Deciding How Best to Treat Cartilage Defects

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abstract

The decision-making regarding and treatment of cartilage abnormalities requires a systematic approach. This article reviews the concepts and principles that guide the management of this complex problem. The precise incidence, demographics, and progression of cartilage lesions have not been clearly delineated. Pursuing a patient-centered approach that considers the available nonsurgical and surgical options remains the cornerstone of patient care. The importance of determining concomitant knee pathologies, the proper interpretation and implications of imaging findings, and an accurate determination of the intra-articular and subchondral findings represent the primary elements of the decision analysis. Treatment options vary depending on patient goals, the disposition of the lesion, and a variety of other factors. The authors recommend proper patient education and consideration of how nonsurgical treatment or less invasive options such as arthroscopic debridement might be effective. If these strategies should fail, appropriate matching of a surgical procedure to the patient's pathology, goals, and expectations is warranted. Surgical options include debridement, marrow stimulation techniques, surface allograft treatments, autologous chondrocyte implantation, and osteochondral grafting (autograft and allograft) in addition to some emerging technologies. This article focuses on the decision-making process. [*Orthopedics*. 2016; 39(6):343-350.]

Articular cartilage injuries often occur in young, active patient populations following direct trauma or in conjunction with other ligamentous injuries.[1] Similarly, these abnormalities may be degenerative in nature as determined by a poorly defined heritable or genetic pathway. Less commonly, metabolic disorders of the subchondral bone, such as osteonecrosis and osteochondritis dissecans, may lead to clinical symptoms. Deciding how best to treat these defects remains an area of controversy and confusion. The challenge for the clinician is how and when to act to minimize symptoms and to potentially delay or prevent pathologic progression of articular cartilage damage. This article provides a systematic approach to decision-making in treating cartilage injury, and a summary of the treatment options currently available.

The precise incidence and demographics of cartilage lesions have not been clearly documented. However, a survey of the literature reveals that full-thickness defects are more common in athletes than in the general population.[1] In a recent systematic review, Flanigan et al[1] found that 36% of 931 athletes had full-thickness chondral lesions on arthroscopy or mag-

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Dr Oliver-Welsh, Dr Griffin, Mr Meyer, and Mr Gitelis have no relevant financial relationships to disclose. Dr Cole is a paid consultant for Arthrex, Regentis, and Zimmer; receives research support from Aesculap/B Braun, Arthrex, Cytori, Medipost, and Zimmer; receives material support from Athletico, Ossur, Smith & Nephew, and Tornier; receives royalties from Arthrex and DJ Orthopaedics; and holds stock in Carticept and Regentis.

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doi: 10.3928/01477447-20161020-03

netic resonance imaging (MRI), with 14% of them being asymptomatic. These data highlight the importance of treating symptoms associated with cartilage defects as opposed to intervening based on imaging findings alone.

Osteoarthritis remains the most common intra-articular pathology in the world, affecting 80% of patients older than 75 years.[2] A proportion of these cases are presumed to be a result of progression of prior cartilage defects. The natural history of cartilage defects has been studied extensively to better understand progression of disease and thus aid in the development of targeted treatment regimens. In a longitudinal study of older adults (mean age, 62.7 years), lesions remained stable with little regression after 2.9 years.[3] Baseline factors associated with increase in defect score included radiographic evidence of osteoarthritis, tibia size, higher body mass index, and female sex. These specific patient factors, including body mass index, are key areas to focus on when assessing and counseling patients in the clinical setting. In this same study, cartilage defects were found to independently predict cartilage volume loss and risk of knee replacement.[3] Certain athletic activities (ie, soccer, elite distance running, weight lifting, and wrestling) appear to have a greater predisposition for knee osteoarthritis.[4] This finding may be related to the increased incidence of ligamentous and cartilage injuries in these higher impact sports.

With an ever-increasing array of surgical and nonsurgical treatment options available, evidence-based decision-making for articular cartilage pathology in the knee is imperative. Furthermore, given the unique presenting clinical scenarios and patient concerns, practicing a patient-centered approach that considers each patient's symptom constellation, imaging findings, performance demands, and individual goals is necessary. For example, the authors consider the needs of a professional basketball player vs those of the recreational athlete or manual laborer when making treatment decisions. It is crucial to ascertain patient expectations and desired outcomes to avoid poor patient and surgeon satisfaction at follow-up. It is equally important to manage expectations in order to arrive at a mutually agreed upon and realistically achievable goal. Using evidence-based tailored treatment plans, surgeons can guide patients to make patient-centered decisions by helping them articulate their desired functional outcome and understand what is achievable with a specific treatment option.

Patient-Centered Evaluation

Evaluation of the patient presenting with a symptomatic chondral abnormality requires a thorough history and detailed physical examination. Patients can be profiled by risk factors, including age, sex, body mass index, alignment, and smoking status.[3] Age is an important factor when considering cartilage restoration, with more predictably positive outcomes in patients younger than 30 years.[5-7] However, cartilage restoration can also benefit older populations and can have the additional value of restoring or maintaining prolonged function to avoid and/or delay the need for arthroplasty.

When obtaining a clinical history, the nature of the injury or symptom onset should be elucidated regarding timing (acute vs chronic), mechanism (twist, fall, or insidious), and other concomitant meniscal or ligamentous injuries. Next, one must consider the severity of the patient's symptoms. Patients should be asked about the quality of their pain (sharp and focal vs dull and diffuse), and symptoms of locking, clicking, swelling, and instability must be explored. The authors pay particular attention to exacerbating factors, such as weight bearing, exercise, and the specific activities the patient can no longer enjoy. Pain at rest, at night, and that is of a disparate nature relative to the intra-articular pathology should elicit caution, as meeting expectations will be unpredictable. The patient's past medical history, including the presence or absence of other comorbidities (eg, ligament ruptures) and previous operative procedures, is investigated, as well as systemic conditions, medications, and recent changes in health.

Patients with symptomatic articular cartilage lesions often present with pain that is worse with load bearing and that is localized to a single compartment correlated with the articular cartilage defect. Others report only effusions with activity but no pain. Symptoms will not always represent the degree of cartilage damage, as there is no reliable correlation between size or grade of chondral lesions and presenting symptoms.[8] Again, the aim is to avoid the treatment of radiographic or arthroscopic findings and to instead treat the patient and his or her specific symptoms and obtain the desired outcome. Prophylactic treatment for the expectation of disease progression at the initial onset of defect-related symptoms is strongly discouraged, given the unpredictable nature these pathologies may follow and the extent at which their treatments are indicated.

Furthermore, attention should be focused on individual performance demands, especially on how the injury affects return to work or return to sport when appropriate. Goals of return to sport or return to work, rather than simple return to activities of daily living, may expedite the decision to pursue operative management instead of initially pursuing nonoperative rehabilitation and therapy. Goals of treatment will also differ greatly between age groups and the systems in which they function (eg, the adolescent with osteochondritis dissecans vs the in-season performing athlete). The authors encourage patients to communicate exactly what they are unable to do and what specific function or task they value most when pursuing higher load activities. This allows for alignment and mutual understanding when planning how and when to treat.

Physical examination of the knee should confirm that symptoms correlate with the cartilage defect. Careful observation of gait and gross musculoskeletal deformities is followed by a holistic assessment of the patient's pathology and muscular imbalances. The patient can also be evaluated for axial malalignment or rotational abnormalities. Malalignment will significantly increase forces felt through the affected compartment and may need to be corrected to allow redistribution of forces prior to cartilage restoration to increase the chances of a successful outcome. Strength and flexibility should be assessed in both lower extremities for baseline comparison and clues of weakness leading to compensatory overuse injury in the symptomatic leg. Ligamentous injury is often accompanied by damage to cartilage, so Lachman and pivot shift testing, anterior and posterior drawers, and varus and valgus testing should all be included to assess for knee instability. Assessment for effusion and limitations in motion can provide clues as to the extent of intra-articular pathology and may speak to the ability of specific treatments to prove effective. Provocative testing can also be employed to evaluate for meniscal pathology.

Concomitant Knee Pathologies

Many articular lesions are associated with other underlying knee pathologies that must also be assessed at the time of evaluation, especially because a high percentage of these patients have a history of prior knee surgery. These include ligament insufficiency, meniscal deficiency, tibio-femoral varus/valgus malalignment, and patellofemoral malalignment. A comprehensive strategy must be developed to ensure optimal short- and long-term results. Often, additional surgical procedures may be indicated in a stepwise or concurrent fashion.

Imaging Techniques

Imaging is essential for diagnosis and management of chondral disease. Independent of the timing of the pathology (ie, acute or chronic), weight-bearing anteroposterior and flexion posteroanterior radiographs should be obtained to assess for early tibio-femoral osteoarthritis, which can "live" differentially in these knee positions. Using the radiographic grading system developed by Kellgren and Lawrence, the severity of osteoarthritis can be determined on the basis of osteophyte formation, joint space narrowing, and subchondral sclerosis or subchondral cysts. Severe osteoarthritis would be a contraindication for several cartilage restoration procedures and may prompt referral to an arthroplasty specialist, assuming nonsurgical care has been exhausted. Merchant and lateral views can be obtained to evaluate the patellofemoral joint, especially for anterior knee pain exacerbated by jumping or squatting. Notably, these views can grossly underestimate the degree of chondral damage in the patellofemoral joint. Finally, standing full-length extremity radiographs are obtained to evaluate for malalignment that may require an offloading osteotomy either primarily or concomitantly if surgical treatment is recommended.

Although radiographs help to identify advanced chondral disease, they have a lower sensitivity for focal cartilage defects. For patients who are symptomatic with relatively normal findings on weight-bearing radiographs, MRI plays a crucial role in diagnosis and decision-making. Aside from assessing for concomitant meniscal and ligamentous injury, MRI can evaluate subchondral bone for areas of high signal corresponding to edema, as well as for the presence of osteochondritis dissecans, avascular necrosis, or fractures. Further developments in MRI technology have allowed for the rapid identification, sizing, and characterization of focal chondral lesions via 2-dimensional fat suppression and 3-dimensional fast-spin echo sequences. Finally, gadolinium enhancement sequences can be used to determine quality of cartilage regarding proteoglycan content. Although advanced imaging has facilitated the identification of chondral disease, it is critical that radiographic and MRI findings correlate with patient history and reported symptoms before a treatment recommendation is reached. Despite these advances, recent arthroscopic evaluation remains the gold standard for intra-articular pathology that can be further understood by evaluating the subchondral bone through the use of advanced imaging.

Arthroscopic Evaluation of Cartilage Defects

A diagnostic arthroscopy and debridement is often the best initial step prior to more advanced restorative procedures when specific index information is either dated or incomplete. Patients should be educated that this arthroscopy might indeed be therapeutic and, if so, that delaying definitive treatment remains an option. In the absence of relatively recent information garnered from arthroscopy, occasionally an index arthroscopy is performed for the patient with symptomatic chondral disease to evaluate the meniscus, the ligaments, and the entirety of articular cartilage abnormalities, including relevant bipolar disease. Defects are often graded according to Outerbridge criteria: 0, normal cartilage; 1, mild softening or swelling of cartilage; 2, fraying or fissuring extending less than 50% of cartilage depth; 3, partial-thickness cartilage loss with focal ulceration extending greater than 50% of cartilage depth; or 4, full-thickness cartilage defect with exposed subchondral bone.[9] Recent classification updates by the International Cartilage Repair Society provide greater specificity for articular cartilage defect grading and should be used by those wishing to communicate findings to others. The defect should be probed to determine true depth of involvement, as lesions extending into the subchondral bone will require a restorative osteochondral procedure, such as an osteochondral allograft. Conversely,

a bony lesion identified on MRI with intact overlying cartilage may be better addressed with a procedure to augment the subchondral bone, such as drilling, and possibly with injection of a biointegratable substance.

Aside from lesion depth, it is critical to note defect dimensions, as indications for restoration vary depending on size. Guettler et al[10] showed that a defect greater than 1 cm in diameter led to increasing symptoms. However, indications for specific restorative procedures depend on absolute area, with microfracture and osteochondral autograft transplantation reserved for smaller (<2.5 cm^2) defects and autologous chondrocyte implantation and osteochondral allograft transplantation limited to larger (-4 cm^2) defects.[11] Beyond absolute measurements, evidence suggests that symptoms are more dependent on the relative size of the cartilage defect in relation to the size of the femoral condyle. Unfortunately, however, a significant disconnect remains between patient symptoms and the presence of a defect of any size or depth.

Defect location plays a prime role in surgical decision-making. Condylar lesions have a wide breadth of restorative options, including microfracture, scaffolds, autologous chondrocyte implantation, and osteochondral transplantation procedures. Conversely, the contour of the patellofemoral joint (both the femoral trochlea and the patella itself) is associated with topographic matching challenges for osteochondral transplantation, resulting in many surgeons preferring surface treatment for larger defects. Tibial defects present a unique treatment challenge, given geometric considerations, lack of access, and little evidence-based medicine to guide treatment. Treatment options generally begin with correction of meniscal deficiency, malalignment, and overlying femoral defects if applicable.

Criteria for Surgery

To give patients the best chance for an excellent outcome, the authors ensure that patients meet the criteria for treatment prior to considering nonsurgical or surgical treatment (**Figure**). Criteria for treatment include ascertaining whether the degree of pain and associated dysfunction meet a threshold whereby the patient is sufficiently dissatisfied despite reasonable reassurance that coexisting with the pathology remains an option. Assuming that the patient wishes to undergo treatment and that the treatment offered has a reasonable likelihood of meeting the patient's (and the surgeon's) expectations in the end, some discussion of nonoperative treatment, including physical therapy and often injections, prior to proceeding with surgical options is worthwhile. Ultimately, the magnitude of pain and dysfunction should be weighed against the risks and benefits of any treatment, especially surgery. This risk-benefit ratio must be acceptable to the patient prior to proceeding with treatment. Perhaps the most important question the surgeon can ask is what the patient might like to see improve as a result of the treatment. Finally, once the authors have exhausted relevant nonsurgical options should they exist for a particular clinical scenario, they may consider the surgical options to ensure that the proposed treatment will predictably deliver what the patient is looking for with minimal risk and a meaningful upside in patient-specific terms.

Nonsurgical Care

Nonsurgical options can alleviate the symptoms attributable to cartilage damage[12] and are often considered prior to surgery.[13] When contemplating nonsurgical interventions, the authors advocate a staged approach[14] to encourage physical activity yet minimize dissatisfying pain.

Physical therapy and proper exercise have been shown to elicit not only effective results but also longer-term relief than other treatments.[14] In the motivated young patient, guided activity complements other interventions. Patients should be encouraged to remain active and should be reassured that this will not necessarily lead to further damage. The benefits of exercise far outweigh any negative connotations, and there is insufficient evidence to suggest that activity increases cartilage damage or progression to osteoarthritis.[15] Obesity and previous knee injury have a far greater association with osteoarthritis, and it is crucial that weight loss be encouraged for all overweight patients. Intuitively, however, patients may become increasingly symptomatic with increased activities, independent of changes in pathoanatomy. Thus, individualized decisions must be made related to activity restriction.

As an adjunct to nonsteroidal anti-inflammatory drugs, exercise, and weight loss, intra-articular injections can be particularly useful. These include corticosteroids, viscosupplementation, and blood-derived products such as platelet-rich plasma (PRP). Intra-articular corticosteroid injections are easy to administer, effective for pain relief, and widely accepted. When used to facilitate pain relief, intra-articular corticosteroid injections can therefore allow for continued participation in sport. Their mechanism of action is anti-inflammatory and has some immunosuppressive effect, but the duration of clinical benefit is short-lived. Effects vary and benefits have been reported at 1 to 6 weeks, although this has been debated in the literature and there is little evidence that benefits remain after 6 months.[16] However, a role remains for corticosteroid injections, provided the clinician and the patient agree that they are for short-term pain relief or are an adjunct to other therapies.

The next intra-articular injection the authors often use is viscosupplementation with hyaluronic acid, which reduces knee pain and improves function for a longer period (up to 24 to 26 weeks).[17] The beneficial effect found is consistent among both patients with articular fluid present within the knee joints and patients with "dry" knee joints.[18] Hyaluronic acid

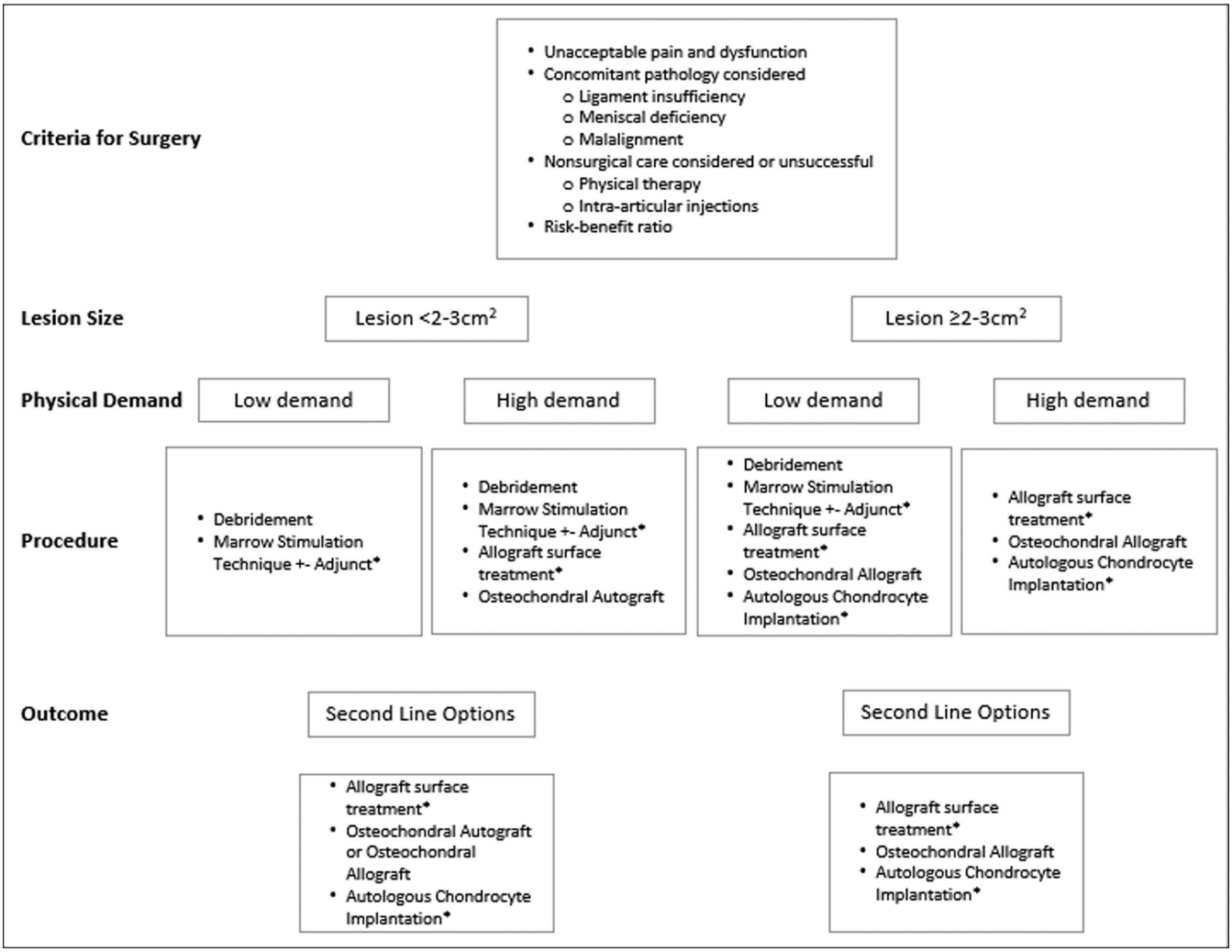

Figure: Treatment algorithm for articular cartilage defects. *Subchondral bone normal or nearly normal.

is thought to restore normal viscoelastic properties of the knee joint by temporarily restoring normal synovial fluid function and articular homeostasis.[19,20]

Platelet-rich plasma is an increasingly popular choice due to its ease of use and minimal side effects. Autologous blood is spun in a centrifuge and the platelet-rich component is injected into the cartilage-damaged knee, providing improvement in symptoms for up to 1 year. It can be used as an adjunct to other surgical procedures based on some clinical studies. In addition to its proposed anti-inflammatory effects, PRP may recruit and expand mesenchymal stem cells, synthesize hyaluronic acid, and allow for matrix synthesis. Despite positive outcomes at 12 months, no cartilage regeneration is likely to occur through the use of intra-articular injections in the office-based management of this patient group. However, in practice, superior results have been seen, particularly among young, active populations with lower grade cartilage damage.[21]

A meta-analysis by Chang et al[22] compared the effectiveness of PRP with that of other injectable agents, finding lasting results for the former. For patients with degenerative pathology, PRP injections led to continual improvement in their conditions for 12 months. Platelet-rich plasma was likely more effective and for a longer period than hyaluronic acid. Patients with lower degrees of degeneration seem to benefit more from PRP injections. Evidence is mixed, and there is no consensus or set protocol to guide administration. The authors consider leukocyte-poor PRP to be the most effective, with the number of injections depending on individual patient response. If the first injection does not yield positive results, it makes sense to stop and consider other treatment options. Conversely, if positive results are evident, it may be worth administering up to 3 rounds of PRP injections.

The final nonsurgical option to consider is autologous bone marrow aspirate of concentrated mesenchymal stem cells. Bone marrow aspirates are easily collected and the cells have good chondrogenic potential, which may be more relevant for use as an adjunct to cartilage repair procedures. Although offering hope for the future of cartilage restoration and symptom relief through office-based delivery, there are barriers to use, including the Food and Drug Administration regulatory pathway, which currently allows the autologous use of bone marrow aspirate concentrate in an intra-articular setting. The mechanism of action involves recruitment of other stem cells, secretion of bioactive factors, and the local benefits of their anti-inflammatory and immunomodulation properties. This can then be delivered via intra-articular injection or surgery. Mixed results have been reported and clinical studies are ongoing.[23] Adverse effects may include swelling, pain, or both. Significant clinical research is warranted to validate the potential benefits in treating this clinical population.

Surgical Options

Typically, patients who have not responded to nonsurgical management and have undergone a recent arthroscopy providing good information pertaining to the pathoanatomy can be considered for surgical intervention. All available information is then combined and concomitant pathology such as malalignment and meniscal and ligament deficiency is considered to arrive at a surgical plan with the patient by shared decision-making.

Debridement

Arthroscopic debridement is considered a first-line treatment option for small cartilage defects (<2 cm^2). There is evidence suggesting that simple irrigation and debridement may temporarily improve symptoms in up to 60% of patients.[24-28] This may represent a first-line treatment for the in-season athlete, or for patients with a lower level of demand with new onset mechanical symptoms. In the authors' practice, most patients initially undergo an arthroscopy and debridement prior to more advanced cartilage restoration, if not for "inventory" purposes to benefit future planning, then for the potentially therapeutic benefit.

Marrow Stimulation Techniques

Several marrow-stimulating techniques exist, such as microfracture, subchondral drilling, and abrasion therapy.[24] These procedures are typically indicated for active patients with defects smaller than 2 cm^2 experiencing moderate symptoms, or for less active patients with lesions larger than 2 cm^2. These techniques attempt to stimulate filling of the cartilage defect with reparative tissue from subchondral bone perforation. Doing so results in fibrocartilagenous repair tissue, including Type I collagen.[25] In small defects measuring 1 to 2 cm^2, marrow stimulation techniques are often the first-line treatment. However, these techniques may be less durable than others, presumably because they do not allow for reintroduction of Type II collagen.[29,30] Commercially available biologic scaffold adjuncts, such as particulated allograft articular cartilage (BioCartilage; Arthrex, Naples, Florida) combined with PRP, offer promise in improving the clinical outcomes of cartilage repair as an adjunct to microfracture.[31]

Recent technologic advances include particulated juvenile cartilage allograft transplantation procedures as an option for managing symptomatic cartilage lesions, with some reports of Type II collagen development (DeNovo NT; Warsaw, Zimmer, Indiana).[32,33]

Osteochondral Autograft Transplantation

The osteochondral autograft procedure is a restorative cartilage procedure. It allows filling of cartilage defects with the patient's own native cartilage, offering an advantage over microfracture. Typically, this is reserved for smaller lesions, ideally less than 1 to 4 cm^2. A plug made of bone and cartilage is harvested from the non–weight-bearing portion of the knee, with several plugs making up a "mosaicplasty." Drawbacks to the procedure include difficulty with filling large areas and donor-site morbidity. A recent systematic review reported a 72% success rate at 10 years after an osteochondral autograft procedure with a high rate of return to sport.[34] Predictors of failure included older age, previous surgery, and larger defect size.[35]

Osteochondral Allograft Transplantation

Several studies have shown that osteochondral allograft produces reliable outcomes in patients with mid-size (2 to 4 cm^2) defects.[36,37] There is some recent evidence supporting its use in the revision setting after failed prior cartilage restoration procedures, including microfracture,[38] and good outcomes have also been reported in the pediatric setting.[39] There is evidence of excellent long-term survival, particularly in defects of the femoral condyle.[40] Use of osteochondral allograft continues to increase for appropriate patients in the senior author's practice (B.J.C.). Also, osteochondral allograft is now being used for bipolar lesions when there is dominant pathology on one side of the joint and in the patellofemoral joint, although long-term data are currently not available to support this.[41] Outcomes have included excellent return to play for high-level athletes.[42]

Autologous Chondrocyte Implantation

Autologous chondrocyte implantation is also a technique for larger lesions. However, its use in the femur has decreased in recent years, possibly due to relative costs and ease of treatment with other techniques, such as the osteochondral autograft procedure and osteochondral allograft. In the authors' practice, autologous chondrocyte implantation is now predominantly used in the patellofemoral joint.[43] The first generation (using a periosteal patch) was associated with patch hypertrophy. Newer, second-generation

patches including a synthetic collagen membrane have yielded better functional outcomes and may offer a more durable solution, although their use remains "off-label" and proper patient consent must be part of the process.[44-47] It is likely that the next generation of cell-based technology, matrix-associated cell implantation, will be available in the United States by 2017. This offers an easier technique whereby the cells are cultured directly onto a collagen membrane that is placed through a small arthrotomy and fixated with fibrin glue.

Emerging Technologies

New technologies are being used to attempt to enhance delivery systems and customization of cartilage repair. Cryopreserved viable osteochondral allograft with pores containing native viable chondrocytes, growth factors, and extracellular proteins exists as a potential method of cartilage repair (Cartiform; Arthrex/Osiris, Naples, Florida). Additionally, recent developments include 3-dimensional cartilage matrices aimed at enhancing and customizing cartilage delivery (ProChondrix; AlloSource, Denver, Colorado). As with all emerging cartilage therapies, outcomes will likely depend on application and proper indication for surgery.

Measures/Outcomes

Outcomes after cartilage surgery are determined by and related to individual factors, such as prior knee function and future functional goals. Resolution of pain is generally the primary objective after cartilage surgery. However, if concomitant procedures were performed, objective measurements of knee ligament and rotational stability and alignment will also be performed. On return to the clinic after cartilage surgery, patients are evaluated via both objective and subjective parameters. Follow-up involves a full physical examination, including strength, range of motion, and assessment of ligaments and menisci, as well as the completion of validated patient-reported outcome surveys, such as Lysholm, International Knee Documentation Committee, and Knee Injury and Osteoarthritis Outcome Score, to track changes over time from a presurgical baseline. Athletes and patients with high-demand jobs are guided through a rehabilitation program of graduated intensity to facilitate return to play or return to work. Finally, adequate patient counselling regarding expected outcomes following surgery must be completed to maximize overlap between expected outcomes and individual functional goals.

Conclusion

Cartilage lesions can often be incidental and, when found, may not result in significant symptoms. When deliberating over how best to treat such lesions, it is important to consider a patient's personal preferences and functional goals. Expectations should be managed accordingly, and nonoperative modalities may be preferred for even the high-level athlete. Short-term solutions such as debridement should always be discussed and remain a viable option prior to advanced cartilage restoration techniques. Multiple outcome studies have reported the long-term effectiveness of advanced transplantation and reparative techniques. Cartilage restoration and biologics remains one of the fastest growing frontiers in orthopedics. Such growth must be balanced with careful patient-centered and evidence-based decision-making.

References

1. Flanigan DC, Harris JD, Trinh TQ, Siston RA, Brophy RH. Prevalence of chondral defects in athletes' knees: a systematic review. *Med Sci Sports Exerc.* 2010; 42(10):1795-1801.
2. Arden N, Nevitt MC. Osteoarthritis: epidemiology. *Best Pract Res Clin Rheumatol.* 2006; 20(1):3-25.
3. Carnes J, Stannus O, Cicuttini F, Ding C, Jones G. Knee cartilage defects in a sample of older adults: natural history, clinical significance and factors influencing change over 2.9 years. *Osteoarthritis Cartilage.* 2012; 20(12):1541-1547.
4. Driban JB, Hootman JM, Sitler MR, Harris K, Cattano NM. Is participation in certain sports associated with knee osteoarthritis? A systematic review [published online ahead of print January 9, 2015]. *J Athl Train.* doi:10.4085/1062-6050-50.2.08.
5. Bekkers JE, Inklaar M, Saris DB. Treatment selection in articular cartilage lesions of the knee: a systematic review. *Am J Sports Med.* 2009; 37(suppl 1):148S-155S.
6. Steadman JR, Briggs KK, Rodrigo JJ, Kocher MS, Gill TJ, Rodkey WG. Outcomes of microfracture for traumatic chondral defects of the knee: average 11-year follow-up. *Arthroscopy.* 2003; 19(5):477-484.
7. Knutsen G, Engebretsen L, Ludvigsen TC, et al. Autologous chondrocyte implantation compared with microfracture in the knee: a randomized trial. *J Bone Joint Surg Am.* 2004; 86(3):455-464.
8. Zamber RW, Teitz CC, McGuire DA, Frost JD, Hermanson BK. Articular cartilage lesions of the knee. *Arthroscopy.* 1989; 5(4):258-268.
9. Outerbridge RE. The etiology of chondromalacia patellae. *J Bone Joint Surg Br.* 1961; 43:752-757.
10. Guettler JH, Demetropoulos CK, Yang KH, Jurist KA. Osteochondral defects in the human knee: influence of defect size on cartilage rim stress and load redistribution to surrounding cartilage. *Am J Sports Med.* 2004; 32(6):1451-1458.
11. Farr J, Lewis P, Cole BJ. Patient evaluation and surgical decision making. *J Knee Surg.* 2004; 17(4):219-228.
12. Filardo G, Kon E, Longo UG, et al. Non-surgical treatments for the management of early osteoarthritis. *Knee Surg Sports Traumatol Arthrosc.* 2016; 24(6):1775-1785.
13. Abbott JH, Robertson MC, McKenzie JE, et al. Exercise therapy, manual therapy, or both, for osteoarthritis of the hip or knee: a factorial randomised controlled trial protocol. *Trials.* 2009; 10:11.
14. Deyle GD, Gill NW, Rhon DI, et al. A multicentre randomised, 1-year comparative effectiveness, parallel-group trial protocol of a physical therapy approach compared to corticosteroid injections. *BMJ Open.* 2016; 6(3):e010528.
15. Alentorn-Geli E, Cole BJ, Cugat R. Sports participation and risk of knee osteoarthritis: a critical review of the literature. In: Doral MN, Karlsson J, eds. *Sports Injuries: Prevention, Diagnosis, Treatment and Rehabilitation.* 2nd ed. Philadelphia, PA: Springer-Verlag; 2015:2513-2532.
16. Jüni P, Hari R, Rutjes AW, et al. Intra-articular corticosteroid for knee osteoarthritis. *Cochrane Database Syst Rev.* 2015; (10):CD005328.
17. Telikicherla M, Kamath SU. Accuracy of needle placement into the intra-articular space of the knee in osteoarthritis patients

for viscosupplementation. *J Clin Diagn Res.* 2016; 10(2):RC15-RC17.

18. Ostalowska A, Nowak D, Święchowicz S, et al. Assessment of knee function and biochemical parameters of articular fluid and peripheral blood in gonarthrosis patients following intra-articular administration of hyaluronic acid. *Pol Orthop Traumatol.* 2013; 78:173-181.
19. Ayhan E, Kesmezacar H, Akgun I. Intra-articular injections (corticosteroid, hyaluronic acid, platelet rich plasma) for the knee osteoarthritis. *World J Orthop.* 2014; 5(3):351-361.
20. Balazs EA, Denlinger JL. Viscosupplementation: a new concept in the treatment of osteoarthritis. *J Rheumatol Suppl.* 1993; 39:3-9.
21. Mascarenhas R, Saltzman BM, Fortier LA, Cole BJ. Role of platelet-rich plasma in articular cartilage injury and disease. *J Knee Surg.* 2015; 28(1):3-10.
22. Chang KV, Hung CY, Aliwarga F, Wang TG, Han DS, Chen WS. Comparative effectiveness of platelet-rich plasma injections for treating knee joint cartilage degenerative pathology: a systematic review and meta-analysis. *Arch Phys Med Rehabil.* 2014; 95(3):562-575.
23. Chahla J, Dean CS, Moatshe G, Pascual-Garrido C, Serra Cruz R, LaPrade RF. Concentrated bone marrow aspirate for the treatment of chondral injuries and osteoarthritis of the knee: a systematic review of outcomes. *Orthop J Sports Med.* 2016; 4(1): 2325967115625481.
24. Baumgaertner MR, Cannon WD Jr, Vittori JM, Schmidt ES, Maurer RC. Arthroscopic debridement of the arthritic knee. *Clin Orthop Relat Res.* 1990; 253:197-202.
25. Fond J, Rodin D, Ahmad S, Nirschl RP. Arthroscopic debridement for the treatment of osteoarthritis of the knee: 2- and 5-year results. *Arthroscopy.* 2002; 18(8):829-834.
26. Spahn G, Hofmann GO, Klinger HM. The effects of arthroscopic joint debridement in the knee osteoarthritis: results of a meta-analysis. *Knee Surg Sports Traumatol Arthrosc.* 2013; 21(7):1553-1561.
27. McCormick F, Harris JD, Abrams GD, et al. Trends in the surgical treatment of articular cartilage lesions in the United States: an analysis of a large private-payer database over a period of 8 years. *Arthroscopy.* 2014; 30(2):222-226.
28. Solheim E, Krokeide AM, Melteig P, Larsen A, Strand T, Brittberg M. Symptoms and function in patients with articular cartilage lesions in 1,000 knee arthroscopies. *Knee Surg Sports Traumatol Arthrosc.* 2016; 24(5):1610-1616.
29. Solheim E, Hegna J, Inderhaug E, Øyen J, Harlem T, Strand T. Results at 10-14 years after microfracture treatment of articular cartilage defects in the knee. *Knee Surg Sports Traumatol Arthrosc.* 2016; 24(5):1587-1593.
30. Gobbi A, Karnatzikos G, Kumar A. Long-term results after microfracture treatment for full-thickness knee chondral lesions in athletes. *Knee Surg Sports Traumatol Arthrosc.* 2014; 22(9):1986-1996.
31. Fortier LA, Chapman HS, Pownder SL, et al. BioCartilage improves cartilage repair compared with microfracture alone in an equine model of full-thickness cartilage loss [published online ahead of print June 13, 2016]. *Am J Sports Med*.
32. Farr J, Tabet SK, Margerrison E, Cole BJ. Clinical, radiographic, and histological outcomes after cartilage repair with particulated juvenile articular cartilage: a 2-year prospective study. *Am J Sports Med.* 2014; 42(6):1417-1425.
33. Griffin JW, Gilmore GJ, Miller MD. Treatment of a patellar chondral defect using juvenile articular cartilage allograft implantation. *Arthrosc Tech.* 2013; 2(4):e351-e354.
34. Pareek A, Reardon PJ, Maak TG, Levy BA, Stuart MJ, Krych AJ. Long-term outcomes after osteochondral autograft transfer: a systematic review at mean follow-up of 10.2 years. *Arthroscopy.* 2016; 32(6):1174-1184.
35. Richter DL, Tanksley JA, Miller MD. Osteochondral autograft transplantation: a review of the surgical technique and outcomes. *Sports Med Arthrosc.* 2016; 24(2):74-78.
36. Chahal J, Gross AE, Gross C, et al. Outcomes of osteochondral allograft transplantation in the knee. *Arthroscopy.* 2013; 29(3):575-588.
37. Demange M, Gomoll AH. The use of osteochondral allografts in the management of cartilage defects. *Curr Rev Musculoskelet Med.* 2012; 5(3):229-235.
38. Gracitelli GC, Meric G, Briggs DT, et al. Fresh osteochondral allografts in the knee: comparison of primary transplantation versus transplantation after failure of previous subchondral marrow stimulation. *Am J Sports Med.* 2015; 43(4):885-891.
39. Murphy RT, Pennock AT, Bugbee WD. Osteochondral allograft transplantation of the knee in the pediatric and adolescent population. *Am J Sports Med.* 2014; 42(3):635-640.
40. Levy YD, Görtz S, Pulido PA, McCauley JC, Bugbee WD. Do fresh osteochondral allografts successfully treat femoral condyle lesions? *Clin Orthop Relat Res.* 2013; 471(1):231-237.
41. Meric G, Gracitelli GC, Görtz S, De Young AJ, Bugbee WD. Fresh osteochondral allograft transplantation for bipolar reciprocal osteochondral lesions of the knee. *Am J Sports Med.* 2015; 43(3):709-714.
42. Krych AJ, Robertson CM, Williams RJ III, Cartilage Study Group. Return to athletic activity after osteochondral allograft transplantation in the knee. *Am J Sports Med.* 2012; 40(5):1053-1059.
43. Gomoll AH, Gillogly SD, Cole BJ, et al. Autologous chondrocyte implantation in the patella: a multicenter experience. *Am J Sports Med.* 2014; 42(5):1074-1081.
44. Saris D, Price A, Widuchowski W, et al. Matrix-applied characterized autologous cultured chondrocytes versus microfracture: two-year follow-up of a prospective randomized trial. *Am J Sports Med.* 2014; 42(6):1384-1394.
45. Nawaz SZ, Bentley G, Briggs TW, et al. Autologous chondrocyte implantation in the knee: mid-term to long-term results. *J Bone Joint Surg Am.* 2014; 96(10):824-830.
46. Gudas R, Gudaite A, Pocius A, et al. Ten-year follow-up of a prospective, randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint of athletes. *Am J Sports Med.* 2012; 40(11):2499-2508.
47. Meyerkort D, Ebert JR, Ackland TR, et al. Matrix-induced autologous chondrocyte implantation (MACI) for chondral defects in the patellofemoral joint. *Knee Surg Sports Traumatol Arthrosc.* 2014; 22(10):2522-2530.