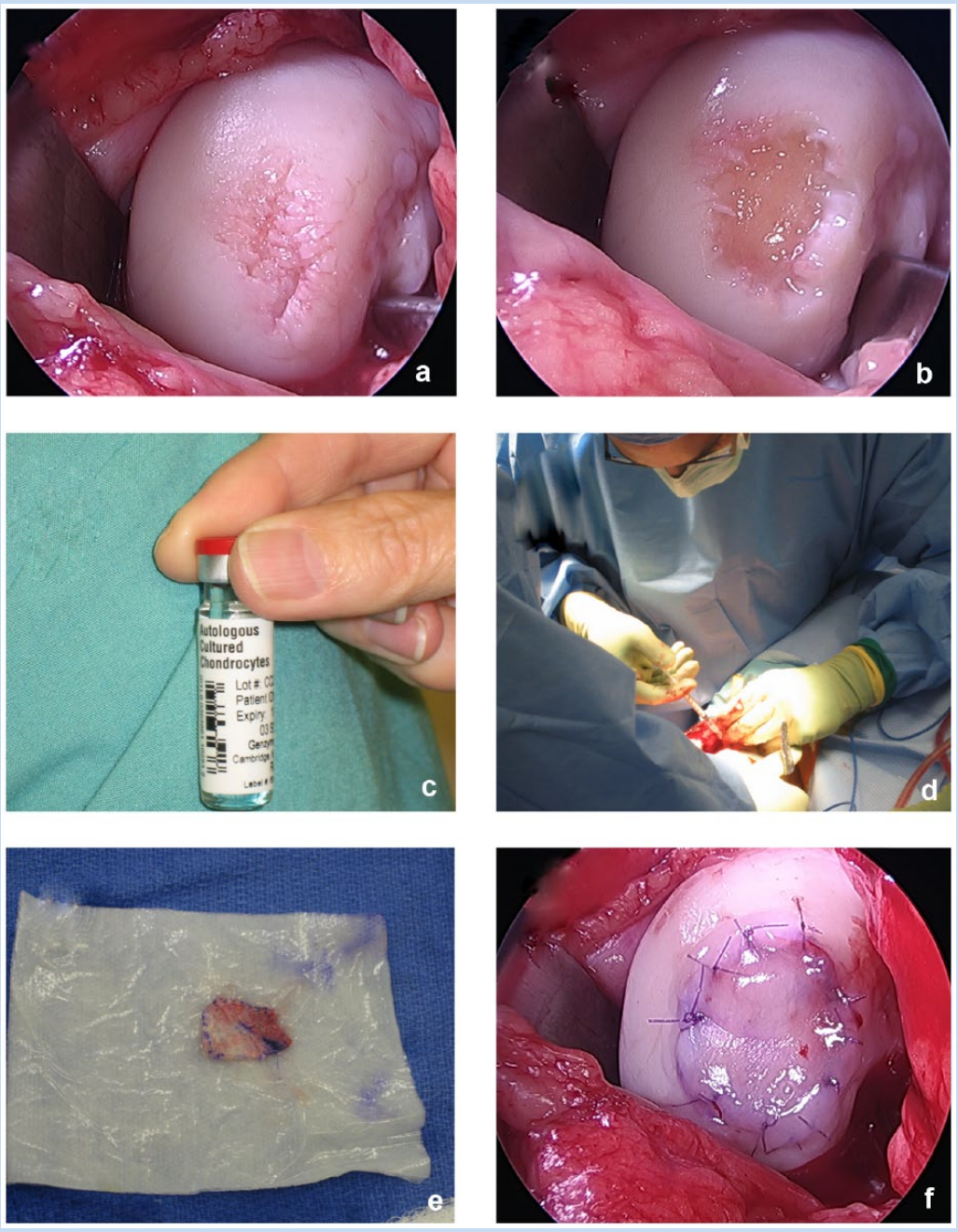

Figure 2. Autologous chondrocyte implantation. (a) A contained chondral lesion in the distal femur predebridement. (b) The same lesion postdebridement. (c) Vial containing the prepared autologous cultured chondrocytes (ACC). (d) Injection of the ACC into the defect. (e) A harvested periosteal patch matching the defect size. (f) The periosteal patch sewn into place, covering the injected ACC.

and sealed with fibrin glue (Figure 2). Second-generation ACI, collagen membrane ACI (C-ACI), changed the cover material by utilizing a collagenous membrane to overlie the suspended chondrocyte culture. Instances of arthrofibrosis and graft hypertrophy in first- and second-generation techniques could neither adequately contain the chondrocytic graft nor restrict fibroblastic infiltration into the isolated chondrocytes.

Third-generation ACI, matrix-induced ACI (MACI) and scaffold-based ACI, identified different substrates to form biologic infrastructures for the culture to reside.[18] These third-generation ACI scaffolds can be protein, carbohydrate, synthetic, or composite polymer derivatives. In particular, MACI uses 2 layers of collagen matrix, with 1 layer opposing the subchondral bone attached to a porous matrix environment for isolated

chondrocytes.[18] In rabbit models, histologic samples showed "hyaline-like repair" with type II collagen content reaching 74.3% of that seen in normal articular cartilage. In addition, the collagen layer acts as a barrier to fibroblast infiltration and subsequent fibrocartilage reconstitution.[18] These results were extrapolated further in equine models, with MACI implantation beyond 6 months showing improved cartilage repair, including subchondral integration, dense proteoglycan reconstitution, and enhanced durability.[46]

Individual rehabilitation protocols should be developed on a case-by-case basis. Protocols for post-ACI patients focus on range of motion, weightbearing, strengthening, and neuromuscular control. The 3 intervals of rehabilitation correlate with chondral tissue maturation: proliferation, transition, and maturation. Continuous passive motion with toe-touch weightbearing is recommended for the initial period as the graft is pliable and sensitive to compression and shear forces.[24] Patients eventually progress to full weightbearing and closed-chain exercises around 7 weeks after surgery. Running and impact activities are usually started around 12 months after surgery, with cutting restrictions until nearly 18 months after surgery.[24]

There is little consensus regarding weightbearing status protocols after MACI surgery. In isolated femoral condyle injuries, accelerated (progressive partial weightbearing from 2 weeks to full weightbearing at 6 weeks) was compared with delayed (toe-touch for 4 weeks to full weight at 10 weeks) weightbearing protocols, finding reduced crutch use, decreased knee pain, and improved function as measured by the Knee injury and Osteoarthritis Outcome Score in the accelerated cohort at 12 weeks.[15] A magnetic resonance imaging assessment using the magnetic resonance observation of cartilage repair tissue (MOCART) score showed that accelerated weightbearing produced increased bone marrow signal up to 24 weeks, but this had no correlation with clinical outcome beyond 12 weeks.[71] This suggests that MACI can quickly meet the demands of native articular cartilage while avoiding prolonged immobilization and muscular atrophy.

First-generation ACI showed promising results in terms of durability and function under arthroscopic and histologic evaluation.[52] In an outcomes study at 2 and 9 years postsurgery, patients endorsed positive clinical outcomes in isolated femoral condyle lesions (92%), multiple chondral lesions (67%), osteochondritis dissecans (89%), and isolated patellar lesions (65%).[52] Using the Brittberg scoring system designed to measure cartilaginous defect repair macroscopically (up to 4 possible points for degree of defect repair, integration of border zone, and appearance), second-look arthroscopy at 6 months determined a mean score of 10.2 to 10.9 (maximum, 12) in the groups analyzed.[52] Adversely, 7% incurred graft failure with central degeneration or edge delamination at 2 years, and 26% experienced periosteal hypertrophy, with symptomatic patients requiring arthroscopic surgical excision. The majority of patients returned to sport within 12 to 18 months postprocedure. Histologically, hyaline-like cartilage was predominant but found to be disorganized compared with normal cartilage due to incorporation of the periosteal cover.[52]

In a 10-year outcome study on survivability, 21% of grafts failed at 5 years and 29% at 10 years, as defined by need for arthroplasty or progression of disease.[38] A history of prior marrow-stimulating procedures such as microfracture has been somewhat detrimental, finding correlations of 26% with graft failure compared with 8% among patients who had not had prior intervention.[38]

When comparing microfracture with conventional ACI, no significant differences in clinical outcomes were found, as defined by the Lysholm score and visual analog score at 5 years posttreatment.[34] In addition, outcomes did not correlate with histologic quality, although no patients with strong hyaline cartilage reconstitution status post-ACI developed graft failure. Location of the defect influenced outcomes, with ACI being more efficacious in patellofemoral lesions. MACI was compared with microfracture, finding significant improvement in Tegner, ICRS, and Lysholm scores, suggesting prolonged maturation of novel chondral implantation is required for maximum benefit and durability.[6]

The major drawbacks of conventional ACI include graft hypertrophy, the need to harvest periosteum for graft coverage, and staged procedures, including debridement and cartilage harvest, followed by ex vivo chondrocyte expansion, and subsequently, arthotomy for implantation of cells.[34]

Scaffolds may prevent fibroblasts from invading the graft, which would lead to fibrocartilage formation.[5] A statistically indistinguishable improvement in modified Cincinnati knee scores has been noted when comparing P-ACI with MACI at 1 year. A small number of histologic samples at 18 to 24 months showed "hyaline-like" or "mixed" articular cartilage to a greater degree in P-ACI (42.9%) compared with MACI (36.4%). Arthroscopic examination showed "excellent" or "good" ICRS grade in 79.2% of P-ACI and 66.6% of MACI samples.[5] This study did not address long-term outcomes and had a small sample size of second-look arthroscopies and histologic samples.

Emerging technologies have offered a variety of materials to act as scaffolds for ACI substrates.[12] Requirements for an ideal scaffold include the following: biocompatibility with host, eventual biodegradability, permeability, readily and easily reproducible, mechanical stability, and noncytotoxicity.[12] In addition, these scaffolds are designed to be single-step procedures, removing the initial step of cartilage harvesting and culture and allowing for immediate introduction and implantation. Scaffolds can be divided into 4 classes, which include but are not limited to protein-based (fibrin, collagen, platelet lysate), carbohydrate-based (agarose, poly-L-lactic acid, polyglycolic acid, hyaluronan, alginate, chitin), synthetic polymer–based (hydroxyapatite, polydioxanone polyethylene glycol), and combination type (rhCo-PLA, MAioRegen [JRI Orthopedics], Trufit [Smith & Nephew], ChondroTissue [BioTissue AG], Gelrin C [Regentis Biomaterials], Chondro-Gide [Geistlisch Pharma AG], Cartipatch [TBF Genie Tissulaire], Bioseed [BioTissue AG], BST-CarGel [Smith & Nephew], Chondux [Zimmer Biomet]).

Preliminary results suggest varying outcomes and histological compositions compared with previous methods.[30,43,44] Limited studies suggest reduction of surgical complications such as time,

periosteal hypertrophy, adhesions, and patient morbidity.[30] Some examples include protein-based, platelet lysate 3-dimensional scaffolds, which are histologically suitable environments for mesenchymal stem cell chondrogenesis and chrondrocyte maintenance.[43] In porcine models, recombinant human type II collagen with polylactide (rhCo-PLA) scaffolds, when paired with autologous chondrocytes, most consistently formed hyaline cartilage compared with spontaneous repair and membrane-ACI procedures, though this was not of statistical significance given the study was underpowered.[44] In vivo equine models have shown that a cartilage autograft implantation system, which utilizes cartilage fragments interdigitated on a polydioxane synthetic polymer scaffold, outperformed empty and polydiaxanone reinforced foam-filled defects ($P < 0.05$).[19]

In summary, ACI is progressing toward the goal of repairing large articular cartilage defects with cartilaginous reconstitutions that are increasingly similar to native hyaline cartilage. Whether these novel efforts will amount to sustained differences in clinical outcomes for patients compared with marrow-stimulating techniques will largely be determined by prospective long-term studies evaluating the durability and progression of the respective implants. Although increased cost and morbidity associated with staged procedures are incurred with ACI in the acute setting, ACI still remains an equitable option for large chondral defects and, perhaps, should be considered a first-line treatment in patellofemoral defects.

OSTEOCHONDRAL TRANSPLANT

Large osteochondral defects present difficult treatment challenges, especially in younger, more active patients who would wish to postpone arthroplasty or arthrodesis. Osteochondral allografts (OCAs) are particularly useful in reestablishing the joint architecture in the setting of large defects of both articular cartilage and bone, such as detached osteochondritis dissecans lesions. The need for OCA remains prevalent for the treatment of large, noncontained defects in critical portions of the joint, in joints with multiple defects, and in revision situations such as a salvage procedure.

While concern over transmission of infection is similar to that with other allografts, the primary challenge related to OCA transplantation is maintaining chondrocyte viability. It is widely accepted that fresh OCA material, as opposed to frozen tissue, provides improved viability of chondrocytes.[10,49] Additionally, there have been laboratory studies suggesting that storage at body temperature (37°C) improves chondrocyte viability compared with refrigeration at 4°C.[49] However, most clinical studies use refrigerated fresh grafts to prolong viability in storage. While it is widely established that an osteochondral graft should ideally be implanted as soon after harvest as possible (provided complete testing and screening), it is generally agreed that the implantation should occur within 28 days from the procurement of the graft.[4,35] Although prolonged storage may affect chondrocyte survivability within the tissue, a few studies have shown that implanted grafts with a mean storage time longer than the suggested 28 days can still be clinically and radiographically successful after many months.[14,41]

A recent comparative analysis of cartilage biochemical properties has demonstrated that freshly preserved OCAs contain significantly lower levels of proteoglycan-depleting metalloproteinases than typical diseased cartilage specimens, suggesting that durability of the grafts might be related to a molecular process.[13] The latter finding suggests that developing strategies to alleviate inflammation may provide additional benefit for the survival of the implanted graft.[13]

Clinical outcomes of fresh OCAs are related to their immunogenic potential, as they are not matched by human leukocyte antigen or blood type.[10] This can lead to prolonged inflammatory reactions, which can result in cartilage degeneration and delayed graft incorporation. Positive human leukocyte antigen antibodies are commonly seen after OCA transplantation.[10] While not every patient will develop these antibodies, those found to manifest a higher expression of tissue-specific antibodies have been reported to have worse clinical outcomes.[10]

Meticulous surgical technique during OCA implantation is of crucial importance for a successful outcome. Cellular damage or death can occur to both donor and recipient chondrocytes during site preparation and implantation with excessive drilling or overuse of the mallet.[7,10] To minimize this complication, new instrumentation has been designed to allow precise press-fitting fixation of the graft to avoid excessive impaction during insertion, which creates impulses large enough to cause chondrocyte apoptosis (Figures 3-5).[22]

Despite improvements in graft preparation, storage, and surgical technique, OCA transplantation is still mainly used as a salvage procedure. Higher failure rates are related to chronic steroid use, larger lesions, multiple previous surgeries, bipolar or kissing lesions, body mass index >26 kg/m^2, joint malalignment, ligamentous instability, inflammatory arthropathies, immunocompromised patients, meniscal insufficiency, patellofemoral disease, and increasing age.[32]

Failure rates vary depending on the location of the transplant. Failure rates as high as 50% have been reported in humeral head transplants.[59] Femoral condyle transplantations have the most success, with failure rates between 0% and 22%.[35,54] Failures include that of the talar dome (28%),[26] bipolar tibiotalar implants (29%),[9,22] knee transplants with associated meniscal transplant (22.9%),[21] and femoral head (23%).[59] Most of these studies, however, are limited by nonstandardized descriptions of failure or success, the timeframe within which they consider the surgery to be a failure, limited follow-up, and low numbers of patients.

Another way to evaluate the effectiveness of these transplantations is survivorship. Varying survivorship has been reported: bipolar tibiotalar (76% and 44% at 5 and 10 years, respectively),[9] knee after subchondral marrow stimulation (82% and 74.9% at 10 and 15 years, respectively),[20] combined with meniscal transplant (73% and 68% at 5 and 10 years, respectively),[21] revision knee (79% and 61% at 5 and 10 years,

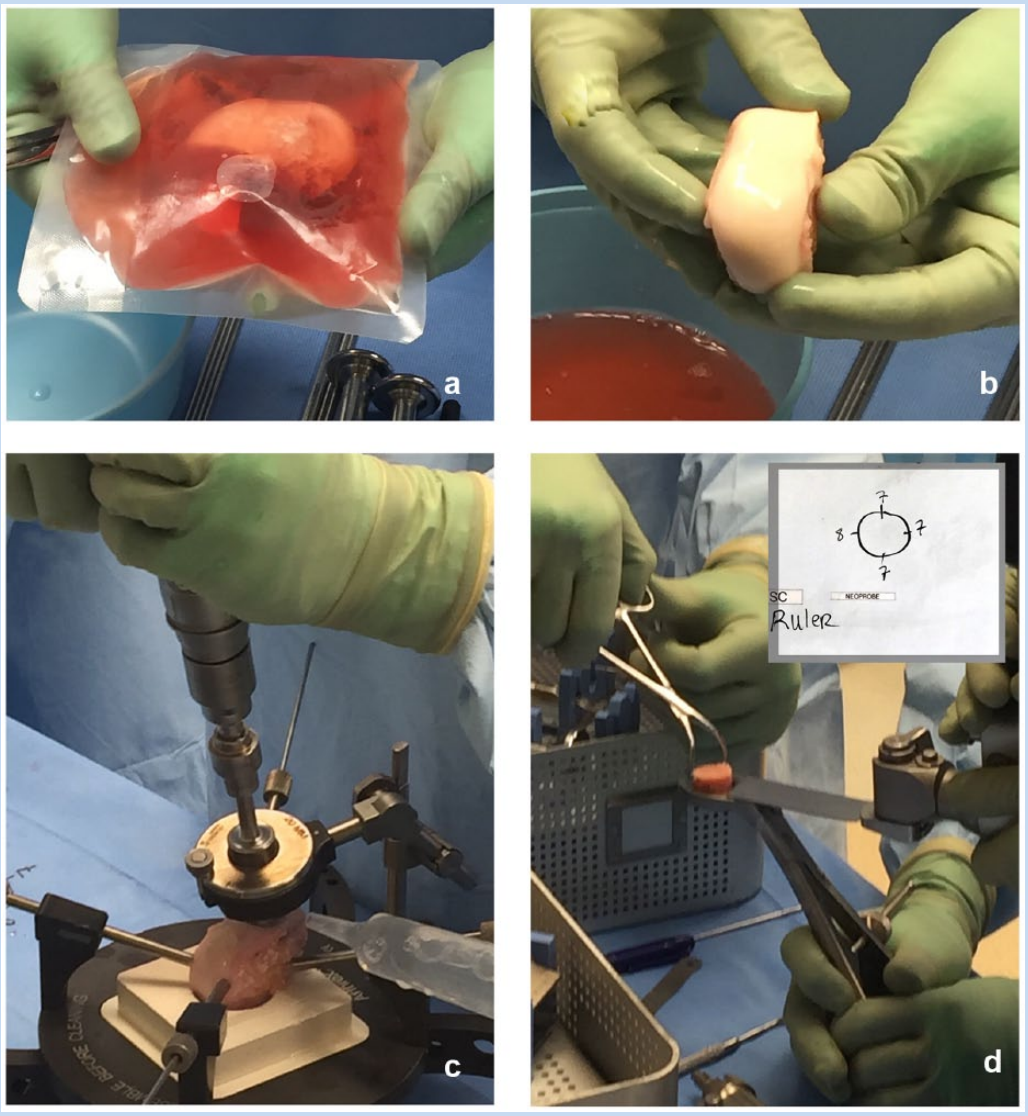

Figure 3. Preparation of the osteochondral allograft. (a) The packaged distal femoral allograft. (b) Allograft removed and washed. (c) Coring reamer used to remove graft to be implanted. (d) The graft is cut to the appropriate depth measured for each quadrant.

respectively),[28] distal femoral (91%, 84%, 69%, and 59% at 10, 15, 20, and 25 years, respectively),[54] and isolated patella (78.1% at 5 and 10 years, 55.8% at 15 years).[20] These values are difficult to interpret because of the fact that the definition of a survived graft is not standardized.

Bugbee et al[10] recently published a level 4 case series of 28 knees, showing that although there were high reoperation rates (60.7%) for patellar defects, pain and function improved, and nearly 90% of patients were satisfied with their OCA. Allograft survivorship was 78.1% at 5 years and 55.8% at 15 years, suggesting that OCAs can provide an acceptable option for salvage treatment even in patellar chondral defects.[10]

Surface cartilage restoration techniques, such as ACI, have high reoperation rates for clinical and radiographic graft failures, especially after subchondral marrow-stimulation procedures.[38] Thus, advantages of OCAs over other resurfacing techniques appear to be related to the ability of reconstituting the entire cartilage–subchondral bone unit. This unit can be adversely affected by cystic formation, osseous overgrowth, and development of a tougher subchondral plate, all of which are avoided with OCA transplantation.[20]

Functional outcomes of OCAs are difficult to interpret because of the wide variety of scales utilized. Additionally, subjective scales of satisfaction may be biased and noninformative. Regardless of the difficulties in ascertaining patient outcomes, it is apparent that those patients whose grafts do not fail in the short-term postoperative period generally report that they are satisfied with the procedure and show improvement on most functional scales. However, given time, most patients continue to progress toward end-stage degenerative changes. Additionally,

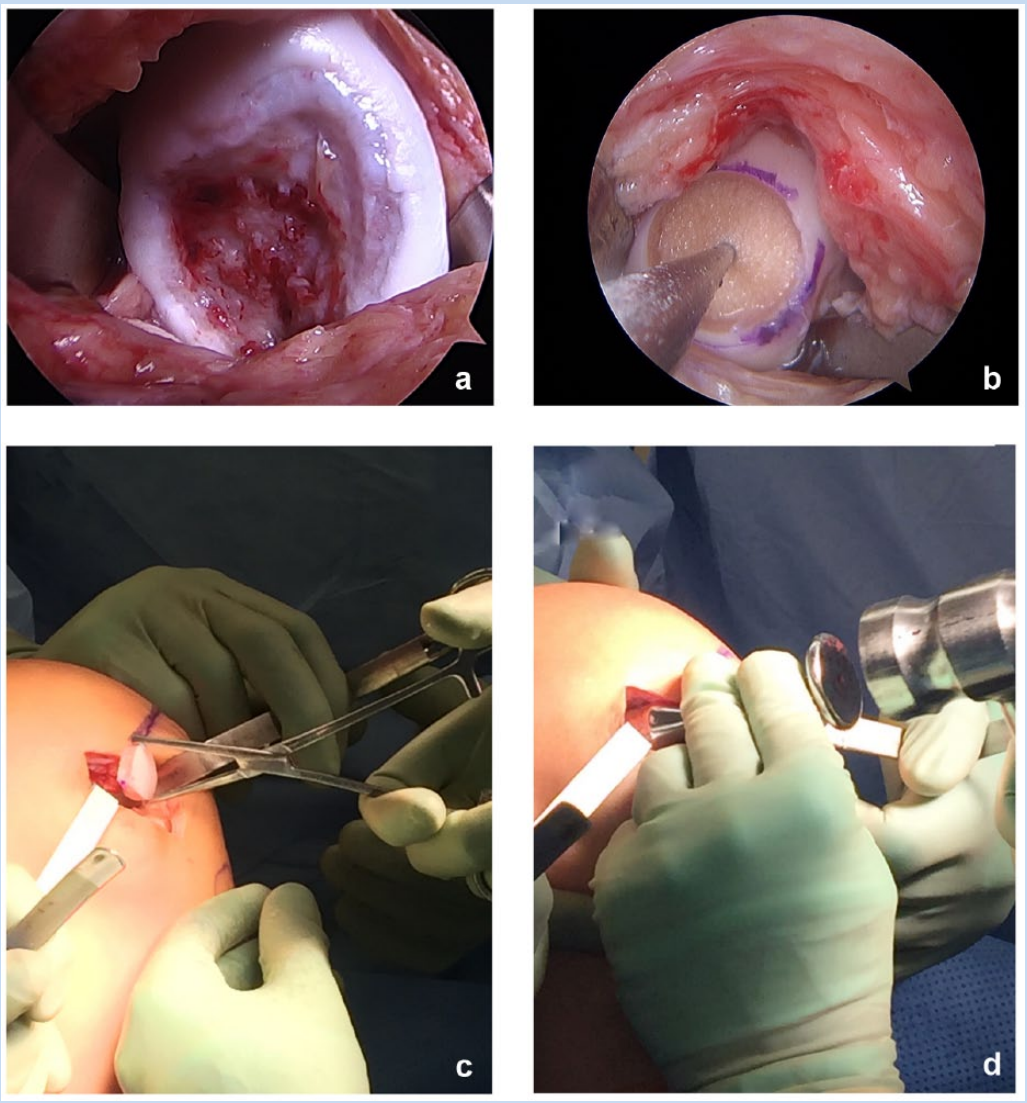

Figure 4. Osteochondral allograft implantation. (a) Arthroscopic image of a large osteochondral lesion. (b) Coring reamer used to prepare the lesion. (c) The prepared graft is placed into the defect. (d) The graft is gently tapped into position taking care to line up the predetermined quadrants.

some grafts, over time, tend to subside, resorb, and in some cases, undergo necrosis.[60] Once again, it appears that the best use of OCAs is as a salvage procedure, which is generally performed to delay arthroplasty or arthrodesis of the joint. These procedures can make subsequent surgeries more difficult and potentially less successful. Morag et al[42] evaluated total knee arthroplasties (TKAs) in patients with previous OCA procedures and showed an increase in the technical challenge as well as a higher rate of earlier revision as compared with standard TKAs.[42]

MENISCUS TRANSPLANTATION

The menisci play a vital role in the knee, as they are used to distribute loads evenly across the joint. Additionally, they provide lubrication, contribute to proprioception, and impart secondary stabilization.[37] Damage to these crucial structures inevitably leads to joint deterioration and, ultimately, arthritis. Advances in repair techniques have allowed surgeons to preserve previously unsalvageable menisci. However, even in skilled hands, many meniscal tears are ultimately irreparable. In these circumstances, partial or even total meniscectomy is often unavoidable. This results in a significant increase in total contact pressures and, at times, rapid degeneration, emphasizing the need for preservation of the meniscus whenever possible.[50]

Since its introduction in the 1980s, meniscal transplantation has become an increasingly viable option in specific patients with meniscal insufficiency.[33,69] Increasing acceptance of the procedure over recent years has led to a better understanding of

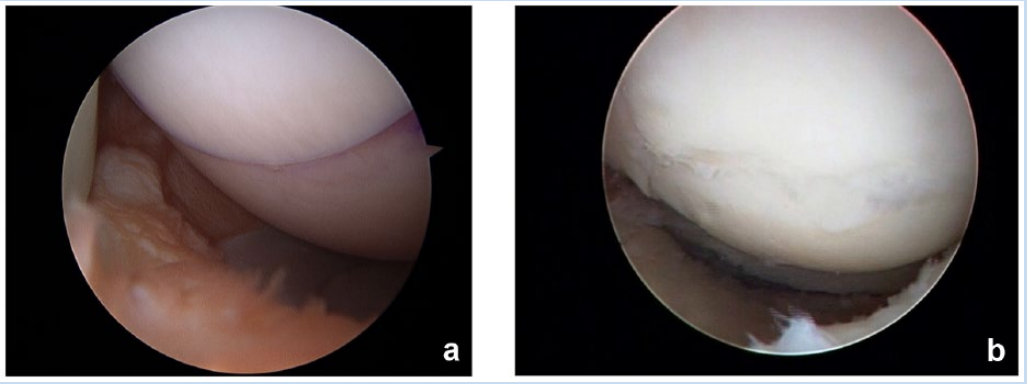

Figure 5. Implanted osteochondral allografts (OCAs) of the femoral condyle. (a) Arthroscopic image of a freshly implanted OCA. (b) An OCA 6 months after implantation.

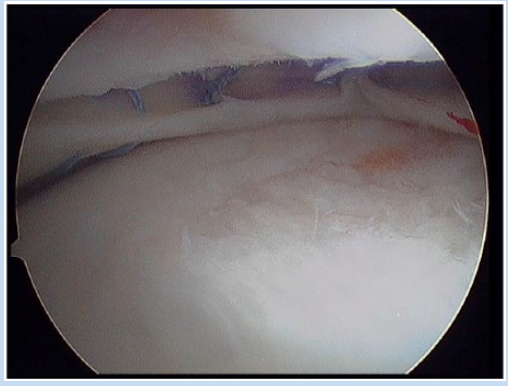

Figure 6. Arthroscopic image of an implanted meniscal allograft.

indications, techniques, and pathophysiology of the meniscus-deficient knee. However, there is a paucity of long-term studies documenting the clinical benefit of meniscal transplantation (Figure 6).

A recent systematic review of 55 studies evaluating meniscal transplantation in human participants demonstrated the lack of high-quality research regarding this topic.[56] The investigation found that 46 of 55 studies were level 4 studies, and no study was classified as level 1.[56] The review attempted to identify which patients were likely to benefit from meniscal transplantation. The conclusion was that the maximum benefit is typically seen in younger patients who display joint line pain after partial or total meniscectomy in the absence of advanced degenerative changes. Additionally, relative contraindications included limb malalignment, ligamentous instability, diffuse high-grade articular cartilage degeneration, joint space narrowing over 2 mm, and high Fairbank radiographic stage.[48,57,61,69]

One of the critical factors for a successful outcome after meniscal transplantation is the method of fixation used for the graft. Various methods of fixation have been described, with empirical evidence emphasizing that bone integration of the graft provides superior healing and stability of the implant compared with an all-suture fixation.[1] Specifically, there is a higher rate of meniscal extrusion with the all-suture technique.[1] Despite improved healing, recent studies show there is no difference in clinical outcomes between bony versus an all-suture fixation technique.[57] Many will argue that anchoring the peripheral meniscus to the capsule is required for incorporation and vascularization of the allograft.[57]

Postoperative rehabilitation plays a significant role in graft incorporation and outcome; however, there is no consensus on the rehabilitation protocol. Nonweightbearing for a period of weeks is usually encouraged, as excessive compression can interfere with graft healing.[47] Controversy surrounds the clinical advantage of and optimal timing to start range of motion after meniscal transplantation.[57] The protocol should protect the fixation while decreasing the risk of developing joint stiffness. Many rehabilitation protocols have been suggested, but the best is unknown.[57]

In terms of survivability, meniscal transplants have a 10-year survival rate ranging from 50% to 76%.[57] Previous studies showed improved outcomes for medial meniscal transplants when they were supplemented with a valgus-producing high tibial osteotomy.[47,67,68] However, a recent systematic review concluded that there was no difference in clinical outcomes between isolated mensicus transplants versus those supplemented with an osteotomy.[57] In decreasing frequency, this systematic review identified complications after meniscal transplant, including tears of the graft, synovitis, superficial infection, decreased range of motion, and deep infection.[57]

In a large analysis of prior studies, 60.6% of studies preferred fresh-frozen allograft, whereas 31.4% preferred cryopreserved grafts. Improved outcomes occur with fresh-frozen meniscal allografts or cryopreserved graft as compared with allografts that have been thoroughly sterilized.[47,57] While previous studies have shown that sterilization processes such as gamma radiation or lyophilization can eradicate the potential transmission of viral, bacterial, or fungal pathogens, the performance of these grafts is

suboptimal because of biomechanical changes that occur.[66] In addition, whether sterilized or not, storage of the grafts is becoming a topic of recent interest. The current options include deep freezing, cryopreservation, or freeze drying. Deep-frozen and freeze-dried grafts contain no viable cells and suffer damage at the cellular level due to ice crystal formation that causes a mass effect on microscopic collagen fibrils. Cryopreservation involves controlled-rate freezing with simultaneous extraction of cellular water. This may allow for cellular viability of up to 80%.[51,65]

OSTEOTOMIES

Younger patients with cartilage damage or joint arthritis pose a difficult scenario for joint preservation techniques. Total or unicompartmental arthroplasties in young patients come with the risk of accelerated prosthetic wear and may subject patients to revision surgeries.[45] An alternative to arthroplasty for younger individuals (<60 years) with unicompartmental knee arthritis is a periarticular osteotomy. For medial compartment wear, high tibial osteotomies create genu valgum to decrease joint-reactive forces across the medial side of the knee, effectively offloading this compartment.[2,36] This can delay or prevent the need for an eventual arthroplasty.[36] In addition, medial opening-wedge high tibial osteotomies with cartilage restoration procedures may be a viable option in patients with a cartilage defect.[8] The ideal candidates are younger, active individuals (<60 years old) with unicompartmental medial knee arthritis, no ligamentous instability, and good range of motion.[2] Medial opening-wedge osteotomies avoid risk of damage to the peroneal nerve and are generally thought to be less technically challenging than lateral closing-wedge osteotomies.[31]

Distal femoral osteotomies can be used for lateral compartment wear or cartilage defects. A lateral opening-wedge osteotomy effectively creates genu varum to offload the lateral compartment.[39] Studies show good outcomes with this technique, but most patients require conversion to TKA by 20 years.[64]

CONCLUSION

Injuries to articular cartilage can be life altering and lead to long-standing pain, dysfunction, and potentially multiple surgeries with extended recovery periods. Our understanding of articular cartilage, its composition, and limited capacity to regenerate under guided circumstances is increasing. More recent studies have emphasized the importance of improved outcomes when reconstituting articular defects with hyaline or hyaline-like cartilage. Technology and surgical techniques continue to evolve in hopes of eventually having a curative option for patients with these injuries. For now, appropriate patient selection and careful surgical planning with a well-planned rehabilitation protocol are paramount to provide the best outcomes.

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