Adapting Cartilage Restoration to the Patellofemoral Compartment

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Abstract

Treating symptomatic chondral and osteochondral defects of the patellofemoral joint poses a challenge to surgeons due to the limited healing potential of articular cartilage as well as complex surface morphology of the patella and trochlea. In addition, the patellofemoral joint is further complicated by high compressive and shear stresses combined with variable alignment and patella tracking between patients. Initial management for most lesions consists of nonoperative measures, but surgery should be considered for symptomatic patients who fail nonoperative treatment. Surgical procedures can be divided into marrow stimulation (microfracture and drilling), cell-based (autologous chondrocyte implantation and particulated juvenile articular cartilage), and osteochondral (osteochondral allograft transplantation and osteochondral autograft transfer). In addition, fixation of chondral or osteochondral fragments can be considered following traumatic injuries and dislocations. Goals of surgical management include recreating the articular surface architecture and improving the biomechanical environment through addressing associated conditions such as malalignment and patellar instability. Historically, outcomes following patellofemoral cartilage restoration have generally been inferior to tibiofemoral outcomes, but newer studies have demonstrated improved results that rival those of the tibiofemoral compartment.

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1 Introduction

Patellofemoral chondral lesions are common and have the potential to result in pain and dysfunction. Several studies [1–3] have identified patellofemoral chondral defects in greater than 33% of patients undergoing knee arthroscopy. Etiologies for these lesions include acute trauma, overuse, patellar instability, chronic maltracking, and osteochondritis dissecans, or they may be idiopathic. The most common location of the defect following patellar dislocation is the inferior aspect of the medial patellar facet [4]. Recurrent patellar dislocations have been known to lead to chondral degeneration in select patients, but data suggests that even a single first-time dislocation or infrequent dislocations may result in a predisposition to gradual cartilage deterioration [5, 6]. It has been speculated that the traumatic nature of the event may lead to an alteration in the local inflammatory milieu of the joint resulting in an ongoing inflammatory cascade and ultimate chondral degeneration. Another etiology although infrequently seen is osteochondritis dissecans which has been described in the patellofemoral joint most commonly affecting the patella and lateral trochlea [7]. Chondral and osteochondral lesions within this region of the knee can be challenging to treat due to the complex anatomy and biomechanics of the patellofemoral joint. The patella articular cartilage is the thickest in the body which creates difficulties when trying to match while performing osteochondral procedures [8, 9]. Additionally, patellofemoral joint loads may reach 6.5 times body weight adding further local biomechanical barriers to successful surgical outcomes [8]. Therefore, a careful evaluation of the underlying patellofemoral pathomechanics and anatomy is of utmost importance for a successful surgical outcome.

2 Clinical Evaluation and Imaging

Patients with patellofemoral cartilage injuries will commonly present with anterior knee pain that is made worse with activity. Activities that involve loading a flexed knee such as squatting, kneeling, and using stairs often elicit pain. Intermittent effusions are common, and mechanical symptoms can occur as a result of an unstable chondral flap. Some patients will present following a dislocation event that they can recall or may have a history of chronic instability. Physical examination should focus on assessing for malalignment, presence of an effusion, and patellar tracking with range of motion including evaluating for a patellar J sign (lateral translation of the patella when extending the knee as a result of the patella disengaging from the trochlea). Standard radiographs are obtained including standing anteroposterior, lateral, merchant, and 45-degree flexion posteroanterior views. These X-rays are evaluated for fractures, loose bodies, joint space narrowing, osteophytes, patellar height, patellar tilt, and patellar subluxation. MRI is the advanced imaging modality of choice to diagnose and characterize chondral and osteochondral defects of the patellofemoral joint. Additionally, the integrity of the medial patellofemoral ligament (MPFL), tibial tubercle-trochlear groove (TT-TG) distance, and presence of trochlear dysplasia should be determined. Both MRI and CT can be used to calculate the tibial tubercle-trochlear groove (TT-TG) distance in the setting of patellar instability, but data suggests that MRI may underestimate this distance [10–12]. Additionally, some studies [13–15] have supported calculating the TT-PCL distance, but there is conflicting data regarding whether the TT-TG or TT-PCL distance is more accurate. Given the high incidence of chondral and osteochondral injury following patellar dislocation, it is prudent to obtain an MRI after the acute (first) dislocation since radiographs are not sensitive in detecting these injuries. Trochlea dysplasia, patella alta, and lateral patellar tilt have been determined to be anatomic risk factors for the development of patellofemoral cartilage lesions and therefore must be considered when developing a treatment plan [16–18].

3 Treatment Options

3.1 Nonoperative Treatment

The initial management of most patients with patellofemoral chondral defects should be directed toward conservative measures. The exception to this is the patient with mechanical symptoms as a result of a displaced chondral flap or osteochondral fragment. The treatment of acute patellar dislocations is rather controversial and is beyond the scope of this manuscript. The mainstays of nonoperative treatment include activity modification, anti-inflammatory medications, physical therapy, injections, and bracing. Injections in the form of steroids or viscosupplementation may help decrease inflammation and improve symptoms in certain patients, especially older individuals. Newer injections include various orthobiologic agents such as platelet-rich plasma (PRP), bone marrow aspirate concentrate (BMAC), amniotic membrane-derived mesenchymal stromal cells (MSC), and adipose-derived MSCs. While early studies have demonstrated promising results with these emerging options, additional high-level randomized controlled trials are warranted. Physical therapy focuses on patellar mobilization, core strengthening, abductor strengthening, and quadriceps strengthening. It has proven to be effective for patellofemoral pain by reducing mechanical stress in the joint and improving patellar tracking [19, 20]. Nonoperative treatment should be attempted for 6 weeks to 6 months depending on the patient's progress.

3.2 Surgical Treatment

Patients who fail nonoperative management or those who have been found to have a displaced chondral or osteochondral defect should be considered for surgical intervention. Surgical treatment is individualized based on defect characteristics (size, location, stability, and status of subchondral bone) and associated conditions such as malalignment and instability. Other factors include patient age, activity level, goals/expectations, and willingness to participate in postoperative rehabilitation. Surgical options include marrow stimulation, osteochondral autograft transfer, osteochondral allograft transplantation, autologous chondrocyte implantation, particulated juvenile cartilage (DeNovo®), realignment procedures (tibial tubercle osteotomy, lateral release/lengthening, and MPFL reconstruction), and patellofemoral arthroplasty.

3.2.1 Arthroscopic Loose Body Removal and/or Chondroplasty

Small chondral or osteochondral loose bodies as a result of patellar dislocation can be removed via arthroscopy. Removal of these fragments can help eliminate mechanical symptoms and prevent potential third body wear. At the same time, associated patellofemoral defects can be further evaluated and addressed with chondroplasty in order to remove loose chondral flaps. When large osteochondral fragments are suspected preoperatively or encountered at time of arthroscopy, primary in situ fixation with metal screws or bioabsorbable implants should be considered. However, small (<1 cm^2) chronic partial or full thickness chondral lesions may only require chondroplasty.

3.2.2 Fixation of Chondral and Osteochondral Fragments

Traumatic injuries such as patellar dislocations have the potential to result in loose chondral or osteochondral fragments that may be amenable to acute fixation (Fig. 1). Unstable osteochondritis dissecans fragments may also be amenable to fixation in select cases. Surgical fixation options include metal headless compression screws, bioabsorbable compression screws, and sutures, as well as various bioabsorbable pins/darts. However, whether or not these injuries should be treated with arthroscopic fragment removal and debridement as opposed to fixation of the fragment has been debated. Until recently there has

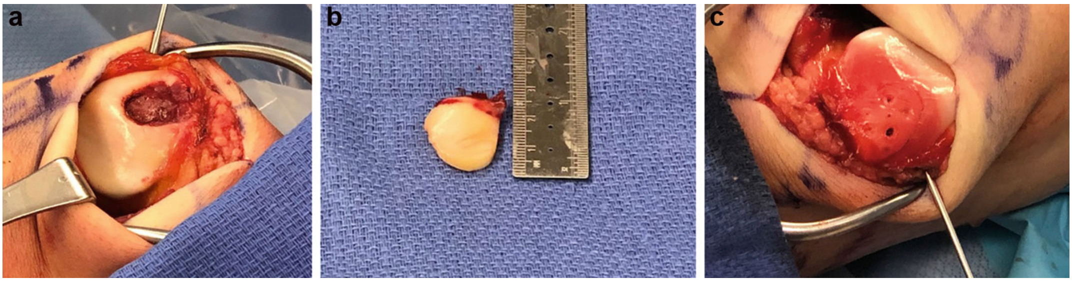

Fig. 1 (**a**) Intraoperative photograph of a full-thickness patellar chondral defect following traumatic patellar dislocation; (**b**) intraoperative photograph of the chondral fragment without subchondral bone attached; and (**c**) intraoperative photograph of chondral fragment fixation with bioabsorbable compression screws

been a limited number of studies to help guide surgeons. A recent retrospective comparative study [21] analyzed 53 consecutive patients with osteochondral fractures following patellar dislocation treated with either refixation or debridement. There were 36 patellar fragments and 17 lateral femoral condyle fragments. Refixation was chosen for 28 patients while 25 patients underwent removal of the fragment followed by debridement of the lesion. Clinical outcomes were assessed using IKDC, KOOS, and Lysholm scores with a mean follow-up of 8.9 years. All clinical outcome scores were significantly better in the refixation group at final follow-up. In addition, refixation resulted in a significant decrease in the reoperation rate (48% vs 7.1%). It is important to note that all refixation cases in this study had evidence of subchondral bone attached to the chondral fragments. However, successful outcomes have been documented with the fixation of chondral fragments without subchondral bone attached. In a case series of ten patients, Kjennvold et al. [22] reported favorable outcomes following the fixation of chondral-only fractures with a median follow-up of 5 years. Included in this cohort were seven patella lesions, two trochlea lesions, and one femoral condyle lesion, and the average age at the time of surgery was 15 years (12–17 years). At final follow-up, all patients returned to preinjury level of sports, MRI demonstrated healing of the fragments with integration to the surrounding articular cartilage, and the mean Lysholm score was 90 (73–100). Similarly, Churchill et al. [23] achieved excellent results following fixation of large pure chondral fragments (mean size 1.9 × 2.0 cm) in a series of ten patients which included four patella, four trochlea, and two lateral femoral condyle lesions. The average age was 14.6 years (10–25 years) with a mean follow-up of 56 months. Subsequent MRI in eight patients revealed complete healing, and all patients except one returned to sports. Although fixation of pure chondral fragments in skeletally mature patients was successful in both of these studies, the majority of the patients were skeletally immature (eight out of ten in both studies).

3.2.3 Marrow Stimulation

Marrow stimulation can be used to treat small (<2 cm^2) full thickness chondral defects of the patella or trochlea. The most common techniques include microfracture and drilling. In this technique, the lesion is prepared by removing all unhealthy articular cartilage and creating stable vertical walls of surrounding healthy cartilage. The calcified layer is removed, and penetration of the subchondral bone is performed with a drill or awl in order to facilitate bleeding into the base of the defect and subsequent formation of fibrocartilage [24]. The procedure can be performed via arthroscopy, mini-arthrotomy, or para-patellar arthrotomy. However, performing microfracture to the patella through an arthroscopic approach is technically challenging due to the difficulty of obtaining a perpendicular angle to the defect. Unfortunately, there are few outcome studies that evaluate patellofemoral treated defects alone and instead combine femoral condyle with patellofemoral data. Nonetheless, Kreuz et al. [25] followed 70 patients who underwent microfracture for full thickness chondral defects involving various compartments of the knee and reported outcomes based on location of the defect. There were 32 femoral condyle, 11 tibia, 16 trochlea, and 11 patella defects. They reported good results and high-score levels in all patients at 6 months and 18 months but found that outcome scores and MRI defect filling deteriorated at 36 months. In addition, greater deterioration was noted in the trochlea and patella groups compared to the femoral condyle group. This is concerning given the already known expected clinical deterioration following microfracture in other areas of the knee [26–30]. As a result, a newer trend involves augmentation of marrow stimulation in an attempt to create a biomechanically superior hyaline-like tissue (Fig. 2). A recent study [31] reported on 49 articular cartilage lesions treated with microfracture augmented with allograft extracellular matrix (BioCartilage; Arthrex, Naples, and FL) and leukocyte-poor platelet-rich plasma. Of the 49 lesions, there were 25 (51.1%) trochlea and 6 (12.2%) patellar lesions. All joint-specific and function-related patient-reported outcomes (PROs) significantly improved compared to baseline at 3, 6, 12, 18, and 24 months with the exception of the Marx activity scale. In addition, 90% of patients reached the minimal clinically important difference (MCID). Despite these favorable results, a subgroup analysis was not performed to determine whether or not location of the defect affected outcomes. Lastly, PRO compliance was only 47.9% at 2 years. Regardless, the results are encouraging and have stimulated further interest in improving outcomes following marrow stimulation.

3.2.4 Osteochondral Autograft Transfer

Osteochondral autograft transfer is an option for small (<2 cm^2) full thickness chondral or osteochondral defects of the patella or trochlea. It restores the osteochondral unit with hyaline cartilage and native bone to the subchondral region. This technique involves harvesting one or multiple osteochondral cylinders (mosaicplasty) from minimal weight-bearing portions of the femur and transferring them to defects in higher weight-bearing areas. Our preferred harvest site is the lateral femoral trochlea, but the intercondylar notch of the femur as well as the medial femoral trochlea can also be considered. The procedure can be performed arthroscopically, open or mini-open, the latter being increasingly recognized as a useful compromise of minimal morbidity and better precision. While the

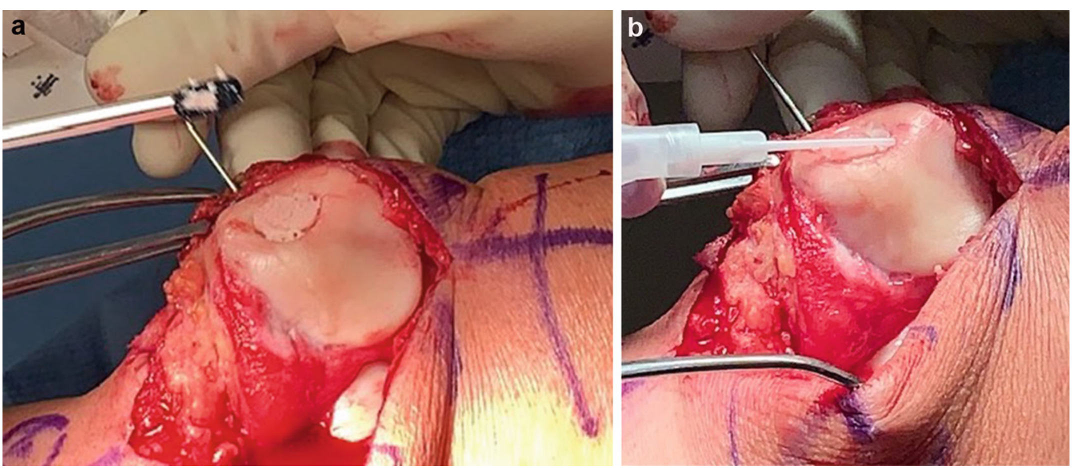

Fig. 2 (**a**) Intraoperative photograph of micronized allograft cartilage combined with platelet-rich plasma being applied to a full-thickness chondral defect of the patella following marrow stimulation in the form of drilling; (**b**) intraoperative photograph of fibrin glue being applied to the micronized allograft cartilage and platelet-rich plasma in order to obtain secure fixation

procedure is a viable option for patellofemoral defects, it is more complicated since it requires matching the complex contour of the patella and trochlea with donor cylinders that commonly lack the same thickness of native patellofemoral cartilage. In one of the early OAT outcomes studies, Bentley et al. [32] found a high failure rate associated with OAT mosaicplasty for patellar chondral lesions. They conducted a prospective randomized study of 100 patients with osteochondral defects treated with either ACI or mosaicplasty. Of the 100 patients, 5 were treated with OAT mosaicplasty of patellar defects. All patellar mosaicplasties failed at a mean follow-up of 1.7 years. Another multicenter study [33] across three institutes with a total of 354 patients and an average follow-up of 9.6 years revealed good to excellent results in 91% of femoral mosaicplasties as opposed to 74% of patellofemoral mosaicplasties. The authors state that improper management of failed patellofemoral biomechanics may explain the differences seen between the two groups of patients. To the contrary, a large recent long-term comparative study [34] reported no difference in survivorship with similar long-term outcomes in patients who underwent mosaicplasty for articular cartilage defects of the patellofemoral joint compared to the tibiofemoral joint. In this study, there were 26 patellofemoral cases and 58 tibiofemoral cases with a mean age of 34 years and median defect size of 3 cm^2. However, eventual gradual failure developed in both groups within the 18-year follow-up in about 50% of cases. Figueroa et al. [35] reported their positive experience in ten consecutive patients with patella defects measuring 1.2 cm^2 on average. At a mean follow-up of 37.3 months, Lysholm scores increased from 73.8 to 95 and there were no complications. Follow-up MRIs at 8 months were favorable with all grafts being flush to adjacent cartilage and no fissures in the graft-host interface for the majority of cases. In another case series, Nho et al. [36] reported on 22 patients treated with OAT for patella defects and documented significant improvement in clinical follow-up with improved IKDC (47.2–74.4), ADL (60.1–84.7), and SF-36 (64.0–79.4) scores at a mean of 28.7 months. The average defect size in this study was 1.65 cm^2. The authors also concluded that patients who received OAT as an isolated procedure demonstrated better outcomes than patients who had other associated procedures. A recent systematic review [37] analyzed five studies with a total of 102 patients who received an isolated OAT for a patellar chondral defect and were followed for a mean follow-up of 19.8–37.3 months. At final follow-up, all patients demonstrated significant improvement in their PRO scores (Lysholm, IKDC, Kujala, Tegner, and SF-36) and four studies included MRI follow-up with most plugs displaying correct position and integration. In another recent series, 26 patients were treated with isolated patellar OAT and followed for a mean of 2.5 years [38]. The average age was 28.5 years with a median defect size of 1.8 cm^2. At final outcome, the mean Kujala and WOMAC scores were 90.42 and 95 while MRI outcomes at 6 months revealed good results in 92% of patients. We feel that OAT can be considered for small (<2 cm^2) lesions but higher failure rates may occur when more donor cylinders are required to treat larger defects. In addition, patients with medial and lateral patellar facet lesions and individuals who are aged >50 years may exhibit inferior outcomes [39, 40].

3.2.5 Osteochondral Allograft Transplantation

Osteochondral allograft transplantation is another procedure that restores the entire osteochondral unit and is ideal for large defects (>2–4 cm^2, Fig. 3). The technique is comparable to that of OAT with the difference being a larger cylinder obtained from a cadaver hemicondyle, patella, or femoral trochlea as opposed to an area of the native knee. The procedure is routinely performed through a medial or lateral parapatellar arthrotomy, but similar to OAT it is a technically demanding procedure as a result of the concave and convex architecture of the patella and trochlea. Torga Spak et al. [41] retrospectively reviewed 14 fresh patellofemoral allografts (11 patients) with average follow-up of 10 years. At last follow-up, eight grafts were in place, four for more than 10 years and two for more than 5 years. Of the nonsurviving allografts, three

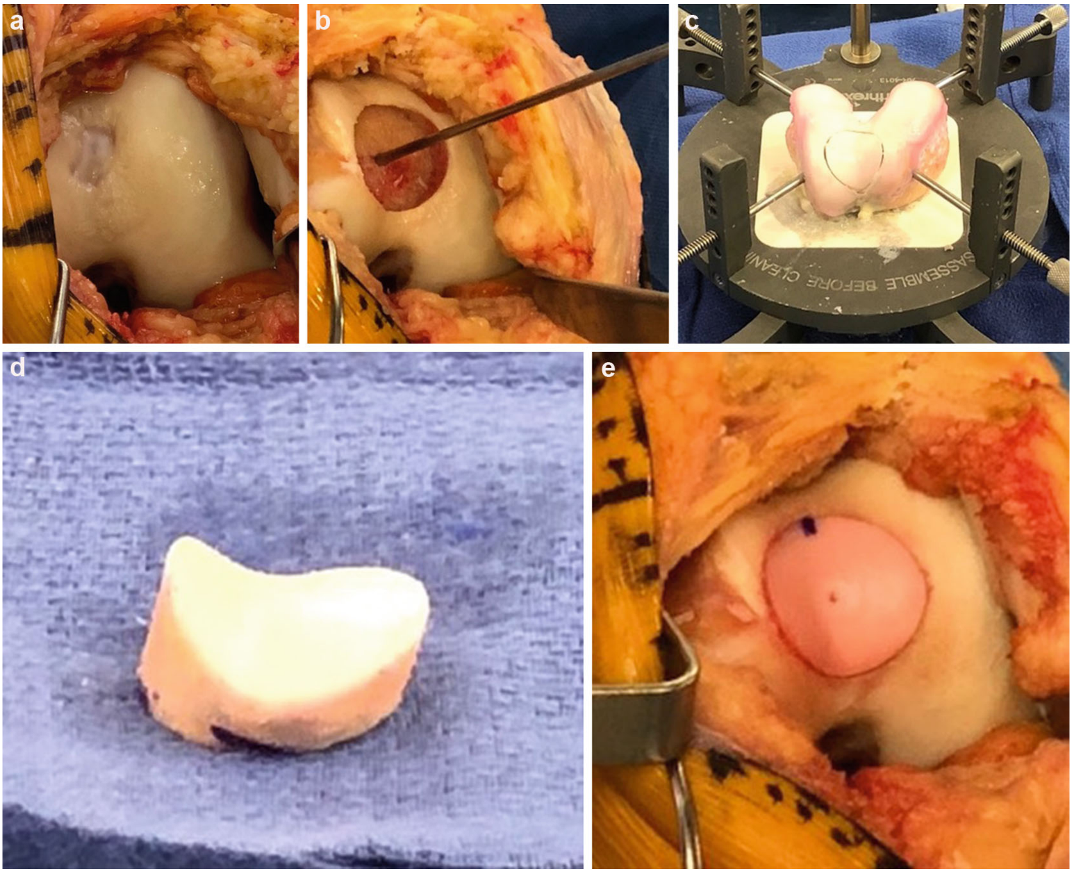

Fig. 3 Photographs of a knee with an osteochondral defect of the femoral trochlea that was treated with osteochondral allograft transplantation: (**a**) Intraoperative photograph of an osteochondral defect of the femoral trochlea; (**b**) intraoperative photograph taken after preparation of the osteochondral defect shows removal of unhealthy cartilage and underlying subchondral bone; (**c**) clinical photograph of a fresh distal femur allograft that was used to obtain an osteochondral allograft cylinder; (**d**) clinical photograph of the donor osteochondral allograft cylinder; and (**e**) intraoperative photograph taken after preparation of the osteochondral allograft transplantation that was performed with the use of the press-fit technique

survived more than 10 years. Ten of the eleven patients in the study stated that they would have the procedure again. Jamali et al. [42] experienced a failure rate of 25% and a reoperation rate of 53% in 20 fresh osteochondral allografts (18 patients) used to treat patellofemoral lesions. In a prospective study [43] involving 28 knees in 27 patients treated with OCA for isolated full thickness patellar injuries, survivorship was 78.1% at 5 and 10 years and 55.8% at 15 years. A high percentage (60.7%) of patients had further surgery after OCA, and 8 of the 28 knees (28.6%) were considered failures. Despite the high rate of adverse outcome, 89% (20 of 28) of the patients who did not suffer a failure stated that they were extremely satisfied or satisfied with the results of surgery. The authors admitted that the outcomes in their study were inferior to the published outcomes following OCA for femoral condyle injuries. In a systematic review involving 19 studies, Chahal [44] and colleagues reported a similar trend and concluded that patellofemoral defects treated with OCA resulted in inferior results compared with treated tibial and femoral condyle lesions. Similarly, Familiari et al. [45] concluded that patellar lesions treated with OCA were associated with worse survival rates compared to femoral condyle lesions. Despite the historic inferior survivorship of PF grafts compared to femoral condyle grafts, newer promising studies have emerged. Mirzayan et al. [46] prospectively collected data on 18 patients with bipolar PF chondral lesions who underwent OCA transplantation of the patella and trochlea. At average follow-up of 33.2 months, there were significant improvements in all PRO measures (KOOS, IKDC, Tegner-Lysholm, Oxford, Cincinnati, VAS, and SANE) and 100% graft survivorship. In another study, Lin et al. followed 25 patients with symptomatic patella cartilage defects who were treated with OCA transplantation of the patella using nonorthotopic femoral condyle grafts [47]. At an average follow-up of 46.5 months, significant improvements were noted in IKDC, KOS-ADL, and VAS with 100% graft survivorship. In addition, MRIs obtained at a mean of 11.4 months postoperatively demonstrated full osseous incorporation and good restoration of the articular surface. In a case series [48] consisting of 29 knees in 28 patients who were treated with OCA transplantation to the femoral trochlea, graft survivorship was 100% at 5 years and 91.7% at 10 years. Although these preliminary short- and mid-term studies are encouraging, longer follow-up reporting will be important to determine long-term outcomes and survivorship.

3.2.6 Autologous Chondrocyte Implantation

Autologous chondrocyte implantation is a surgical option for medium to large (>2–4 cm^2) chondral defects of the patellofemoral joint. As opposed to osteochondral autograft and allograft procedures, ACI allows for improved ability to match the native morphology of patellofemoral chondral surfaces. It is a two-stage procedure consisting of initial arthroscopic cartilage biopsy, 4–6 weeks of in vitro chondrocyte expansion, followed by reimplantation. The current third-generation technique (Matrix-Induced Autologous Chondrocyte Implantation, MACI) consists of expansion and direct in vitro seeding of the chondrocytes onto the type I/III collagen membrane. This allows for fixation of the implant to the subchondral bone with fibrin glue and an even distribution of chondrocytes on the membrane. The implantation procedure is most commonly performed through an open or mini-open approach, but select trochlea defects may be amenable to an arthroscopic approach (Fig. 4). At the time of implantation, the defect is identified and outlined using a scalpel or proprietary cutters, establishing a stable rim of surrounding cartilage. Ring curettes are used to remove all remaining unhealthy cartilage within the contained defect while making sure not to penetrate the subchondral plate. The defect is then traced on sterile material (glove paper or foil) in order to create a template for the MACI implant. Alternatively, proprietary instruments can be used to efficiently size and cut the implant to match the size and shape of the prepared defect. After trimming the graft to the desired size and shape, a thin layer of fibrin glue is applied to the base of the defect. The implant is placed cell-seeded side face down within the defect, and digital pressure is used to ensure fixation to the underlying subchondral bone (Fig. 5). It is important that the MACI implant lay within the base without extending beyond or over the surrounding articular margins. Using the first-generation technique, Peterson's

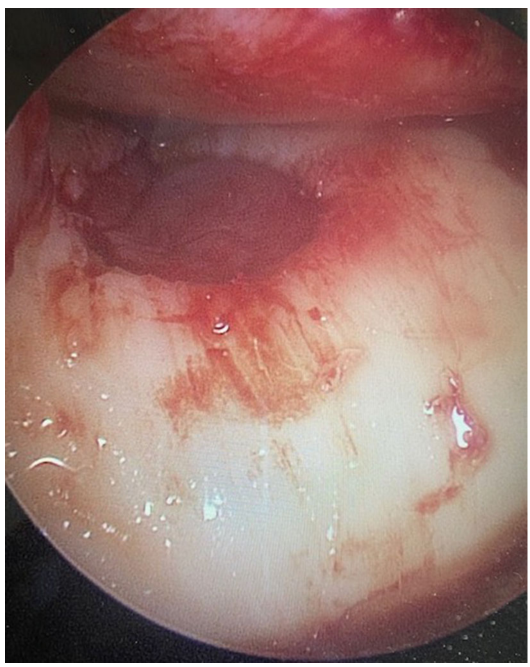

Fig. 4 Arthroscopic view of full-thickness cartilage defect of the femoral trochlea treated with MACI

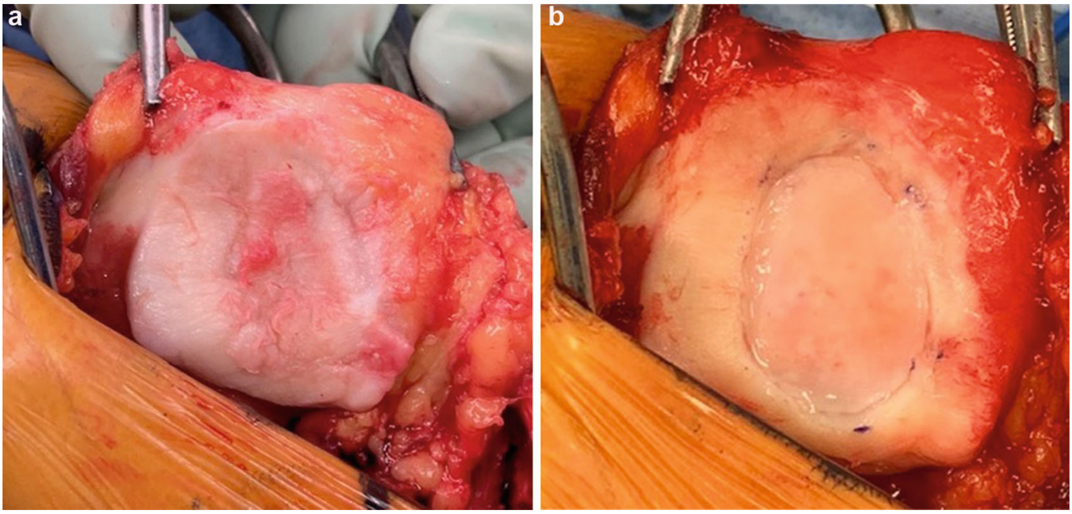

Fig. 5 Intraoperative photographs of a knee with a patellofemoral defect that was treated with MACI: (**a**) Photograph shows a large chondral defect of the patella; (**b**) photograph shows the patella after MACI

[49] early results with ACI for the patella were disappointing with 65% good to excellent results compared to 92% for isolated femoral condyle lesions at 2- to 9-year follow-up. However, since then an improved understanding of patellofemoral biomechanics and anatomy has led to more favorable results in the patellofemoral compartment. In a large multicenter study, Gomoll et al. [50] presented 110 patients treated with ACI for cartilage defects of the patella and followed for at least 4 years. The patients as a group experienced statistically significant and clinically important improvements in all physical outcome scales. The IKDC scores improved from 40 to 69, modified Cincinnati scores from 3.2 to 6.2, and the WOMAC scores from 50.4 to 28.6. Of importance, 92% of patients stated they would undergo the procedure again while 86% rated their knees as good or excellent at final follow-up. In a comparison study [51], similar clinical and radiographic outcomes were obtained in patients who underwent MACI in the patellofemoral joint compared to patients treated with MACI for medial femoral condyle (MFC) defects. A total of 194 patients were included (127 TF and 67 PF), assessed with several PRO measures (KOOS, SF-36, MCS, PCS, and VAS), and followed for 2 years. At final follow-up, 93.7% of TF and 91% of PF patients were satisfied with the ability of MACI to relieve their knee pain and MRI composite score was good/excellent in 77% TF patients and 81% PF patients. It is important to note that preoperative KOOS ADLs and QOL subscales were worse for the PF group compared to the TF group. Furthermore, many of the PROs were comparable between groups, but a significant group effect did exist for the KOOS subscales of ADLs, sport, and QOL in favor of the TF group. However, since the PF group had lower preop scores they were found to have similar net improvement over time for KOOS ADLs and sport and a larger net improvement for KOOS QOL compared to the TF group. Therefore, the data suggests similar effectiveness of MACI in the PF group for those KOOS subscales despite the lower values at final follow-up. Similarly, favorable outcomes were reached in the patellofemoral joint based on a large randomized controlled trial [52] comparing MACI to microfracture. In this study, patellofemoral and tibiofemoral patients were found to have similar KOOS subscale results following MACI and overall superior scores to patients who underwent microfracture. As a result of the encouraging outcome studies and improved ability to recreate complex surface architecture, MACI has become a popular technique of choice to treat cartilage defects in the patellofemoral compartment. A recent systematic review [53]

that included 28 studies determined that ACI was the most common restoration technique of the patellofemoral joint. In addition, the authors found a statistically significant increase in the use of third-generation ACI (MACI) while there was a concurrent decrease in the use of microfracture. Similarly, another systematic review [54] reported that chondrocyte cell-based therapy which includes ACI was the most common technique utilized in the PF joint (utilized in 65% of the studies). The authors also discovered a statistically significant higher failure rate associated with osteochondral allograft transplantation compared to the other techniques. In the same way, Andrade et al. [55] reported that ACI was the most commonly performed technique for PF cartilage lesions in their systematic review that included 42 studies. The authors also found a higher failure rate associated with OCA (16%, 9 in 59) compared to ACI (5%, 18 in 330). These trends are most likely attributed to the lack of favorable outcome data following microfracture in the patellofemoral joint while several recent studies have documented great success with ACI. Additionally, ACI allows for surgeons to recreate the surface architecture of the patellofemoral joint with relative ease compared to the more technically challenging osteochondral procedures.

3.2.7 Particulated Juvenile Articular Cartilage

This cell-based procedure can be used to treat patellofemoral defects of any size. Similar to ACI, matching the contour of the native patellofemoral surface is technically easier with this approach compared to OAT or OCA. The product DeNovo® (Zimmer-Biomet Inc., Warsaw, IN) consists of small, minced pieces of juvenile articular cartilage allograft obtained from donors 13 years of age or younger. These cartilage pieces are applied to a prepared defect in a monolayer and attached via fibrin sealant (Fig. 6) [56]. The advantages of the technique include being a single stage procedure, absence of donor site morbidity, and relative simplicity compared to other more technically challenging cartilage-restoring procedures. Tompkins et al. [57] treated 15 (two bilateral lesions) patella chondral defects in 13 patients

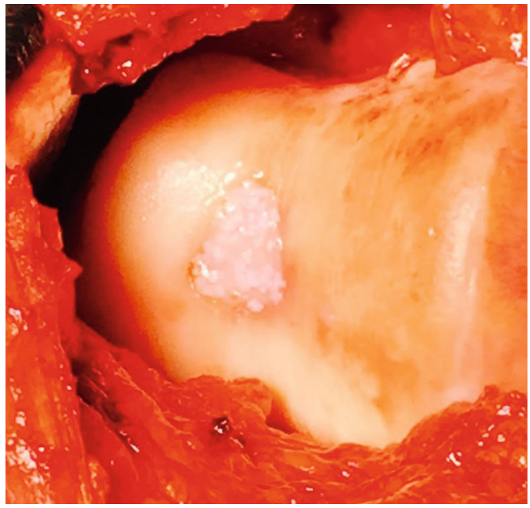

Fig. 6 Intraoperative photograph of the knee of a patient with a femoral trochlear defect that was managed with particulated juvenile articular cartilage

with PJAC. At an average follow-up of 28.8 months, patients demonstrated favorable IKDC, visual analog (VAS), and KOOS scores with a mean fill of the defect of 89% based on MRI. Two patients required knee manipulation under anesthesia for arthrofibrosis, and three patients required reoperation for symptomatic grafts. In another study [58], 27 patients were treated with PJAC for 30 patellofemoral cartilage lesions and followed for a mean of 3.84 years. Statistically significant improvements in both IKDC (45.9 vs 71.2) and KOS-ADL (60.7 vs 78.8) scores were documented with no patients requiring reoperation for graft-related issues. Despite these promising short-term outcome studies, in recent years PJAC has been difficult to get approved by commercial insurances in the United States.

3.2.8 Osteotomy

Tibial tubercle osteotomy (TTO) has been extensively researched for the treatment of patellar instability and patellofemoral disease. The osteotomy most commonly performed involves anteromedialization of the tibial tubercle as described by Fulkerson [59, 60]. Decreased lateral patellofemoral contact pressures following this technique have been proven in the biomechanical

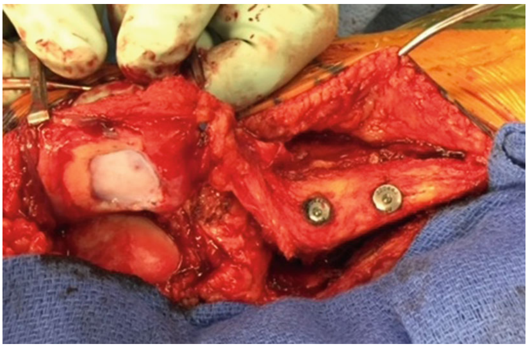

Fig. 7 Intraoperative photograph of a large chondral defect of the lateral patellar facet treated with MACI combined with a tibial tubercle osteotomy

model [61, 62]. As a result, defects of the lateral trochlea or patella are ideal and would have the greatest potential to benefit from TTO (Fig. 7). Several studies have been published regarding the use of osteotomy in conjunction with cartilage repair in the patellofemoral joint. Peterson's [49] early results with ACI for the patella were disappointing and revealed only two of seven patients (29%) with good to excellent results. Realignment procedures were then performed when needed in the later 14 patients in this series, resulting in 11 of 14 patients (79%) with good to excellent results. Since then, strict attention has been given to patellofemoral malalignment. Henderson et al. [63] compared patellar ACI with concomitant extensor realignment to ACI with normal patellar tracking. They found superior modified Cincinnati knee scores, better function, better SF-36 scores, and higher IKDC scores in the realignment group. They conclude their paper by stating that an unloading osteotomy could be desirable in selected patients with normal patellofemoral biomechanics to improve outcome. However, both groups included a substantial number of patients with lateral patellar facet defects, which would be expected to respond strongly to an unloading osteotomy, amplifying differences between groups. In another study, Pascual-Garrido et al. [64] determined that combined ACI with anteromedialization improves outcomes more than ACI alone. Gillogly et al. [65] reported good to excellent results in 83% of patients after ACI and anteromedialization of the tibial tubercle at a mean of 7.6 years. Only one patient in this series underwent patellofemoral arthroplasty at 5.9 years. A systematic review [66] showed significantly greater improvements in multiple clinical outcomes in patients undergoing ACI combined with osteotomy compared to ACI alone for patellofemoral chondral defects. On the contrary, no significant difference was noted between patients treated with and without TTO at the time of patellofemoral ACI in a large, multicenter study [50]. The authors pointed out, however, that most of the defects were pan-patellar, which would respond less to TTO, and that overall the use of concomitant TTO was quite high (70%). They stressed that TTO is indicated to normalize an abnormal biomechanical environment and concluded that the outcome of patellar ACI was similar to that in the femoral condyle. Patellar instability must be addressed in patients being treated with cartilage restoration for patellofemoral chondral defects. Therefore, TTO should be considered in patients with an elevated TT-TG distance (>15-19 mm) and patellar instability. Combined lateral retinacular lengthening is commonly performed at the time of TTO. Concomitant MPFL reconstruction can be performed in select patients. Typically, these patients will have an acute or chronically disrupted MPFL and intraoperative evidence of continued lateral maltracking or instability despite distal realignment and lateral retinacular lengthening. In the absence of an elevated TT-TG distance (<15 mm), isolated MPFL reconstruction or trochleoplasty is an option.

3.2.9 Newer Developing Techniques

Currently available cartilage-restoring procedures each is plagued by specific limitations, which has led to increased interest in developing biologic solutions in the form of allografts, orthobiologic agents, and various scaffolds. A cell-based cartilage repair procedure has been described utilizing a hyaluronic acid-based scaffold embedded with bone marrow aspirate concentrate [67]. A series of 23 patients with large chondral defects (median 6.5 cm^2) of the knee were treated with this technique and followed for a mean of 8 years. At final follow-up, statistically significant improvements in Tegner, VAS, IKDC, and KOOS scores were reached. A subgroup analysis was not performed based on location of defect, but the authors did state that patients treated for multiple lesions had comparable outcomes to those treated for single lesions and that those who underwent multiple compartment treatment had comparable outcomes to those who underwent single compartment treatment. Other available treatment options with a lack of data to support their clinical efficacy include human umbilical cord blood-derived mesenchymal stem cells (CARTISTEM; Medipost, Seongnam-si, Gyeonggi, Korea), viable cartilage allograft putty (CartiMax; ConMed, Largo, FL), cryopreserved osteochondral allografts (Cartiform; Arthrex, Naples, FL / Prochondrix; Stryker, Kalamazoo, MI), and aragonite biphasic osteochondral scaffolds (Agili-C; CartiHeal, Kfar Saba, Israel).

3.2.10 Patellofemoral Resurfacing

Patellofemoral arthroplasty is a primary surgical option for advanced diffuse patellofemoral degeneration and as a salvage option for failed cartilage procedures. Historically there was a high failure rate and mediocre results associated with the procedure, but newer implant design and techniques have significantly improved outcomes and implant survivorship [68].

4 Conclusion

In summary, cartilage repair in the patellofemoral joint remains a challenge to surgeons, but an improved understanding of the biomechanics and anatomy has led to improvements in outcome and longevity of the procedures. Debridement is useful to provide temporary pain relief and reduce mechanical symptoms especially as a result of small defects. Marrow stimulation can be considered for small defects, but results in the patellofemoral joint have been shown to be inferior to those of the tibiofemoral joint with a high likelihood of deterioration after 2 years. Osteochondral autograft transfer provides mature hyaline cartilage but is ideally reserved for lesions amenable to one plug and has potential for donor site morbidity. Osteochondral allograft transplantation can be used to address large osteochondral defects and revise failed prior cartilage repair procedures, although its use in the patellofemoral compartment is complicated by the difficulty matching the varied anatomy. Autologous chondrocyte implantation can more easily address patellofemoral defects of any size but requires intact subchondral bone and requires two-staged procedures. Associated procedures such as tibial tubercle osteotomy, medial patellofemoral ligament reconstruction, lateral lengthening, and trochleoplasty should be considered based on anatomic and dynamic patient-specific factors. Increasing interest in orthobiologic and synthetic adjuvants have resulted in newer techniques and products that have become available as well as many others that are in the early stages of development. Although many preliminary studies show promising results, additional high-level randomized controlled trials are needed to further evaluate safety and efficacy.

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