Managing the Patient With Failed Cartilage Restoration

Jaskarndip Chahal, MD, FRCSC, Geoffrey V. Thiel, MD, MBA,† Kristen Hussey, BSc,† and Brian J. Cole, MD, MBA†*

Abstract: In comparison to the amount of published information on the surgical management of cartilage defects in general, there has been a relative lack of emphasis regarding the management of patients who present with failed attempts at index cartilage repair. The objectives of this review are to: (1) identify patient and procedure-specific factors that are associated with failed cartilage surgery; (2) identify strategies that have the potential to decrease failure rates after articular cartilage restoration; and (3) develop an algorithmic approach to managing patients who present with prior failed cartilage procedures.

Key Words: cartilage restoration, revision, prognostic factors, treatment algorithm, failed, outcomes

(*Sports Med Arthrosc Rev* 2013;21:62–68)

The goals of treatment for patients with symptomatic articular cartilage lesions in the knee joint are to provide pain relief, improve joint function, and ultimately to delay and/or prevent the development of secondary degenerative sequelae.[1] In response to the significant burden of illness represented by articular cartilage disorders and realization of the aforementioned goals, there has been a rapid rise in clinical and basic science research endeavors aiming to improve the cartilage-based therapies we can offer patients.[2] On the basis of the best available evidence, albeit of variable quality,[3] there are a number of resultant clinical algorithms that exist in order to guide orthopedic sports medicine surgeons to select the optimal cartilage restoration procedures for different patient subpopulations.[1,4,5] In general, surgical options are guided by both defect-specific (size, depth, location, number, subchondral bone change) and patient-specific (age, activity, expectations, goals) factors. In keeping with these principles, the treatment algorithm should ideally consist of a graduated surgical plan. The least destructive and least invasive treatment option necessary to alleviate the symptoms and restore joint function is performed first. The more extensive treatments are reserved for potential salvage operations later. In the event of treatment failure and the associated persistence of symptoms, future treatment should not be compromised by previous management.[1]

In comparison to the amount of published information on the surgical management of cartilage defects in general, there has been a relative lack of emphasis regarding the management of patients who present with failed attempts at index cartilage repair. Furthermore, the clinical outcomes pertaining to this patient population are less clear thereby rendering decision-making reliant largely upon expert opinion and experience, and, a case-by-case consideration of pertinent patient-specific and disease-specific variables.

Given the shortcomings in the existing body of literature pertaining to "revision" articular cartilage restoration of the knee, the objectives of this review are to: (1) identify patient-specific and procedure-specific factors that are associated with failed cartilage surgery; (2) identify strategies that have the potential to decrease failure rates after articular cartilage restoration; and (3) develop an algorithmic approach to managing patients who present with prior failed cartilage procedures.

FACTORS ASSOCIATED WITH FAILED CARTILAGE SURGERY

There have been several studies that have attempted to determine prognostic factors after cartilage restoration procedures including bone-marrow stimulation (microfracture), autologous chondrocyte implantation (ACI), osteochondral autograft transfer, and osteochondral allograft (OAG) transplantation.

Microfracture

In a systematic review on the efficacy of microfracture, Mithoefer et al[6] identified several factors that affected functional outcomes. Younger age (less than 30 to 45 y) resulted in better clinical outcome scores and better repair cartilage fill on magnetic resonance imaging (MRI). Preoperative symptoms for <12 months were associated with better postoperative scores and macroscopic repair cartilage grading. Microfracture was most effective as a first-line procedure, whereas its results in a salvage situation were less predictable. Although some authors reported better results with cartilage defects on the femoral condyles, others found no effect or worse outcomes for lesions in the central weight-bearing femoral condyle. Furthermore, worse functional outcomes scores were observed for a body mass index (BMI) $>30\,\text{kg/m}^2$ that in turn was associated with decreased cartilage volume at the repair site. Higher preoperative activity levels (Tegner score >4) improved knee scores and athletic ability after microfracture. Finally, with regard to lesion size, patients with lesions $4\,\text{cm}^2$ or smaller had better knee function scores, with an even smaller threshold ($<2\,\text{cm}^2$) reported for the demanding athletic population.[6] It is our opinion that the results of microfracture might indeed be improved if management of

From the *Toronto Western Hospital, Women's College Hospital, University of Toronto Sports Medicine Program, Toronto, ON, Canada; and †Division of Sports Medicine, Rush University Medical Center, Chicago, IL.

Disclosure: B.J.C. has received research support from Arthrex, DePuy, and Zimmer that is unrelated to this manuscript. He is a consultant for Genzyme, Zimmer, Arthrex, DePuy, and DJ Ortho; and has received royalties from Arthrex and Elsevier. He has also received grant support for other independent research studies from the Musculoskeletal Transplant Foundation. He is a member of multiple boards that do not pertain to this manuscript. The remaining authors declare no conflict of interest.

Reprints: Brian J. Cole, MD, MBA, Division of Sports Medicine: Shoulder, Elbow and Knee Surgery, Rush University Medical Center, 1611 W Harrison, Suite 300 Chicago, IL 60612.

comorbidities (malalignment, meniscal deficiency, etc.) were more aggressively managed at the time of the index procedure. Typically, however, because of the relatively low morbidity and ease with which microfracture can be performed, comorbidities are often neglected unlike what occurs when more invasive procedures are recommended and performed (below).

ACI

Harris et al[7] conducted a systematic review comprised level I and II clinical studies to compare the efficacy of ACI with alternative treatments. On the basis of this review, complications were reported to be higher with open, periosteal-covered, first generation techniques. Furthermore, younger patients with a shorter duration of preoperative symptoms and fewer surgical procedures had the best outcomes after both microfracture and ACI. Defect size $>4\,cm^2$ was the only factor predictive of better outcomes when ACI was compared with osteochondral autograft transplantation system or microfracture.

Jungmann et al[8] conducted a level III retrospective cohort study that looked at both individual and environmental risk factors that were predictive of reintervention after an index ACI procedure. Of 813 patients who underwent an ACI procedure, 88 (21.3%) required reintervention at a mean time of 1.8 years. The 4 prognostic factors associated with a significantly higher risk for repeat surgery were female sex, previous surgeries of the affected joint, previous bone-marrow stimulation, and previous patch-covered ACI. Additional findings include lower reintervention rates for the intermediate (overweight) BMI group (16.8%), suggesting a BMI higher than 30 (obesity; 25.0%) and increased physical activity of patients with low BMI (23.7%) to be associated with an inferior outcome. Furthermore, the authors demonstrated that unlike that for microfracture, defect size was not a predictor of reintervention after ACI. The authors highlighted that these facts are easily obtainable in the preoperative period when considering an ACI procedure. Finally, a recent case-control study by Pestka et al[9] demonstrated that age-matched and defect-matched patients treated with ACI after a failed initial microfracture procedure were significantly more likely to have higher failure rates and lower knee injury and osteoarthritis outcome score pain and knee injury and osteoarthritis outcome score activities of daily living scores compared with patients whose first-line treatment was with ACI.

Jungmann et al[8] also demonstrated that the most common diagnoses at the time of revision surgery included incomplete regenerative cartilage, graft hypertrophy, and delamination of the transplant. As mentioned above, the use of periosteal-patch covered ACI is an independent predictor of increased reoperation rates and the reason for this is due to its strong association with graft hypertrophy. The use of collagen-based membranes has significantly decreased the incidence of this complication.[8]

Osteochondral Autograft Transplantation

Strategies to avoid failure of osteochondral autograft transplants include: (1) filling the recipient socket as much as possible to avoid cyst formation; (2) using minimal force during impaction to avoid chondrocyte death; and (3) fitting the plug to the surrounding surface to minimize alterations in contact stress.[10] It is well recognized that graft prominence of $>1\,mm$ that is poorly tolerated, results in early clinical failure, and can result in increased contact pressures, increased gap formation at the graft-tunnel junction with perigraft fissuring, fibroplasia, and subchondral cavitations.[11] Robb et al[12] reported outcomes for 55 patients at a mean follow-up of 5.9 years and demonstrated an 87.5% survival at 8 years (95% confidence interval, 72%-97%). The mean Oxford score at follow-up was 163% (95% confidence interval, 10.6%-22.1%) at follow-up. Two of 6 failures occurred in patients with varus malalignment. Linear regression analysis demonstrated an improved outcome in Oxford knee score in younger patients. Gender, BMI, previous or associated knee surgery, site and size of the graft had no influence on the outcome.[12] Gudas et al[13] reported the results of a randomized trial comparing osteochondral autograft transplantation versus microfracture at 10 years and demonstrated that lesion size of $<2\,cm^2$ was associated with a significantly higher rate of return to sports when compared with larger lesions after both procedures. Finally, in a retrospective multicenter study conducted by the French Arthroscopy Society (142 cases, mean follow-up 96 mo), the factors for a good prognosis included: male sex, medial femoral condyle defects (vs. lateral and patellofemoral defects), osteochondritis dissecans (vs. a traumatic etiology), deep (ICRS IV) and small ($<2\,cm^2$) defects, and a shorter delay from presentation to surgery.[14]

Osteochondral Allograft Transplantation

After fresh OAG transplantation, there are several clinical studies that report failure rates ranging from 0% to 20%.[15] Available studies indicate that the treatment of steroid-associated osteonecrosis produces results that are inferior to that for posttraumatic lesions[16]; it is also evident that patellofemoral lesions treated with fresh osteochondral grafting demonstrate poorer results compared with lesions in the femoral condyle or tibial plateau.[17,18] In contrast, patellofemoral lesions treated with ACI have been reported to have durable and sustainable successful outcomes at a mean follow-up of 4 years.[19] In this latter study, patients undergoing anteromedialization tended toward better outcomes than those without realignment. Forty-four percent of patients needed a subsequent procedure. There were 4 clinical failures (7.7%), which were defined as progression to arthroplasty or conversion to OAG transplantation after an index patellofemoral ACI procedure.

STRATEGIES THAT MAY DECREASE THE RATE OF FAILURE FOR CARTILAGE RESTORATION PROCEDURES

In the context of a well-performed surgical procedure, the existing literature suggests that appropriate patient selection likely remains the most effective way to minimize the rate of failed cartilage surgery. Cartilage repair should be offered to patients who have symptoms that are concordant with radiographic and MRI findings and whose activity or quality of life is limited by their physical impairment. Treatment selection should be guided by patient-specific and defect-specific factors, as well as, global knee and lower extremity structure and function.

In regards to pertinent patient-specific factors, the type of treatment offered is influenced by patient expectations, the number and type of previous surgeries, BMI, and activity level. Defect-specific factors that must be considered include defect etiology (eg, traumatic, osteochondritis dessicans, osteonecrosis), size, location, number, and the presence of subchondral bone change; of these, defect size is most often utilized by orthopedic surgeons to guide treatment recommendations. The caveat to remember is that MRI should not be used exclusively for predicting lesion size nor inexorably tied to the cause of a patient's symptoms. Gomoll et al[20] have demonstrated that MRI is a poor predictor of defect size—in a retrospective review, the authors demonstrated that intraoperative defect measurements were larger than predicted by MRI in the range of 47% to 377% depending on defect location. This suggests that although MRI may be effective in measuring the zone of full-thickness cartilage loss, most defects are surrounded by an area of degenerated or fissured cartilage that is less easily quantified. Given that most cartilage restoration treatments have upper size limit beyond which they are less successful, the importance of accurately quantifying defect size cannot be overstated. The use of computed tomography (CT) arthrogram and quantitative MRI techniques such as dGEMRIC may prove to be better predictors of defect size in future studies. A preliminary staging arthroscopy is an alternative method to obtain accurate measurement of defect size. Another defect-specific factor that must be taken into consideration is the presence of subchondral bone changes and edema as represented on preoperative MRI slices. The presence of subchondral change implies a bone and cartilage pathologic process, whereas its absence signifies mainly a chondral origin. In the former situation, therapeutic options that address the cartilage and subchondral components (eg, OAG) are preferred. In the latter, surface treatments such as microfracture, de Novo NT (Zimmer, Warsaw, IN), ACI and microfracture are more likely to be efficacious based on the experience at our center. While making decisions based upon high-level imaging is useful in the patients who are failing to thrive, clinical findings may not always be associated with MRI findings in the asymptomatic patient.

In a knee with multiple pathologies, each entity must be considered individually with respect to its influence on the overall status of the knee. Global knee and lower-extremity factors that require careful consideration include the presence of varus or valgus malalignment (> 5 degrees), ligamentous instability, and the degree of prior meniscal resection. Prior subtotal meniscectomy decreases joint contact area[21] and increases peak stresses[21] with a 14× increased relative risk of developing unicompartmental arthritis.[22–24] Furthermore, multiple studies have demonstrated worse outcomes associated with[25,26] young age, chondral damage found at time of meniscectomy, ligamentous instability,[27–29] and/or tibiofemoral malalignment. In addition, meniscal repair and meniscal transplantation have less favorable outcomes when performed with untreated concomitant instability, malalignment, and/or articular cartilage disease.[30–34] Thus, addressing multiple coexisting pathologies in a single patient's knee is certainly challenging, neglecting to correct concomitant comorbidity can compromise overall results and in the worst case scenario lead to a uncorrectable salvage situation. As symptoms are frequently load related, realignment is an effective adjunct to reducing symptoms through load transfer to the intact compartment.

Knee malalignment causes excessive loading of articular cartilage, which can lead to degenerative joint disease. Varus malalignment shifts the center of the knee joint lateral to the mechanical axis, leading to medial tibial cartilage volume and thickness loss, as well as increases in tibial and femoral denuded bone.[35] Valgus malalignment shifts the center of the knee medial to the mechanical axis, leading to increased, unbalanced lateral-sided forces. Osteotomy procedures alter the biomechanical axis by shifting load away from the damaged compartment. The pathophysiological principle of this procedure is to correct the weight-bearing axis if possible to avoid rapid and irreversible progression of unicompartmental degenerative joint disease.[36–38]

A recent systematic review performed by Harris et al[39] analyzed clinical outcomes in patients undergoing combined meniscal allograft transplantation with cartilage repair or restoration. Out of the 6 studies included, 110 patients were identified as having undergone meniscal allograft transplantation and either ACI (n = 73), OAG transplantation (n = 20), osteochondral autograft transplantation (n = 17), or microfracture (n = 3). Of note, 33% of patients (36/110) underwent other concomitant procedures including high tibial or distal femoral osteotomy, ligament reconstruction, and/or hardware removal. The authors noted improved outcomes in combined procedures compared with isolated surgery in 4 of the 6 studies. Overall, 12% of patients experienced failure of their combined procedure requiring revision surgery and 85% of these failures were noted to be related to the meniscus procedure as opposed to the cartilage procedure.[39] These results emphasize the importance of a global knee and lower extremity assessment. Avoiding linear thinking and attributing the entirety of a patients impairment and activity limitations to a focal defect without a comprehensive evaluation of all pertinent pathoanatomic factors is likely to compromise treatment outcomes and compromise patient recovery.

Routine imaging studies that are requested include standing anteroposterior, 45-degree flexion postero-anterior, lateral, and skyline radiographs. Three foot standing hip to ankle radiographs are taken to evaluate the mechanical axis. A minimum of 1.5 T MRI sequences are required to visualize articular cartilage with adequate resolution. The MRI can also be used to assess the extent of remaining meniscus in the ipsilateral compartment and the integrity of ligamentous structures. A CT scan is helpful when evaluating failed prior osteochondral autograft transplantation system or OAG procedures where bony incorporation or necrosis can be assessed.

In a revision situation, it is common in our institution to request for old operative reports and arthroscopy images. This allows for pertinent information to be derived from the exam under anesthesia (ie, instability), and confirmation of the extent of prior meniscal resection, the number and extent of chondral defects, the quality of subchondral bone, and most importantly, the post-debridement dimensions of treated lesions. One can also get an appreciation of the technique utilized by the prior surgeon for a given cartilage repair procedure. As mentioned above, an additional method of confirming defect size and surveying the knee is to perform a staging arthroscopy procedure where one can perform an examination under anesthesia to assess ligamentous structures, measure the defect, look for additional lesions, and assess the extent of prior meniscal resection. Such an undertaking provides all of the pertinent information needed for preoperative planning and decision-making when old operative reports and arthroscopy pictures are not available. Even when this information in available, if a significant amount of time has

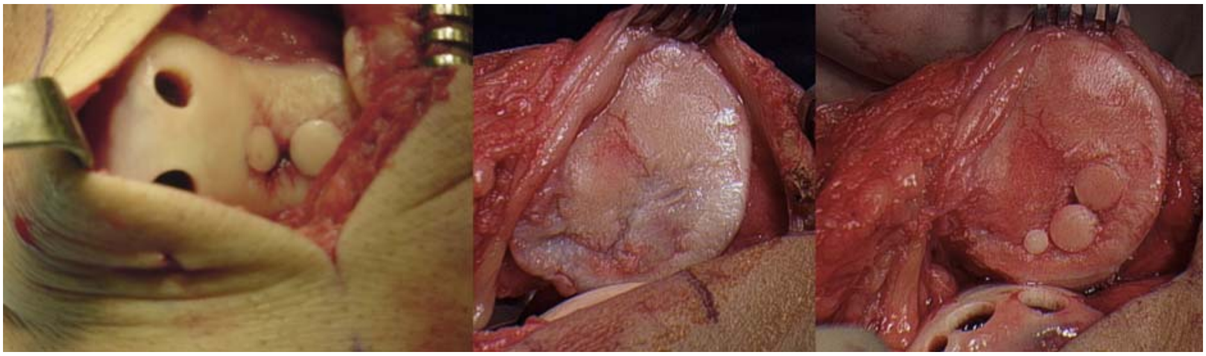

FIGURE 1. Osteochondral autograft transplantation system procedure performed for a central trochlear defect and a patellar defect in 2 cases. Note the difficulty in matching the contour and geometry in the trochlea, as well as, the mild height mismatch of the donor plugs.

passed since the last treatment, an "inventory" arthroscopy may still be required for proper planning.

AN ALGORITHM FOR THE MANAGEMENT OF PATIENTS WITH FAILED PRIOR CARTILAGE SURGERY

Diagnosis

Patients who have had prior unsuccessful cartilage surgery will present with recurrent or new-onset knee symptoms and may include compartmental pain, swelling, and/or mechanical symptoms. One must also attempt to elicit symptoms of instability and stiffness to look for associated ligamentous instability and secondary degenerative changes, respectively. It is also important to clarify if patients ever had resolution of symptoms after the index surgery and whether there was an inciting traumatic event associated with symptom onset.

As mentioned above, a focused physical examination must be conducted to assess global lower extremity and knee function including alignment, core strength, knee range of motion and strength, joint line tenderness, and stability testing.

Radiographic investigations include x-rays, MRI, and CT scans with the latter being indicated when combined bony and cartilage procedures (eg, OAT) had been performed during the original surgery. Access to old operative reports and arthroscopy pictures allows one to appreciate the technical details of the prior operation and gain an appreciation of the overall status of the knee joint cartilage, meniscus, and ligamentous structures.

Etiology

Early Failure

Early failure of cartilage repair is most likely associated with technical errors, failure of graft incorporation, noncompliance with postoperative rehabilitation protocols (early weight-bearing, lack of continuous passive motion with microfracture), or due to an unanticipated traumatic event. Common technical errors that can result in failure include subchondral bone plate fracture associated with microfracture procedures, osteochondral grafts that are incongruent with the surrounding articular surface (Fig. 1), inadequate press-fit fixation for osteochondral grafts, and absence of a water-tight closure of a periosteal or collagen patch sutured with ACI procedures resulting in the loss of implanted chondrocytes from the defect site.

Late Failure

Later failures after cartilage repair can be secondary to the progression of focal lesions and degenerative changes associated with the natural history of focal cartilage defects, breakdown of the repair tissue over time (eg, microfracture), concomitant unaddressed pathology at the time of prior repair (eg, malalignment, instability, meniscal deficiency), failure of biological incorporation, and technique specific complications. In the latter situation these may include graft hypertrophy (ACI; Fig. 2A), articular cartilage failure or delamination of an ACI or osteoarticular graft (Fig. 3), and, failure of osseous integration/necrosis of an osteochondral graft or lack of chondral integration for lesions treated with ACI (ie, biological failure; Figs. 2B and 4). Late failure can be potentiated with concomitant ligamentous instability, malalignment, or a meniscectomized

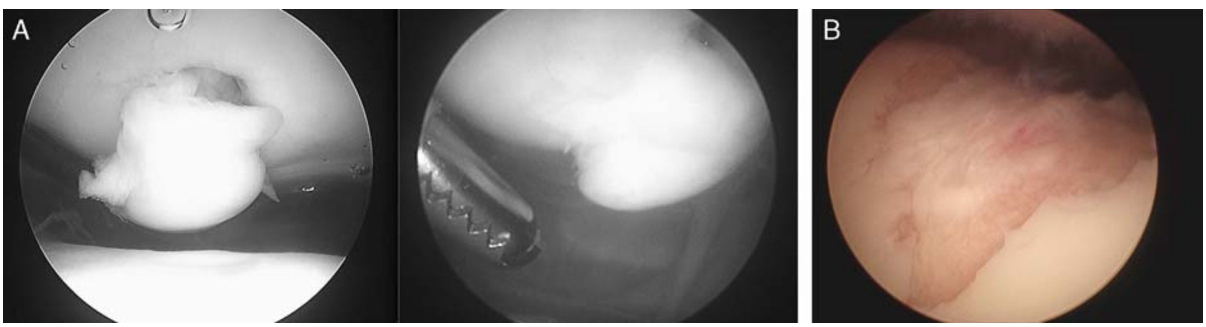

FIGURE 2. A, Autologous chondrocyte implantation graft hypertrophy. B, Incomplete take in autologous chondrocyte implantation.

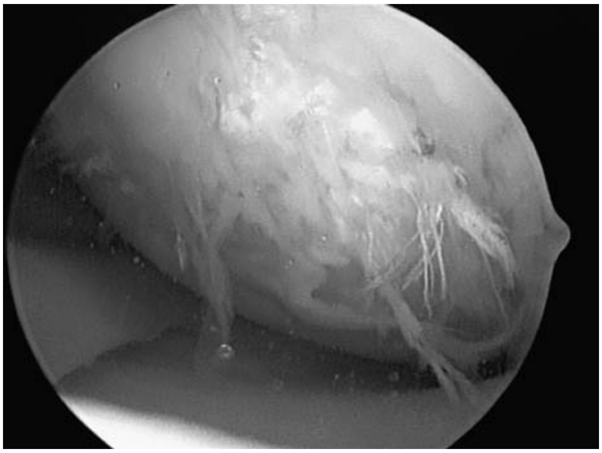

FIGURE 3. Cartilage delamination 1-year status after autologous chondrocyte implantation for a lesion on the medial femoral condyle.

state was not recognized or addressed at the time of index surgery.

As noted, a firm understanding of the reason(s) for failure is crucial before a revision procedure is performed to ensure prevention of further complications. Often, a comorbid condition, such as malalignment, instability, or meniscal deficiency, can lead to a premature degradation of the surgically induced replacement tissue. A diagnostic arthroscopy is often required to evaluate the extent of these comorbid conditions and to determine the integrity of the cartilage lesion and subchondral bone.

Treatment Algorithm

At the present time there is a relative lack of focused clinical studies on revision cartilage repair that precludes a formal meta-analysis that would attempt to identify the most optimal treatment strategies. On the basis of the information above, selecting "the next treatment" is based on a myriad of factors that are patient-specific, defect-specific, and that depends on a global assessment of lower extremity and knee structure and function. The treatment algorithm that we have proposed (Fig. 5) in this review takes into consideration the most recent failed cartilage surgery procedure that was performed on a given patient in the context of the aforementioned patient-specific and disease-specific factors (Figs. 6A, B). Furthermore, this algorithm has been constructed based on the experience at our tertiary care referral center over a 15-year period in addition to evidence-based principles.

Overview

A focal cartilage defect in association with meniscal deficiency and/or with varus or valgus alignment can be managed simultaneously or in stages. Focal cartilage defects previously treated with a reparative technique can be followed by a restorative technique, such as with ACI, OAT, or OAG, depending on the location of defect and the condition of the subchondral bone. In the presence of varus or valgus alignment, a high tibial osteotomy or a distal femoral osteotomy can be performed simultaneously with the revision articular cartilage procedure, especially in young and active patients. Older, less active patients with lower physical demands may benefit from a staged procedure. An osteotomy is performed first in an effort to offload the symptomatic compartment, followed by a period of observation. If patients present with satisfactory symptomatic relief, an additional restorative cartilage procedure may not be warranted. In the case of cartilage restoration, an osteotomy should be performed to correct the mechanical axis to neutral; however, in the setting of pain and arthrosis, the osteotomy should be corrected slightly beyond neutral.

Patellofemoral lesions are most often treated with a distal realignment procedure of the tibial tubercle to decrease the contact pressure of the patellofemoral joint with the cartilage procedure. The degree of anteriorization versus medialization can be titrated based on the patient's history of instability, maltracking (TT-TG distance), or arthrosis.[40–42]

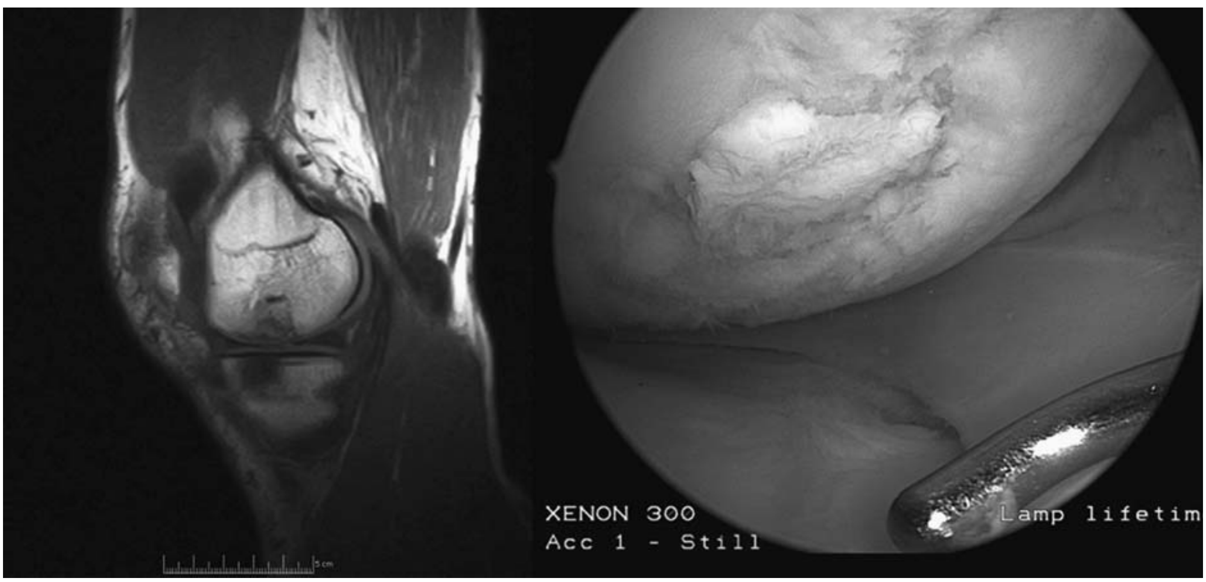

FIGURE 4. Failed incorporation of an osteochondral autograft transplant involving the medial femoral condyle.

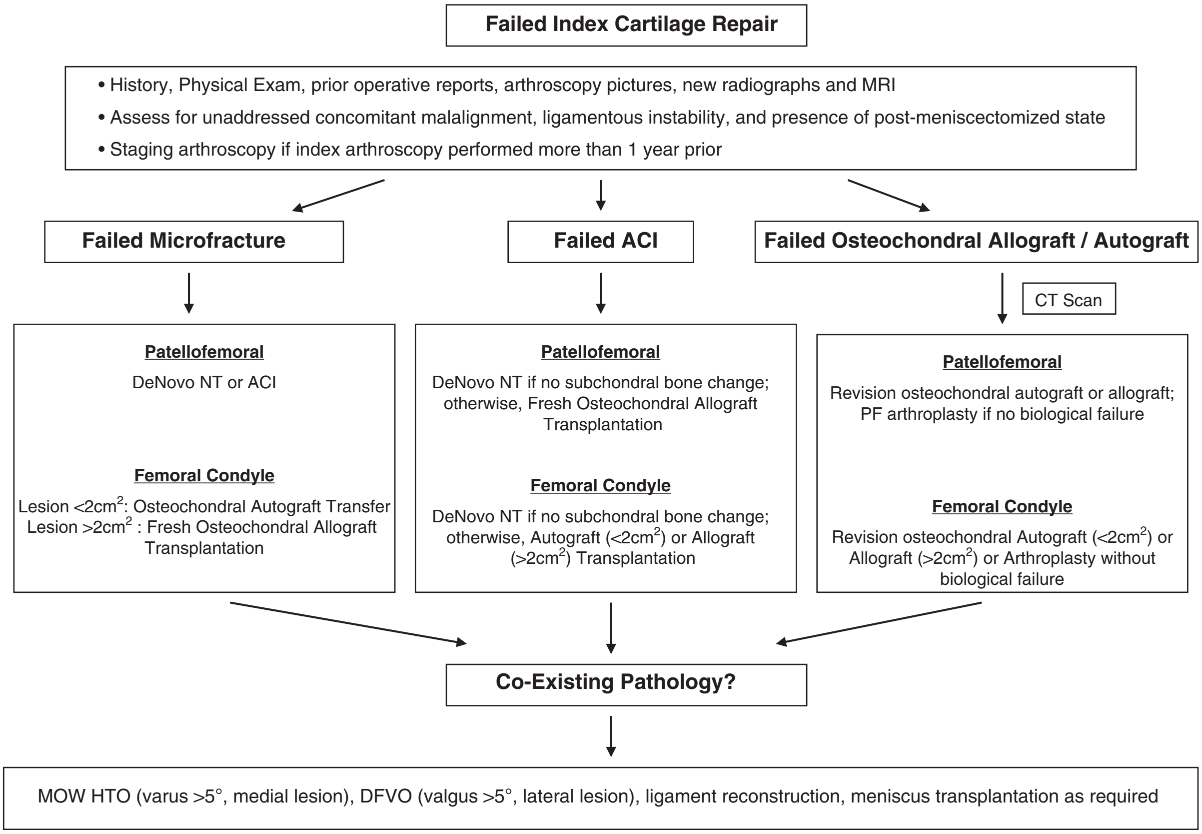

FIGURE 5. Treatment algorithm for managing patients with failed index cartilage restoration procedures. ACI indicates Autologous chondrocyte implantation; CT, computed tomography; DeNovo NT, DeNovo Natural Tissue; DFVO, distal femoral varus osteotomy; MOW HTO, medial opening wedge high tibial osteotomy; MRI, magnetic resonance imaging; PF, patellofemoral.

Revision procedures fall into categories based on their location and the index treatment. The algorithm used by the authors is listed below. In brief, failure of microfracture can be surgeon-specific and technique-specific based on preference. Data suggest that multiple procedures can do well after a failed microfracture. However, the author's treatment of choice for failure in the patellofemoral joint is either an ACI or Denovo NT procedure. These techniques allow an accurate reconstruction of the complex topography in the PF joint. Alternatively, an OAG or autograft is the revision treatment of choice for failed microfracture in the femoral condyle especially when the subchondral bone is active based upon the pretreatment MRI.

If the index treatment was an ACI procedure, the revision treatment of choice is an OAG or autograft. However, with no subchondral bone change, a Denovo NT procedure can be considered in the patellofemoral joint. Lastly, the failure of an osteochondral graft is typically revised with a second OAG with demonstration of biological failure. In the absence of biological failure after OAG transplantation, a patellofemoral/unicompartmental arthroplasty may be the treatment of choice. If a surface treatment is chosen in this situation, bone grafting must occur in order to provide an appropriate "bed" for the cells to adhere and integrate. Regardless of the index technique used, revision cartilage procedures and the rehabilitation associated with them can be

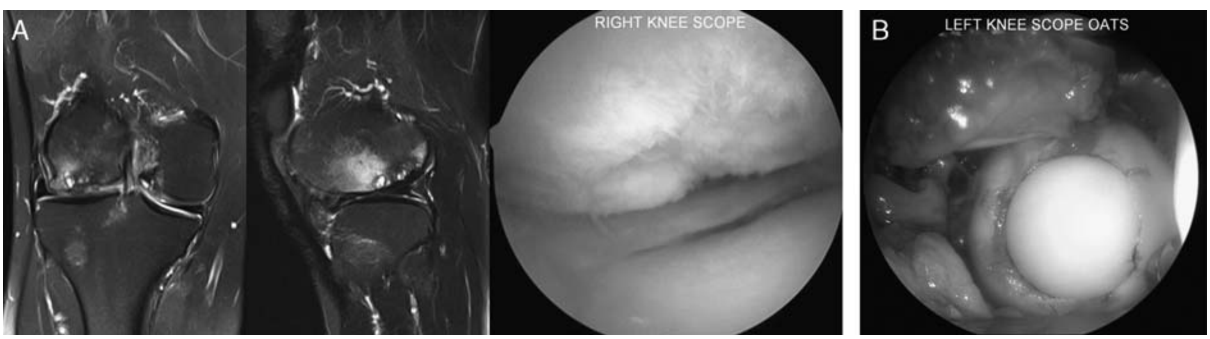

FIGURE 6. A, Symptomatic chondral lesion in the lateral femoral condyle 2 years after autologous chondrocyte implantation. Note the presence of subchondral bone marrow edema. B, Revision performed using a fresh OAG.

very difficult for a multitude of lesion and patient-specific factors. Figure 5 is meant to be a guide and the authors recognize the variability on a case-by-case basis.

REFERENCES

1. Cole BJ, Pascual-Garrido C, Grumet RC. Surgical management of articular cartilage defects in the knee. *J Bone Joint Surg Am*. 2009;91:1778–1790.
2. Jones DG, Peterson L. Autologous chondrocyte implantation. *J Bone Joint Surg Am*. 2006;88:2502–2520.
3. Benthien JP, Schwaninger M, Behrens P. We do not have evidence based methods for the treatment of cartilage defects in the knee. *Knee Surg Sports Traumatol Arthrosc*. 2011;19:543–552.
4. Gomoll AH, Farr J, Gillogly SD, et al. Surgical management of articular cartilage defects of the knee. *J Bone Joint Surg Am*. 2010;92:2470–2490.
5. Redler LH, Caldwell JM, Schulz BM, et al. Management of articular cartilage defects of the knee. *Phys Sportsmed*. 2012;40:20–35.
6. Mithoefer K, McAdams T, Williams RJ, et al. Clinical efficacy of the microfracture technique for articular cartilage repair in the knee: an evidence-based systematic analysis. *Am J Sports Med*. 2009;37:2053–2063.
7. Harris JD, Siston RA, Pan X, et al. Autologous chondrocyte implantation: a systematic review. *J Bone Joint Surg Am*. 2010;92:2220–2233.
8. Jungmann PM, Salzmann GM, Schmal H, et al. Autologous chondrocyte implantation for treatment of cartilage defects of the knee: what predicts the need for reintervention? *Am J Sports Med*. 2012;40:58–67.
9. Pestka JM, Bode G, Salzmann G, et al. Clinical outcome of autologous chondrocyte implantation for failed microfracture treatment of full-thickness cartilage defects of the knee joint. *Am J Sports Med*. 2012;40:325–331.
10. Farr J, Cole B, Dhawan A, et al. Clinical cartilage restoration: evolution and overview. *Clin Orthop Relat Res*. 2011;469: 2696–2705.
11. McCoy B, Miniaci A. Osteochondral autograft transplantation/mosaicplasty. *J Knee Surg*. 2012;25:99–108.
12. Robb CA, El-Sayed C, Matharu GS, et al. Survival of autologous osteochondral grafts in the knee and factors influencing outcome. *Acta Orthop Belg*. 2012;78:643–651.
13. 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;40:2499–2508.
14. Ollat D, Lebel B, Thaunat M, et al. Mosaic osteochondral transplantations in the knee joint, midterm results of the SFA multicenter study. *Orthop Traumatol Surg Res*. 2011; 97(suppl):S160–S166.
15. Demange M, Gomoll AH. The use of osteochondral allografts in the management of cartilage defects. *Curr Rev Musculoskelet Med*. 2012;5:229–235.
16. Gortz S, De Young AJ, Bugbee WD. Fresh osteochondral allografting for steroid-associated osteonecrosis of the femoral condyles. *Clin Orthop Relat Res*. 2010;468:1269–1278.
17. Jamali AA, Emmerson BC, Chung C, et al. Fresh osteochondral allografts: results in the patellofemoral joint. *Clin Orthop Relat Res*. 2005;437:176–185.
18. Torga Spak R, Teitge RA. Fresh osteochondral allografts for patellofemoral arthritis: long-term followup. *Clin Orthop Relat Res*. 2006;444:193–200.
19. Pascual-Garrido C, Slabaugh MA, L'Heureux DR, et al. Recommendations and treatment outcomes for patellofemoral articular cartilage defects with autologous chondrocyte implantation: prospective evaluation at average 4-year follow-up. *Am J Sports Med*. 2009;37(suppl 1):33S–41S.
20. Gomoll AH, Yoshioka H, Watanabe A, et al. Preoperative measurement of cartilage defects by MRI underestimates lesion size. *Cartilage*. 2011;2:389–393.
21. Lee SJ, Aadalen KJ, Malaviya P, et al. Tibiofemoral contact mechanics after serial medial meniscectomies in the human cadaveric knee. *Am J Sports Med*. 2006;34:1334–1344.
22. McNicholas MJ, Rowley DI, McGurty D, et al. Total meniscectomy in adolescence. A thirty-year follow-up. *J Bone Joint Surg Br*. 2000;82:217–221.
23. Roos EM, Ostenberg A, Roos H, et al. Long-term outcome of meniscectomy: symptoms, function, and performance tests in patients with or without radiographic osteoarthritis compared to matched controls. *Osteoarthritis Cartilage*. 2001;9:316–324.
24. Roos H, Lauren M, Adalberth T, et al. Knee osteoarthritis after meniscectomy: prevalence of radiographic changes after twenty-one years, compared with matched controls. *Arthritis Rheum*. 1998;41:687–693.
25. Burks RT, Metcalf MH, Metcalf RW. Fifteen-year follow-up of arthroscopic partial meniscectomy. *Arthroscopy*. 1997;13: 673–679.
26. Maletius W, Messner K. The effect of partial meniscectomy on the long-term prognosis of knees with localized, severe chondral damage. A twelve- to fifteen-year followup. *Am J Sports Med*. 1996;24:258–262.
27. Hart AJ, Buscombe J, Malone A, et al. Assessment of osteoarthritis after reconstruction of the anterior cruciate ligament: a study using single-photon emission computed tomography at ten years. *J Bone Joint Surg Br*. 2005;87:1483–1487.
28. Ruiz AL, Kelly M, Nutton RW. Arthroscopic ACL reconstruction: a 5-9 year follow-up. *Knee*. 2002;9:197–200.
29. Shirazi R, Shirazi-Adl A. Analysis of partial meniscectomy and ACL reconstruction in knee joint biomechanics under a combined loading. *Clin Biomech (Bristol, Avon)*. 2009;24:755–761.
30. Gomoll AH, Kang RW, Chen AL, et al. Triad of cartilage restoration for unicompartmental arthritis treatment in young patients: meniscus allograft transplantation, cartilage repair and osteotomy. *J Knee Surg*. 2009;22:137–141.
31. Kang RW, Lattermann C, Cole BJ. Allograft meniscus transplantation: background, indications, techniques, and outcomes. *J Knee Surg*. 2006;19:220–230.
32. Noyes FR, Barber-Westin SD. Meniscus transplantation: indications, techniques, clinical outcomes. *Instr Course Lect*. 2005;54:341–353.
33. Packer JD, Rodeo SA. Meniscal allograft transplantation. *Clin Sports Med*. 2009;28:259–283, viii.
34. Rue JP, Yanke AB, Busam ML, et al. Prospective evaluation of concurrent meniscus transplantation and articular cartilage repair: minimum 2-year follow-up. *Am J Sports Med*. 2008;36:1770–1778.
35. Sharma L, Eckstein F, Song J, et al. Relationship of meniscal damage, meniscal extrusion, malalignment, and joint laxity to subsequent cartilage loss in osteoarthritic knees. *Arthritis Rheum*. 2008;58:1716–1726.
36. Sharma L, Song J, Felson DT, et al. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. *JAMA*. 2001;286:188–195.
37. Van Thiel G, Frank RN, Gupta A, et al. Biomechanical evaluation of a high tibial ostetomy with a meniscal transplant. *J Knee Surg*. 2011;24:45–53.
38. Verdonk PC, Demurie A, Almqvist KF, et al. Transplantation of viable meniscal allograft. Survivorship analysis and clinical outcome of one hundred cases. *J Bone Joint Surg Am*. 2005;87:715–724.
39. Harris JD, Cavo M, Brophy R, et al. Biological knee reconstruction: a systematic review of combined meniscal allograft transplantation and cartilage repair or restoration. *Arthroscopy*. 2011;27:409–418.
40. Beck PR, Thomas AL, Farr J, et al. Trochlear contact pressures after anteromedialization of the tibial tubercle. *Am J Sports Med*. 2005;33:1710–1715.
41. Farr J, Schepsis A, Cole B, et al. Anteromedialization: review and technique. *J Knee Surg*. 2007;20:120–128.
42. Rue JP, Colton A, Zare SM, et al. Trochlear contact pressures after straight anteriorization of the tibial tuberosity. *Am J Sports Med*. 2008;36:1953–1959.