Management of Patellofemoral Chondral Injuries

Adam B. Yanke, MD*, Thomas Wuerz, MD,
Bryan M. Saltzman, MD, Davietta Butty, BS, Brian J. Cole, MD, MBA

KEYWORDS

• Articular cartilage • Patellofemoral • Autologous chondrocyte implantation
• Osteochondral allograft • Microfracture • Patellofemoral chondral defects
• Tibial tubercle osteotomy • Articular cartilage techniques

KEY POINTS

- Proper clinical indications is the keystone to successful outcomes in patellofemoral cartilage lesion treatment.
- Overlooking an unloading or realignment osteotomy may lead to clinical failure.
- There is limited data to recommend microfracture of the patellofemoral joint.
- Improved reliability in surgical treatment is seen with: low BMI, pain for less than a year, objective effusions, and no prior surgery.

INTRODUCTION: NATURE OF THE PROBLEM

Patients can develop patellofemoral pain for several reasons, including acute trauma and overuse injuries. The underlying cause may be rooted in a chondral defect. In the professional athlete, the prevalence of patellofemoral defects was 37%, with 64% of these being patellar.[1] Similar findings have been described in patients undergoing routine knee arthroscopy, with patellar lesions present in 36% of knees.[2]

Despite the relatively high prevalence of incidental lesions, no data exist to support prophylactic treatment. Although chondral lesions may progress in size,[3] clinicians should focus on short-term improvement in patient symptoms, including objective findings, such as swelling.

Department of Orthopedic Surgery, Rush University Medical Center, 1611 W Harrison Street, Chicago, IL 60612, USA
* Corresponding author.
E-mail address: basworth@mac.com

Clin Sports Med 33 (2014) 477–500
http://dx.doi.org/10.1016/j.csm.2014.03.004 sportsmed.theclinics.com

Although patellofemoral defects are commonly associated with valgus malalignment or patellar instability, this review focuses on the treatment of the defect itself. Associated osteotomies and their role are also included; however, the general treatment of patellar dislocations is not covered.

HISTORY

Successful treatment hinges on accurate diagnosis, which can be obtained from a thorough history and physical examination. Factors that can modify patient outcome are workers' compensation status, and previous surgery. Body mass index (BMI, calculated as weight in kilograms divided by the square of height in meters) may not have the same role in progression of patellofemoral defects as it does in tibiofemoral defects.[4] Typically, patients complain of anterior knee pain that is deep to the patella, and patients gesture with 1 finger to the patella or describe a band inferior to the patella adjacent to the infrapatellar fat pad. Trochlear lesions can also cause posterior knee pain. Symptoms are exacerbated by going down stairs, which requires the most knee flexion of activities of daily living. Stairs also place the largest load on the patellofemoral joint, causing symptom flares. Running, jumping, kneeling, and squatting also exacerbate pain. Patients also describe the movie theater sign, in which anterior knee pain is increased after prolonged sitting. Symptoms are typically not worsened with walking on level ground.

Although these are classic symptoms, a history of knee swelling and symptoms caused by a traumatic event is more focal and indicates a true lesion. The duration of pain should be evaluated, because patients with more acute onset and shorter duration of symptoms are more likely to have predictable pain relief. Catching, popping, or clicking that is not associated with true mechanical symptoms or pain isolated to these events are nonspecific and unlikely to be addressed successfully with surgery.

If the patient has a history of patellar instability, the clinician should be diligent to determine if pain and discomfort are present when the knee is stable or only when dislocation/subluxation events occur. If it is the former, there is a possibility that a chondral defect is the culprit. However, our preference is not to treat lesions that are found incidentally in patients with symptoms related only to instability events. This history is not always clear; therefore, using a patellar stabilization brace can aid patients in determining if instability is the inciting factor. Similarly, a positive yet transient response to an intra-articular injection can correlate with improved response to foretell the response that a patient might have to a cartilage procedure.

Nonoperative management should include injections and bracing, as discussed earlier. However, the mainstay of treatment is physical therapy, which includes quadriceps strengthening, peripatellar mobilization, core strengthening, abductor strengthening, and physiotaping. Antiinflammatories in conjunction with an injection can also decrease the effect of the inflammatory cascade. This treatment should be continued for 6 weeks to 6 months, depending on the patient's response. Continued pain in the setting of normal range of motion and symmetric thigh circumference are concerning for failure of nonoperative management.

PHYSICAL EXAMINATION

- General
  - Gait (antalgic, Trendelenburg, in-toeing)
  - Lower extremity alignment

    - Q angle (anterior superior iliac spine–central patella–tibial tuberosity): male: $14 \pm 3^\circ$, female: $17 \pm 3^\circ$[5]
      - Measure at 0° and 30° of flexion when patella is engaged in the trochlea
    - Femoral anteversion
- Inspection
  - Patellar tracking with flexion and extension
  - If J sign is present, determine at what degree of flexion it occurs
    - Hold medializing force on the patella during knee range of motion to determine if improved symptoms of instability
      - Improvement of symptoms is most likely related to medial patellofemoral ligament laxity opposed to lateral contracture[6]
  - Vastus medialis atrophy and thigh circumference difference
- Palpation
  - Joint effusion
  - Patellar tilt, translation, and apprehension
  - Patellar grind test and crepitus
  - Decreased range of motion
  - Iliotibial band contracture
  - Provocative maneuvers (deep squat, laterally directed patellar force with knee range of motion)

INDICATIONS/CONTRAINDICATIONS

Indications and contraindications are listed in **Boxes 1–4**.

SURGICAL TECHNIQUE/PROCEDURE

- Preoperative planning
  - Radiographs
    - Standing anteroposterior, Rosenberg posteroanterior (45° of flexion), lateral and sunrise or Merchant view (45°–60° of flexion)
    - 30° flexion views of the patellofemoral joint are best to assess patellar maltracking and condylar dysplasia
    - Lateral view to asses for patella alta (Blumensaat line, Blackburn-Peel, or Insall-Salvati methods)
    - Standing mechanical axis in the setting of instability
  - Advanced imaging
    - Magnetic resonance imaging (MRI)

Box 1
General indications for cartilage restoration

- Characteristic anterior knee pain
- Pain not always associated with instability
- Failure of aggressive nonsurgical management
- Joint effusions
- Corresponding lesion on radiographs with possible bone marrow edema
- Positive response to injection even if temporary
- Outerbridge grade III to IV lesion

Box 2
Relative contraindications for cartilage restoration

- Increased BMI
- Worker's compensation
- Significant bone marrow edema at the time of surgery
- Radiographic evidence of joint space narrowing (Kellgren Lawrence grade III–IV)

        - Axial T1 and T2 useful for detecting effusions and to evaluate the patellofemoral chondral surface
        - Axial T2 evaluation for subchondral edema
        - Axial view for trochlear dysplasia or lateral patellar facet prominence
        - The TT-TG distance can be measured on axial views, with normal being ~15 mm and 50% of patients with symptomatic patellofemoral disease have TT-TG greater than 20 mm, whereas this is true in only 5% of asymptomatic knees (**Fig. 1**)[7]
        - Sagittal views aid in determining proximal/distal aspect of the lesion and evaluation of the suprapatellar pouch for loose bodies
        - Determine presence of acute chondral or osteochondral fragment associated with patellar dislocation
        - Remainder is important to rule out any concomitant disease
    - Computed tomography
        - Similar to MRI, the TT-TG distance can be measured on axial views
- Preparation and patient positioning
    - Supine on operating table
    - Bump placed under the operative hip is optional based on alignment
    - Tourniquet (we prefer to use throughout the procedure)
- Surgical approach
    - Arthroscopy should be performed using an inferolateral and inferomedial parapatellar portal with an optional outflow portal
        - Because these lesions are rarely treated primarily unless debridement or microfracture is performed, arthroscopy should be performed first for appropriate staging and possible cartilage biopsy
    - Three incisions can be chosen based on the likelihood of an isolated cartilage procedure, isolated osteotomy, or combined treatment (**Fig. 2**)
        - Incision is based centrally parallel to the tibial crest from the proximal pole of the patella to the 5 to 7 cm distal to the tibial tuberosity

Box 3
Indications for tibial tubercle (TT) osteotomy

- Symptomatic patellar or bipolar lesion
- Lateral or central patellar defect
- Direct anteriorization for isolated central/medial defect
- Patellar instability with increased TT–trochlear groove (TG) distance
- Patella alta
- Failed primary cartilage procedure with proper indication/technique

Box 4
Guidelines for specific cartilage procedures

Debridement

- Large flap component
- Not indicated for incidental lesions
- Lesions staged to undergo autologous chondrocyte implantation (ACI)

Microfracture

- Low demand
- Unipolar (trochlea>>patella)
- Lesion size less than 2 to 3 cm^2
- Augmentation of other cartilage procedures

Osteochondral allograft/autograft

- High demand
- Lesion size smaller than 3 cm^2 or lesions larger than 3 cm^2 with bone loss
- Revision of failed cartilage procedure

Cell-based cartilage therapies (ACI [Carticel, Genzyme, Cambridge, MA], DeNovo NT [Zimmer, Warsaw, IN])

- Lesion size greater than 3 cm^2 without bone loss
- Bipolar lesions are a relative contraindication
- Minimal bone marrow edema at time of treatment

- ○ We prefer a lateral versus medial arthrotomy
  - ▪ Increased ability to access the patellofemoral joint without entering the quadriceps (vastus lateralis relatively more proximal than the vastus medialis)
  - ▪ The arthrotomy is closed only proximal to the superior pole of the patella to act as a lateral release

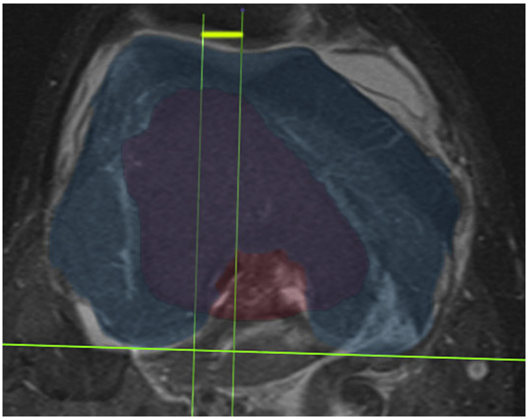

Fig. 1. The TT-TG distance as measured on MRI. Starting with a line perpendicular to the posterior condylar axis, a second line is drawn parallel to this through the TG. The distance between these 2 lines (*yellow line*) represents the TT-TG distance.

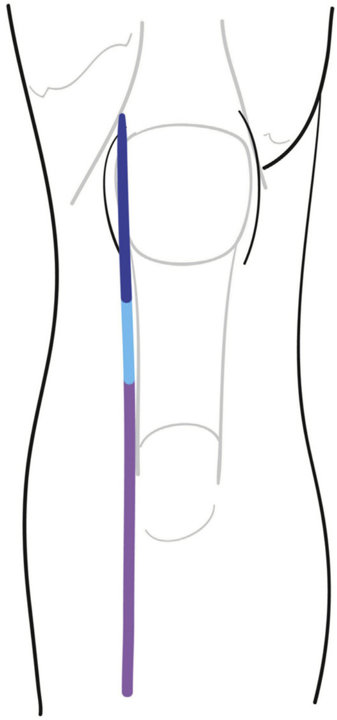

Fig. 2. The lateral-based skin incision for the surgical approach to address isolated cartilage lesions (*blue*), isolated osteotomy (*purple*), or both (*entire line*). The actual deep arthrotomy can be undermined up to the muscle belly of the vastus lateralis to aid in patellar eversion.

- Dissection for combined osteotomy and cartilage treatment
- Superficial dissection
- The skin incision is made sharply, with soft tissue flaps developed above the fascia both medially and laterally, with adequate exposure to the tibial crest, the medial and lateral extent of the patellar tendon, and the medial and lateral portion of the patella, if a medial imbrication and lateral arthrotomy are to be performed
- The fascia is then incised over the anterior compartment along the lateral crest of the tibia with a Bovie and continued proximally along the lateral aspect of the patellar tendon (Fig. 3)
  - If the osteotomy is performed in conjunction with a cartilage procedure, this is carried proximally to the vastus lateralis to allow for patellar eversion or trochlear access
- Use a Bovie to release the tissue medial to the patellar tendon and continue this distally until it converges at the tip of the osteotomy fragment, leaving a periosteal hinge
- Use a Kelly clamp to ensure that the patellar tendon is freely mobile

- Deep dissection
  - The anterior compartment is then elevated off the tibia subperiosteally so that the posterior aspect of the tibia can be palpated with the surgeon's finger
    - Depending on the osteotomy system used, the surgeon should ensure that a retractor such as a Chandler can fit to protect the neurovascular bundle (anterior tibial artery and deep peroneal nerve)

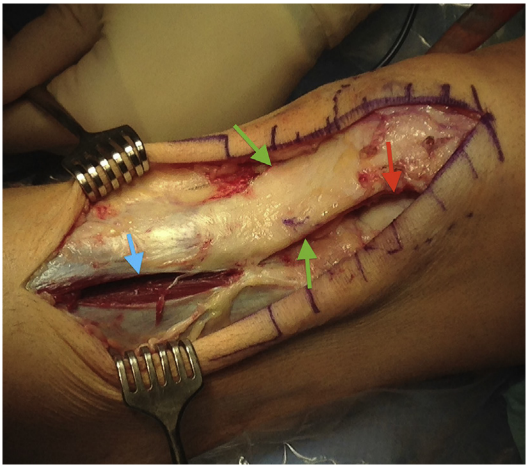

Fig. 3. Superficial dissection to perform both open cartilage restoration procedure and osteotomy. The arthrotomy is created laterally (*red arrow*), with the patellar tendon being freed both medially and laterally (*green arrows*). Distally, the fascia to the anterior compartment is released (*blue arrow*).

    - Plan for the osteotomy to exit near the ridge anterior to the posterior aspect of the tibia
- Osteotomy
  - If performed in conjunction with a cartilage procedure, osteotomy should be performed first to aid in eversion of the patella
  - The exact technique of osteotomy formation varies based on the system used; here, the Arthrex (Naples) T3 system is discussed
    - Regardless of the system, most allow either a guide-based or freehand 45°, 60°, or 90° cut
    - We prefer the 60° cut in almost all instances to allow for 1 mm of medialization for every 2 mm of elevation
    - Typically, the osteotomy is translated 1 cm
  - Using a guide pin placed through the tibial tuberosity and perpendicular to the extremity long axis, the guide is used to prepare the osteotomy location
    - The proximal portion of the guide should start at the medial aspect of the patellar tendon, with the distal aspect just medial to the anterior aspect of the tibial crest
  - The jig should be provisionally fixed, and the osteotomy is performed with careful attention to prevent exit posterior to the tibia (Fig. 4)
    - Some systems allow for placement of a drill bit before osteotomy creation to ensure that the exit point is anterior to the posterior aspect of the tibia
    - The cuts should be made through the cortical portion of the tibia distally, with the proximal, metaphyseal portion finished with an osteotome
    - All attempts should be made to leave a distal hinge intact for osteotomy rotation
  - After the cartilage restoration procedure is completed, this can be provisionally fixed with a Kirschner wire and final fixation is performed with either 2 4.5-mm or 3 3.5-mm cortical screws
    - Care should be taken to use proper Arbeitsgemeinschaft für Osteosynthesefragen (AO) technique and countersink the screw heads to decrease prominence and decrease the chance of requiring a screw removal later

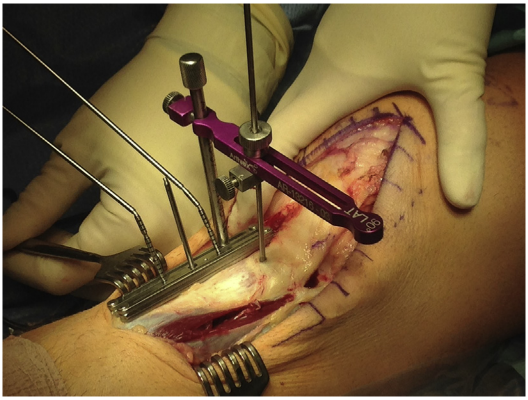

Fig. 4. The TT osteotomy is performed with the initial guide pin placed through the TT. The alignment arm (in this case set to 90°) is then attached to aid in placement of the cutting block.

- ○ Any prominent osseous ridge medial or lateral should be filed or sawed so there is no prominence
  - ▪ Sterile bone wax can be used for a similar purpose and to decrease bleeding
  - ▪ The tourniquet should be deflated at this point if used to control bleeding
- Cartilage restoration procedure
  - ○ Microfracture
    - ▪ Equipment: microfracture awl or drill, curette
    - ▪ Microfracture can be performed through an open or arthroscopic technique; if performed arthroscopically, care should be taken that angled awls are available to allow for perpendicular access to the subchondral bone
    - ▪ The defect should initially be defined by removing all remaining diseased cartilage to the level of the calcified cartilage layer; this can be performed with a combination of a scalpel and curette; care should be taken to create vertical borders around the periphery of the defect of healthy hyaline articular cartilage
    - ▪ The calcified cartilage should then be removed, with care taken not to penetrate the subchondral bone
    - ▪ Using a microfracture awl or drill, the subchondral bone is penetrated, starting at the periphery of the defect, moving centrally, with 2 to 3 mm between perforations; care should be taken not to cause fracture of the region of the subchondral bone between microfracture sites (Fig. 5)
    - ▪ After completion, the inflow can be let down to ensure that subchondral bleeding is present from the microfracture sites
  - ○ ACI (second generation)
    - ▪ ACI requires 2 separate procedures, with the initial procedure involving harvest of 200 to 300 μg of full-thickness cartilage from the intercondylar notch for expansion (6–12 weeks)
    - ▪ Performed though an open exposure, the patellar or trochlear defect should be prepared as in the microfracture protocol with regard to creating vertical walls at the periphery and debridement of the calcified cartilage layer
    - ▪ The surgeon should ensure that no bleeding is present at this stage with the tourniquet down; if there is bleeding, fibrin glue can be pressed into the defect to decrease bleeding

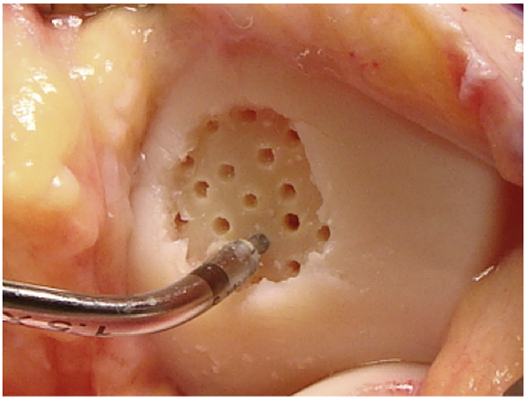

Fig. 5. Patellar microfracture as performed with a drill. Note the well-defined, vertical walls, with even spacing of the microfracture holes.

- First-generation ACI required usage of a periosteal patch, which resulted in a 30% reoperation rate; this has been improved with off-label usage of a type I/III synthetic collagen patch (Bio-Gide; Geistlich Pharma AG, Wolhusen, Switzerland); although we use this method in clinical practice, it cannot officially be recommended because of lack of US Food and Drug Administration approval
  - One vial of cells can be placed on the patch before insertion to allow chondrocyte adherence
  - The patch should be sewn to the periphery using a 6-0 Vicryl on a cutting needle (Ethicon, Somerville, NJ) spaced evenly (approximately 2 mm apart)
  - Care should be taken not to penetrate the patch multiple times for a given suture, and the needle should be passed from the patch to the cartilage
  - Leaving a small opening at the superior portion of the patch, place fibrin glue at the periphery of the patch; after this dries, place a small angiocatheter with a saline-filled syringe to test for a watertight seal and add sutures or fibrin where any deficiencies are present
  - Then use the angiocatheter to inject the remaining cells under the patch, followed by a final suture and fibrin glue layer (**Fig. 6**)
- DeNovo NT (Zimmer)
  - Usage of DeNovo NT, an off-the-shelf source of particulated juvenile articular cartilage, can also be used in the setting of an Outerbridge grade III/IV of the trochlea or patella
  - The defect is prepared in a similar fashion to ACI before the patch is placed
  - At this stage, the DeNovo NT tissue is mixed with fibrin glue and placed in the defect site (**Fig. 7**)
- Osteochondral allograft
  - Equipment: Arthrex osteochondral allograft tray, open orthopedic tray, pulsatile lavage irrigation
  - Perform standard parapatellar arthrotomy
  - Size the defect by placing the cylindrical guide over the defect
  - Mark the 12 o'clock position with a marking pen
  - Place guide pin through the cylinder guide and penetrate 2 cm

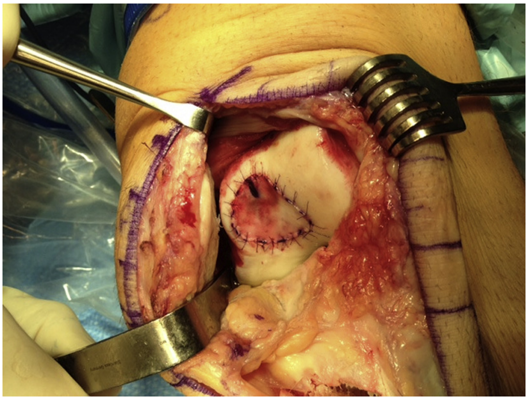

Fig. 6. The finished ACI construct as seen in the trochlea. Note the even spacing of the sutures, with the knots placed on the patch surface. Tension across the patch should be uniform and no dog-ears should be present.

- Remove sizing cylinder and ream with the corresponding size to 6 to 8 mm, decreasing allogeneic load
- Using a small ruler, measure the depth of the hole at 3, 6, 9, and 12 o'clock positions to allow contouring of the allograft to ensure that the graft is not proud or recessed
- Prepare the donor graft using an appropriately sized coring reamer in a similar manner to the recipient site preparation
- After plug removal, adjust the depth of the plug to match the clockface measurements
- The graft is then irrigated with pulsatile lavage to flush out bone marrow elements

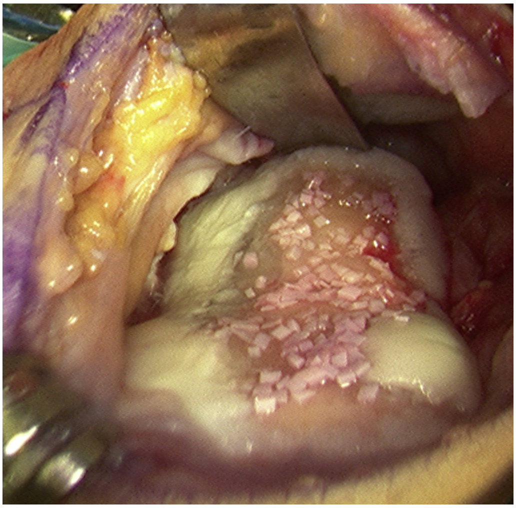

Fig. 7. DeNovo performed in an open manner in the trochlea. The explants are secured with fibrin glue, which is allowed to set before closure.

- Insert the donor plug in a press-fit manner with an oversized tamp
- Err on the side of more frequent, lighter taps, and do not leave the graft proud

COMPLICATIONS AND MANAGEMENT

TT osteotomy
- Symptomatic hardware (removal rate as high as 50%)[8]
- Infection
- Nonunion (increased BMI, smokers, obese)
- Fracture[9]
- Wound complications
- Compartment syndrome
- Peroneal nerve injury
- Deep vein thrombosis

Microfracture
- Intralesional osseous overgrowth
- Possibly obviates further cell-based technology

ACI
- Periosteal patch hypertrophy in first-generation ACI (Fig. 8)

DeNovo NT
- No specific complications

Osteochondral autograft
- Donor site morbidity
- Cyst formation

Osteochondral allograft
- Disease transmission
- Graft resorption

POSTOPERATIVE CARE

Postoperative care is outlined in Table 1.

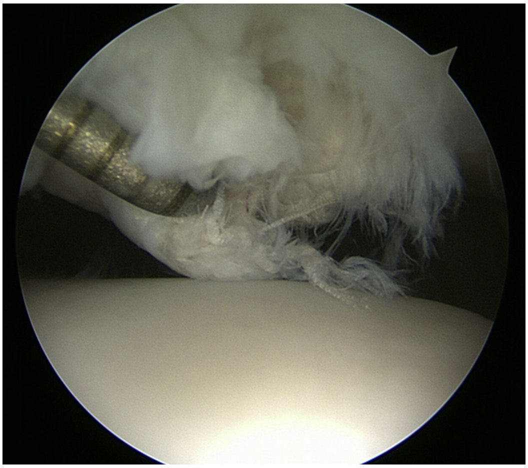

Fig. 8. First-generation ACI was plagued with a second operation rate of about 30% secondary to patch hypertrophy.

Table 1
Patellofemoral cartilage procedure rehabilitation

	Therapeutic Exercise	WB Without AMZ	WB with AMZ	Brace	Range of Motion
Phase I (0–6 wk)	1–6 wk: quad sets, SLR, hamstring isometrics; complete exercises in brace if quad control is inadequate	WB as tolerated	0–6 wk: heel touch with WB (20%)	0–1 wk: locked in full extension (removed for CPM and exercises) 2–4 wk: gradually open brace in 20° increments as quad control is gained; discontinue use of brace when quads can control SLR without an extension lag	0–6 wk: CPM, use for 6–8 h/d; begin at 0°–40°, increasing 5°–10° daily per patient comfort Patient should gain 100° by week 6
Phase II (6–12 wk)	6–10 wk: begin isometric closed chain exercises. At 6–10 wk, may begin weight-shifting activities with involved leg extended if full WB. At 8 wk, begin balance activities and stationary bicycle with light resistance 10–12 wk: hamstring strengthening, theraband 0°–30° resistance, light open chain knee isometrics		6–8 wk: transition to full WB	None	Gain full pain-free motion
Phase III (12 wk–6 mo)	Begin treadmill walking at a slow to moderate pace Progress balance/proprioceptive activities, initiate sport cord lateral drills		WB as tolerated		
Phase IV (6–9 mo)	Advance closed chain strengthening, initiate unilateral closed chain exercises, progress to fast walking and backward walking on treadmill (initiate incline at 8–10 mo), initiate light plyometric activity				
Phase V (9–12 mo)	Continue strength training, emphasize single leg loading, begin a progressive running and agility program. High-impact activities may begin after 12 mo if no swelling or pain				

Abbreviations: AMZ, anteromedialization; CPM, continuous passive motion; SLR, straight leg raise; WB, weight bearing.

OUTCOMES

Microfracture

In an evidence-based systematic review, Mithoefer and colleagues[10] evaluated 28 studies describing 3122 patients who had microfracture surgery for articular cartilage injury in the knee The average postoperative follow-up was 41 $\pm$ 5 months (range, 12–136) with an average age of 39 $\pm$ 10 years (range, 24–65) and an average lesion size of 3.0 $\pm$ 0.8 cm^2 (range, 0.1–20). None of the studies evaluated microfracture results specifically for patellofemoral cartilage defects only. Nineteen of the 28 studies reported on knees with both femorotibial and patellofemoral chondral defects. Microfracture improved knee function in all studies during the first 24 months after surgery. Improvement in knee function was reported in 67% to 86% of patients at an average of 6 to 7 years after surgery. Although 2 studies reported maintained outcomes after 2 years, 7 studies reported deterioration of initial functional improvement in 47% to 80% of patients between 18 and 36 months after the procedure (still better than preoperative). Younger patients, with threshold age varying between 30 and 40 years, resulted in better clinical outcome scores and better repair cartilage fill on MRI. The procedure was also more effective when used as a first-line procedure. These investigators concluded that microfracture provides effective short-term functional improvement of knee function, with limited hyaline repair tissue and possible deterioration over time.[10]

Microfracture was found to be a successful option for the treatment of full-thickness cartilage lesions of the knee (medial or lateral femoral condyle, trochlear, or patella) in a meta-analysis by Negrin and colleagues.[11] These investigators mentioned how numerous publications on microfracture show deterioration over time and that microfracture is ineffective for the treatment of large chondral lesions, better in patients younger than 35 years, and superior for lesions of the femoral condyles than of the patella.

When interpreting the outcomes of microfracture in the patellofemoral joint, it is important to remember that surgical technique plays a large role as well as to address concomitant factors. We believe that microfracture, compared with other cartilage techniques, is performed more frequently in isolation for defects that require concomitant osteotomy, unfairly biasing microfracture outcome data.

ACI

ACI has evolved since its inception, when it was first described using a periosteal patch.[12] Subsequent iterations have been termed as generations. Because this terminology is confounding through the literature, we define each generation as follows: first, covered with periosteal patch, second, covered with synthetic membrane, third, seeded onto a three-dimensional scaffold.[13]

Outcomes of patients with patellar chondral defects treated with first-generation, second-generation, or third-generation ACI were reported by Niemeyer and colleagues.[14] These investigators reported that patients aged 34.3 $\pm$ 10.1 years with 4.41 $\pm$ 2.15 cm^2 defects had favorable outcomes at 38.4 $\pm$ 15.6 months with regard to Lysholm and International Knee Documentation Committee (IKDC) scales. Eighty-four percent of patients believed that their symptoms were better after the operation, with 2.9% feeling the same and 12.9% saying their symptoms were worse. Defects located on the lateral facet had improved outcomes compared with other regions. Trochlear lesions treated with first-generation ACI by Mandelbaum and colleagues[15] showed an improvement in pain and swelling at a mean of 59 months. Of these patients, 43% were receiving workers' compensation. Data are conflicting regarding the effect of previous cartilage procedures on ACI outcome; however, we have not noticed this effect regarding first-generation ACI of the patellofemoral joint.[16] Long-term follow-up of first-generation ACI of the patellofemoral joint at an average of 12.6 years showed maintained improvement of Lysholm and Tegner scores.[17] In this study, although age was not predictive of outcome, kissing lesions had inferior results.

With regard to second-generation ACI, Vanlauwe and colleagues[18] reported that 84% of patients with patellofemoral joint lesions had clinically relevant improvement. Similarly, third-generation ACI of the patellofemoral joint has also yielded promising results at 5 years with the added benefit of arthroscopic implementation.[19] Subset analysis performed by Kreuz and colleagues[20] looked at third-generation ACI in the context of gender and defect location to determine if either influenced the results of the procedure. These investigators determined that all groups (males/females with condylar or patellofemoral defects) improved their clinical scores over the follow-up period; however, the cohort with the worst results was female patients with patellar defects. A retrospective matched-pair analysis compared 10 patients who underwent CaReS technique (third-generation ACI) with those treated with microfracture for patellofemoral lesions ($\sim$3 cm^2).[21] Although the CaReS ACI cohort improved at 36 months, this was not significantly different from the microfracture cohort.

As clinical results of first-generation, second-generation, and third-generation ACI continue to be reported, it is difficult to determine true superiority without adequate randomized controlled trials. In the meantime, systematic reviews have reported marginal improvement of second and third generation over first generation, but longer-term follow-up is necessary.[13]

Osteotomy

The role of the TT osteotomy has long been researched in the setting of patellofemoral disease. Several individual reports have specifically reported improved outcomes in combination with first-generation[8,16,22] and third-generation ACI compared with ACI alone.[23]

Trinh and colleagues[24] performed a systematic review of the literature to compare clinical outcomes of patients undergoing isolated patellofemoral ACI and ACI combined with patellofemoral realignment. Their report included 11 studies (10 level III or IV evidence), with a mean 4.2 years of follow-up, having 78% of defects located on the patella and 23% of which underwent previous or concomitant osteotomy (anteriorization, medialization, or anteromedialization). The ACI procedure was a first-generation procedure in 235 patients (64%) and a second-generation procedure in the remaining 131 patients (36%). Although significant improvements were observed in all studies, analysis showed that patients who underwent ACI and a TT unloading osteotomy had significantly greater improvements and absolute clinical scores (IKDC, Lysholm, Knee Injury and Osteoarthritis Outcome Score, Tegner score, modified Cincinnati score, Short Form 36 score, and Short Form 12 score) than those patients receiving ACI in isolation. Overall complication rates for isolated ACI patients was 15.2% (43 patients), which was not significantly less when compared with the 19% rate in patients undergoing previous or concomitant distal realignment procedures.

Because patients seem to have improved outcomes from the osteotomy aspect of surgery, it is reasonable to question to what extent the cartilage procedure affects the outcome. Atkinson and colleagues[25] reported on 50 isolated TT osteotomy procedures for Outerbridge III-IV defects. Twenty patients with a history of dislocation also received lateral trochlea elevation osteotomies. Ninety-four percent of knees had sustained significant improvement in visual analogue scales at mean 81 months follow-up, with 96% satisfied.

Although osteotomies have a clear role in improving the outcome of patellofemoral chondral defects, level I research is necessary to determine the true usefulness compared with the cartilage restoration procedure. We prefer distal realignment in patients with malalignment, instability, bipolar lesions, and all patellar lesions.

Osteochondral Autograft/Allograft Transplantation

Osteochondral autograft treatment of patellofemoral defects remains an option for salvage procedures and some primary lesions with bone loss (avascular necrosis/osteochondritis dissecans/osteochondral defects).[26] Procedures performed for primary lesions of the patella (average 1.2 cm^2) evaluated 8 months postoperatively showed improved Lysholm scores.[27] Although MRI showed that the autograft surface was flush, 80% had mild bone marrow edema about the graft. Similarly, Karataglis and colleagues[28] reported 86.5% improvement of their preoperative symptoms. Although not performed frequently, osteochondral defects of the patella in patients not willing to undergo treatment with cadaveric tissue can successfully be treated with an osteochondral autograft.

Although limited literature exists on osteochondral allografts for the patellofemoral joint, a recent systematic review by Chahal and colleagues[29] described these outcomes compared with the tibiofemoral joint. Most studies used allografts for posttraumatic defects (38%), osteochondritis dissecans (30%), osteonecrosis from all causes (12%), and idiopathic (11%). With regards to the patellofemoral joint, these investigators concluded that diffuse lesions in this location treated with fresh osteochondral grafting show poorer results compared with lesions in the tibial plateau or femoral condyle.

Jamali and colleagues[30] analyzed osteochondral allograft treatment of the patellofemoral joint with improved pain, function, range of motion, and low risk of progressive arthritis. The high failure rate (25%) and revision surgery (53%) are likely caused by the size of the lesions treated (patella: 7.1 cm^2, range 1.8–17.8; trochlea 13.2 cm^2, range 2.5–22.5). Kaplan-Meier analysis showed a 67% $\pm$ 25% allograft survival probability at 10 years. Patellofemoral resurfacing with shell allografts has been reported by Torga Spak and Teitge.[31] These investigators reported a high failure rate (42%); however, patients who did not fail were satisfied and had improved subjective scores. Three grafts survived for more than 10 years.

Osteochondral allografts and autografts can be successful in unipolar patellofemoral lesions with bone loss in young patients (**Table 2**).

Patellofemoral Arthroplasty

Although not discussed in detail in this review, patellofemoral arthroplasty (PFA) remains an option as a primary procedure for radiographic patellofemoral arthritis or a salvage procedure for failed cartilage procedures. Because data for the latter are lacking, the outcomes of PFA for diffuse patellofemoral arthritis are reported. Data on PFA report that patients do well at 3 to 7 years with regard to pain relief and 88% survival, with 3.6% to 11.6% total knee arthroplasty (TKA) conversion rate.[32–34] Long-term follow-up of the Richards prosthesis at an average of 17 to 20 years showed 86% good to excellent results; however, this was tempered by a 44% rate of surgical revision for disease progression and 31% conversion rate to TKA.[35,36]

A systematic review of the literature on PFA was completed by Tarassoli and colleagues.[37] Poor outcomes were associated with evidence of tibiofemoral osteoarthritis before surgery, BMI greater than 30 kg/m^2, previous meniscectomy, patella

Table 2
Studies of patellofemoral chondral injuries

Procedure Citation	Study Design Cohort (Age, Previous Operation Number)	Defect Size	Follow-up	Results	Concluding Remarks
Microfracture Mithoefer et al,[10] 2009	Systematic review, 28 studies, N = 3122 Coleman Methodology Score: 58 Age 39 ± 10 y Lesions of trochlea, patella, MFC, LFC	Mean 3.0 ± 0.8 cm^2 (range 0.1–20 cm^2)	Mean 41 ± 5 mo (range 12–136 mo)	Knee function improved 67%–86% at 6–7 y Longest study: 32% pain free, 54% mild pain, 14% moderate pain (11 y follow/up) Failure/revision: 2.5% at 2 y, 23%–31% between 2–5 y (in 6 randomized controlled trails)	7 studies reported deterioration of initial functional improvement in 47%–80% between 18–36 mo postoperatively Age <30–40 y: better outcomes and MRI cartilage fill
Microfracture Negrin et al,[11] 2012	Meta-analysis, 5 studies, N = 187 Age 15–60 y	Range 1–10 cm^2	Range 2–5 y	Mean standardized treatment effect: 1.106 Expected increase of 22 overall KOOS points	Decreased outcomes after 18–24 mo Ineffective for treatment of large chondral lesions <35 y improved outcomes LFC/MFC outcomes superior to patella
First-generation ACI Mandelbaum et al,[15] 2007	Prospective cohort study, N = 40 43% workers' compensation Age 37.1 ± 8.5 y 78% previous surgery Lesions of trochlea	Mean 4.5 ± 2.8 cm^2	Mean 59 ± 18 mo	Significant improvements in condition score (3.1 ± 1.0 to 6.4 ± 1.7), pain (2.6 ± 1.7 to 6.2 ± 2.4), and swelling (3.9 ± 2.7 to 6.3 ± 2.7)	First-generation ACI adequately addresses pain, condition, and swelling in trochlear lesions

First-generation ACI Vasiliadis et al,[17] 2010	Retrospective cohort study, N = 92 Age 35 y (range, 14–57)	Mean 5.5 ± 2.9 cm^2	Mean 12.6 ± 2.3 y	Median Tegner score = 2→3 (*P*<.05) Median Lysholm score = 61→70 (*P*>.05) 72% better or unchanged 93% would undergo the operation again Outcomes not affected by age or lesion size	One of the longest clinical follow-up studies for first-generation ACI 93% of patients would undergo surgery again
First-generation ACI Pascual-Garrido et al,[16] 2009	Prospective cohort study, N = 62 Age 31.8 y (range 15.8–49.4)	Mean 4.2 ± 1.6 cm^2	Mean 4 y (range 2–7)	Significant improvement in Lysholm, IKDC, KOOS Pain, KOOS Symptoms, KOOS Activities of Daily Living, KOOS Sport, KOOS Quality of Life, SF-12 Physical, Cincinnati, and Tegner No significant improvement in SF-12 Mental 44% reoperation rate 7.7% failure rate (arthroplasty or conversion to osteochondral allograft)	Outcome was not affected by previous cartilage procedures Patients undergoing AMZ tended to have better outcomes
Second-generation ACI Vanlauwe et al,[18] 2012	Prospective cohort study, N = 38 Age 30.9 y Lesions of patella (28), trochlea (7), or both (3) 84% of patients had previous surgery	Mean 4.89 cm^2 (range 1.5–11 cm^2)	Mean 37 mo (range 24–72 mo)	Significant improvements in KOOS and VAS at 48 mo 84% clinically relevant improvement >10 patients at 3 y 13% failure 24% reoperation	Second-generation ACI yields promising outcomes in the patellofemoral joint at 3 y

(*continued on next page*)

Table 2 (*continued*)

Procedure Citation	Study Design Cohort (Age, Previous Operation Number)	Defect Size	Follow-up	Results	Concluding Remarks
Third-generation ACI Gobbi et al,[19] 2009	Case series, N = 34 Age 31.2 y (range 15–55 y) Lesions of the patella (21), trochlea (9), or both (4)	Mean 4.45 cm^2	5 y	Significant improvement in IKDC, VAS, and Tegner at 2 and 5 y	Third-generation ACI has good results in the patellofemoral joint at 5 y
Third-generation ACI Kreuz et al,[20] 2013	Comparison study (men vs women), N = 25 men; 27 women Age, 35.6 y 20 PF compartment lesions	Males: 7.00 ± 3.7 cm^2 Females: 4.33 ± 1.1 cm^2	Follow-up at 6, 12, and 48 mo	Female PF lesions: Lysholm/ IKDC improved at 6 mo, with continued IKDC improvement Male PF lesions: Lysholm/ IKDC improved at 6 mo with significant improvement at 12 mo also	Male and female patients both improve after third-generation ACI for patellar defects; however, men have greater improvement
First-generation, second-generation, and third-generation ACI Niemeyer et al,[14] 2008	Retrospective study, N = 70 Age 34.3 ± 10.1 y Mean previous operations 1.55 ± 1.4	Mean 4.41 ± 2.15 cm^2	Mean 38.4 ± 15.6 mo	Improved IKDC (61.6 ± 21.5), Lysholm (73.0 ± 22.4), and Cumulated Ambulation Score 61.5 ± 21.5 Symptoms better 84%, same 2.9%, and worse 12.9% 67% normal/nearly normal International Cartilage Repair Society 81.4% would have operation again	Patellar ACI yields good results in 70%–80% of patients

First-generation ACI ± AMZ (73.7% concomitant) Farr,[8] 2007	Prospective study, N = 39 (38 knees) Age 31.2 ± 11.3 y Patella and trochlea	Trochlea: 4.3 ± 1.9 cm^2 (46% of cohort) Patella: 5.4 ± 1.9 cm^2 (36% of cohort) Bipolar: 8.8 ± 3.5 cm^2 (18% of cohort)	Mean 1.2 y	Modified Cincinnati Overall Condition score: median 3-point improvement Lysholm score: median 31-point improvement VAS score resting: median 2-point improvement VAS score maximum: 3-point improvement 25 patients had 32 subsequent surgeries 3 patients failed ACI	Overall condition improved regardless of concurrent AMZ or presence of >1 lesion
First-generation ACI ± AMZ Henderson & Lavigne,[22] 2006	Comparison study, N = 22 per group, lesions of patella	N/A	Mean 2 y	Osteotomy with greater increase in mean modified Cincinnati Knee Score (4.5 vs 1.7 points), better function (1.7 vs 2.5), better SF-36 physical component scores (70.9 vs 55.4 points), higher IKDC scores (85.2 vs 60.6 points)	Patellar ACI with osteotomy has better outcomes than ACI alone, possibly in patient with normal PF biomechanics
Third-generation ACI + distal realignment Gigante et al,[23] 2009	Prospective cohort study, N = 14 knees (12 patients) Age 31 y	Median 4 cm^2 (range 3–9 cm^2)	Mean 3 y	Improved Modified Cincinnati and median Lysholm, Tegner, and Kujala Score 13/14 patients satisfied 50% excellent, 43% good, 7% poor final outcomes	93% of patients with third-generation ACI and osteotomy have good/excellent results

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Table 2
(*continued*)

Procedure Citation	Study Design Cohort (Age, Previous Operation Number)	Defect Size	Follow-up	Results	Concluding Remarks
TT advancement osteotomy ± medialization (50%) ± lateral trochlea elevation osteotomy (25%) Atkinson et al,[25] 2012	Retrospective cohort study, N = 40 Age 29 y (range 17–51 y)	N/A	Mean 81 mo (26–195 mo)	92%–96% satisfied and improved VAS and Shelbourne and Trumper anterior knee function scores 77% excellent/good, 35% fair, 8% poor 2 knees required arthroplasty (18 mo, 8 y) 12% major complications 8% superficial wound infections 44% hardware discomfort	TT osteotomy alone yields promising results at an average of 81 mo This study helps challenge the effect of the cartilage procedure, promoting the need for level I evidence for cartilage restoration with osteotomy
Osteochondral autograft transplantation Figueroa et al,[27] 2011	Retrospective cohort study, N = 10 Lesions of patella	Mean 1.2 cm^2	N/A	Lysholm 73.8 ± 8.36 → 95 ± 4.47 IKDC postoperatively 95 ± 1.74 No postoperative complications MRI: no fissures in graft-receptor interface in 60%, mild bone marrow edema about the graft in 80%	Clinical outcomes scores and advanced imaging show that osteochondral autografts are a viable option for defects with bone loss
Osteochondral autograft transplantation Karataglis et al,[28] 2006	Case series, N = 37 knees Age 31.9 y (range 18–48 y) 26 femoral condyle, 11 patellofemoral joint	Mean 2.73 cm^2 (range 0.8–12 cm^2)	Mean 36.9 mo (18–73 mo)	86.5% reported improvement in their preoperative symptoms and returned to previous occupation 48.6% returned to sports	Although no patellofemoral subset analysis was performed, no correlation was found with respect to lesion size or location

Osteochondral allograft transplantation Chahal et al,[29] 2013	Systematic review, 19 studies; N = 644 knees Age 37 y (range 20–62 y) 20 trochlear and 45 patellar lesions	Mean 6.3 cm^2	Mean 58 mo (range 19–120 mo)	Overall satisfaction rate 86% 65% showed little/no arthritis at final follow-up Short-term complication rate 2.4% Overall failure rate 18%	Osteochondral allografts have inferior results in the patellofemoral joint compared with tibiofemoral lesions
Osteochondral allograft transplantation Jamali et al,[30] 2005	Retrospective cohort study, N = 20 (18 patients) Age 42 y (range 19–64 y) 8 patellar and 12 trochlea/patella	Mean patella 7.1 cm^2 (range, 1.8–17.8 cm^2) Mean trochlea 13.2 cm^2 (range 2.5–22.5 cm^2)	Mean 94 mo (range 24–214 mo)	60% good/excellent 25% failure: revision allograft (2), total knee arthroplasty (2), arthrodesis (1) Radiographs (12 knees): no PF arthrosis (4), mild arthrosis (6) Kaplan-Meier analysis 67 $\pm$ 25% allograft survival probability at 10 y	Osteochondral allografts can yield promising results when successful; however, this study reported poor long-term survival in these large defects
Osteochondral allograft transplantation Torga Spak & Teitge,[31] 2006	Retrospective cohort study, N = 14 knees (11 patients) Age 37 y (range 24–56 y) Mean previous operations, 4.4 2 patellar and 12 patellofemoral	Shell PF grafts	Mean, 10 y (range, 2.5–17.5 y)	6/14 revised to arthroplasty 10 of 11 successes would have procedure again Knee Society Scores 46 $\rightarrow$ 82 Functional Scores 50 $\rightarrow$ 75 Lysholm 27 $\rightarrow$ 80 Mean extension lag 12° $\rightarrow$ 3° Reoperation in 12 of 14 Complications in 4 patients (persistent anterior knee pain, skin rash)	Fresh osteochondral allografts for diffuse PF osteoarthritis can provide limited results, with a 42% failure rate Patients may benefit because of delay of arthroplasty

Abbreviations: AMZ, anteromedialization; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; LFC, Lateral Femoral Condyle; MFC, Medial Femoral Condyle; N/A, not applicable; PF, patellofemoral; SF, Short Form; VAS, visual analogue scale.

alta or baja, and ligamentous instability. The most common reason that they found cited for failure necessitating revision was progression of tibiofemoral osteoarthritis. However, it was concluded that PFA is a less invasive operation, with more rapid postoperative recovery and preservation of bone stock to allow for conversion to TKA at a later date.

SUMMARY

Treatment of patellofemoral chondral defects is fraught with difficulty because of the generally inferior outcomes and significant biomechanical complexity of the joint. Noyes and Barber-Westin[38] performed a systematic review of large (>4 cm^2) patellofemoral ACI (11 studies), PFA (5 studies), and osteochondral allografting (2 studies) in patients younger than 50 years. Respectively, failures or poor outcomes were noted in 8% to 60% after ACI, 22% after PFA, and 53% after osteochondral allograft treatment. As noted in the outcome reviews earlier, unacceptable complication and reoperation rates were reported from all 3 procedures, and it was concluded that each operation had unpredictable results for this patient demographic. This study highlights the importance of strict indications and working to address all concomitant diseases to decrease revision rate. Outcomes are most predictable in young patients with low BMI and unipolar defects lower than 4 cm^2.

REFERENCES

1. Flanigan DC, Harris JD, Trinh TQ, et al. Prevalence of chondral defects in athletes' knees: a systematic review. Med Sci Sports Exerc 2010;42:1795–801.
2. Widuchowski W, Widuchowski J, Trzaska T. Articular cartilage defects: study of 25,124 knee arthroscopies. Knee 2007;14:177–82.
3. Wang Y, Ding C, Wluka AE, et al. Factors affecting progression of knee cartilage defects in normal subjects over 2 years. Rheumatology (Oxford) 2006;45:79–84.
4. Ding C, Cicuttini F, Scott F, et al. Natural history of knee cartilage defects and factors affecting change. Arch Intern Med 2006;166:651–8.
5. Mihalko WM, Boachie-Adjei Y, Spang JT, et al. Controversies and techniques in the surgical management of patellofemoral arthritis. Instr Course Lect 2008;57:365–80.
6. Cole BJ, Gomoll AH, Minas T, et al. Treatment of chondral defects in the patellofemoral joint. J Knee Surg 2006;19:285–95.
7. Dejour H, Walch G, Nove-Josserand L, et al. Factors of patellar instability: an anatomic radiographic study. Knee Surg Sports Traumatol Arthrosc 1994;2:19–26.
8. Farr J. Autologous chondrocyte implantation improves patellofemoral cartilage treatment outcomes. Clin Orthop Relat Res 2007;463:187–94.
9. Pidoriano AJ, Weinstein RN, Buuck DA, et al. Correlation of patellar articular lesions with results from anteromedial tibial tubercle transfer. Am J Sports Med 1997;25:533–7.
10. 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;37:2053–63.
11. Negrin L, Kutscha-Lissberg F, Gartlehner G, et al. Clinical outcome after microfracture of the knee: a meta-analysis of before/after-data of controlled studies. Int Orthop 2012;36:43–50.
12. Brittberg M, Lindahl A, Nilsson A, et al. Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. N Engl J Med 1994;331:889–95.

13. Goyal D, Goyal A, Keyhani S, et al. Evidence-based status of second- and third-generation autologous chondrocyte implantation over first generation: a systematic review of level I and II studies. Arthroscopy 2013;29:1872–8.
14. Niemeyer P, Steinwachs M, Erggelet C, et al. Autologous chondrocyte implantation for the treatment of retropatellar cartilage defects: clinical results referred to defect localisation. Arch Orthop Trauma Surg 2008;128:1223–31.
15. Mandelbaum BR, Browne J, Fu F, et al. Treatment outcomes of autologous chondrocyte implantation for full-thickness articular cartilage defects of the trochlea. Am J Sports Med 2007;35:915–21.
16. 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.
17. Vasiliadis HS, Wasiak J, Salanti G. Autologous chondrocyte implantation for the treatment of cartilage lesions of the knee: a systematic review of randomized studies. Knee Surg Sports Traumatol Arthrosc 2010;18:1645–55.
18. Vanlauwe JJ, Claes T, Van Assche D, et al. Characterized chondrocyte implantation in the patellofemoral joint: an up to 4-year follow-up of a prospective cohort of 38 patients. Am J Sports Med 2012;40:1799–807.
19. Gobbi A, Kon E, Berruto M, et al. Patellofemoral full-thickness chondral defects treated with second-generation autologous chondrocyte implantation: results at 5 years' follow-up. Am J Sports Med 2009;37:1083–92.
20. Kreuz PC, Niemeyer P, Müller S, et al. Influence of sex on the outcome of autologous chondrocyte implantation in chondral defects of the knee. Am J Sports Med 2013;41:1541–8.
21. Petri M, Broese M, Simon A, et al. CaReS (MACT) versus microfracture in treating symptomatic patellofemoral cartilage defects: a retrospective matched-pair analysis. J Orthop Sci 2013;18:38–44.
22. Henderson IJ, Lavigne P. Periosteal autologous chondrocyte implantation for patellar chondral defect in patients with normal and abnormal patellar tracking. Knee 2006;13:274–9.
23. Gigante A, Enea D, Greco F, et al. Distal realignment and patellar autologous chondrocyte implantation: mid-term results in a selected population. Knee Surg Sports Traumatol Arthrosc 2009;17:2–10.
24. Trinh TQ, Harris JD, Siston RA, et al. Improved outcomes with combined autologous chondrocyte implantation and patellofemoral osteotomy versus isolated autologous chondrocyte implantation. Arthroscopy 2013;29:566–74.
25. Atkinson HD, Bailey CA, Anand S, et al. Tibial tubercle advancement osteotomy with bone allograft for patellofemoral arthritis: a retrospective cohort study of 50 knees. Arch Orthop Trauma Surg 2012;132:437–45.
26. Lu AP, Hame SL. Autologous osteochondral transplantation for simple cyst in the patella. Arthroscopy 2005;21:1008.
27. Figueroa D, Meleán P, Calvo R, et al. Osteochondral autografts in full thickness patella cartilage lesions. Knee 2011;18:220–3.
28. Karataglis D, Green MA, Learmonth DJ. Autologous osteochondral transplantation for the treatment of chondral defects of the knee. Knee 2006;13:32–5.
29. Chahal J, Cole BJ, Gross AE, et al. Outcomes of osteochondral allograft transplantation in the knee. Arthroscopy 2013;29:575–88.
30. Jamali AA, Emmerson BC, Chung C, et al. Fresh osteochondral allografts: results in the patellofemoral joint. Clin Orthop Relat Res 2005;(437):176–85.

31. Torga Spak R, Teitge RA. Fresh osteochondral allografts for patellofemoral arthritis: long-term followup. Clin Orthop Relat Res 2006;444:193–200.
32. Ackroyd CE, Chir B. Development and early results of a new patellofemoral arthroplasty. Clin Orthop Relat Res 2005;(436):7–13.
33. Leadbetter WB, Kolisek FR, Levitt RL, et al. Patellofemoral arthroplasty: a multicentre study with minimum 2-year follow-up. Int Orthop 2009;33(6):1597–601. http://dx.doi.org/10.1007/s00264-008-0692-y.
34. Mont MA, Johnson AJ, Naziri Q, et al. Patellofemoral Arthroplasty 7-year Mean Follow-Up. J Arthroplasty 2011. http://dx.doi.org/10.1016/j.arth.2011.07.010.
35. Kooijman HJ, Driessen APPM, van Horn JR. Long-term results of patellofemoral arthroplasty. A report of 56 arthroplasties with 17 years of follow-up. J Bone Joint Surg Br 2003;85(6):836–40.
36. van Jonbergen H-PW, Poolman RW, van Kampen A. Isolated patellofemoral osteoarthritis. Acta Orthop 2010;81(2):199–205. http://dx.doi.org/10.3109/17453671003628756.
37. Tarassoli P, Punwar S, Khan W, et al. Patellofemoral arthroplasty: a systematic review of the literature. Open Orthop J 2012;6(1):340–7. http://dx.doi.org/10.2174/1874325001206010340.
38. Noyes FR, Barber-Westin SD. Advanced patellofemoral cartilage lesions in patients younger than 50 years of age: is there an ideal operative option? Arthroscopy 2013;29:1423–36.