Articular Cartilage Restoration of the Knee

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Abstract

Articular cartilage defects are common and play a significant role in degenerative joint disease. Cartilage is unable to regenerate, secondary to an inherent lack of vascular supply, thus, various techniques have been described in an attempt to treat and potentially restore these defects. Treatment decisions should be based on appropriate evaluation and classification of the pathology. Only then can the surgeon choose to perform a repair or a restoration of the articular surface. Current literature and techniques for the treatment of articular cartilage defects are reviewed, with an algorithm developed for the management of articular cartilage defects by orthopaedic surgeons.

Articular injuries associated with trauma or overuse have plagued those afflicted and been problematic to treat for over 200 years. William Hunter, a Scottish physician, in his paper to the Royal Society, in 1743, is quoted as saying, "From Hippocrates to the present age, it is universally allowed that ulcerated cartilage is a troublesome thing and that, once destroyed, is not repaired."[1]

The management of these highly prevalent injuries continues to be challenging for orthopaedic surgeons. Without intervention, articular cartilage lesions have little or no healing potential with normal hyaline cartilage. In a retrospective review of over 31,000 knee arthroscopies, in all age groups, chondral lesions were found in 63% of patients, with an average of 2.7 lesions per knee.[2] Another study of 993 consecutive knee arthroscopies found articular cartilage pathology in 66% of patients.[3] Moreover, 11% of these knees had localized, full-thickness articular cartilage lesions.

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Basic Science

Understanding the cellular organization of cartilage explains the lack of healing potential of this tissue. The basic structural components of articular cartilage include chondrocytes, collagen, proteoglycans, noncollagenous proteins, and water. Their distribution varies within four separate histologic zones: the superficial, middle, deep, and calcified. The superficial layer, or lamina splendens, is thin, noncellular, and porous. Fibers are arranged in parallel to the joint surface. In the middle zone, collagen fibrils have a larger diameter, with a higher concentration of proteoglycans and lower water and collagen concentrations. In the deep zone, the diameter of the fibers and concentration of proteoglycans increases. The fibers are oriented perpendicular to the joint surface, resist compressive loads, and pass through the tide mark into the calcified zone. This microanatomy produces superior loading and minimal friction characteristics of cartilage. Cartilage is avascular, which therefore limits spontaneous regeneration. Therefore, injuries that do not penetrate into the subchondral bone have little chance of regeneration without intervention.

Patient Evaluation

The first step in the evaluation of the patient is a careful history, detailing the mechanism of injury, onset, and characteristics of symptoms as well as prior treatments. Patients with

discrete focal articular lesions can present with a variety of complaints. Commonly, there is a history of an acute injury, with a sudden onset of symptoms. Patients often describe a locking of the knee, associated with a joint effusion, and commonly present symptoms consistent with a loose body. Other scenarios by which the patient may present include patellar dislocations, direct trauma, and twisting injuries. Though some patients may have an insidious onset of symptoms, one must distinguish the patient with a focal articular defect from one with degenerative arthritis, as these are two separate entities that are not treated in the same manner.

The physical exam should attempt to elucidate coexisting abnormalities, including ligamentous stability of the knee, patellofemoral tracking, and mechanical alignment of the extremity. If any comorbidities are identified, correction of these conditions should be included in the operative plan, as it becomes integral to a successful outcome.

Radiographic examination should begin with weightbearing anteroposterior, lateral, patellar, and flexion posteroanterior views. Though previous studies have indicated that arthroscopy is far more accurate than MRI,[4] more recent studies have shown a greater than 95% accuracy of MRI with new sequences in detecting lesions.[5] With this latest evidence, MRI has emerged as a highly effective noninvasive method for detecting articular cartilage lesions.

Classification of Cartilage Defects

Due to the increase in the use of arthroscopy in the 1960s, orthopaedists gained a better understanding of articular cartilage degeneration and were able to begin classifying lesions. Outerbridge originally classified these defects, in the 1960s, based on their gross appearance during arthrotomies.[6] Other classification systems exist that are more comprehensive and take into account factors such as size and location of lesions; however, the Outerbridge classification is still the most widely accepted. In grade I lesions, the articular cartilage is swollen and soft and may be blistered. Grade II lesions are characterized by fibrillation, fissures, and clefts less than 1.5 cm in diameter. Grade III lesions are characterized by deep fissures extending down to the subchondral bone. Finally, Grade IV lesions are differentiated by exposed subchondral bone.

Natural History

The natural history of articular cartilage defects is mostly unknown and remains controversial. Shelbourne and colleagues studied chondral defects noted incidentally during arthroscopic articular cartilage lesion (ACL) reconstructions.[7] After an average of eight years, knees with cartilage defects did not show any radiographic evidence of progression to arthritis. However, patients did have lower subjective functional scores than the control group, though no objective functional loss was noted. What can be extrapolated from this study is not clear, since these were all asymptomatic patients. Linden reported a long-term follow-up study on osteochondritis dissecans (OCD) lesions of the knee that went untreated.[8] At a mean of 33 years, two out of 23 (9%) patients, who were children at the time of initial diagnosis, had only mild osteoarthritis. In contrast, 81% of patients with adult-onset lesions had signs of osteoarthritis at last follow-up. Therefore, it seems that surgical measures should only be considered in adult symptomatic patients that fail nonoperative measures.

Nonoperative Treatment

Nonoperative treatment of ACL includes nonsteroidal anti-inflammatory drugs (NSAIDs), viscosupplementation, bracing, weight loss, and rehabilitation. These treatments may provide symptomatic relief and have the potential to alleviate some symptoms. However, there has been no evidence, to date, that any of these techniques provide structural improvement of the lesions.

Arthroscopic Lavage and Debridement

If nonoperative treatment fails, there are various techniques available for surgical intervention. The first of these techniques to be applied was arthroscopic debridement, which was initially popularized by Magnusson 6 decades ago.[9] The debridement should include resection of all unstable cartilage back to a stable rim, with abrasion of exposed calcified cartilage. The goal of debridement is to remove loose flaps of cartilage that mechanically impinge on the joint and cause inflammation. Hubbard performed a prospective study on debridement in 76 knees.[10] Grade III and IV lesions were randomized to receive either debridement or arthroscopic lavage. The debridement group showed significant pain relief at 1 year, with 80% being pain free, as compared to 20% in the lavage group. However, these results significantly deteriorated at 5 years, indicating a poor long-term benefit of debridement alone in treating articular cartilage injuries.

Cartilage Reconstruction

Cartilage reconstruction procedures can be broadly categorized into reparative and restorative procedures. Reparative surgical techniques reconstruct the defect in a manner that does not necessarily restore the cartilage architecture, but may still alleviate symptoms. In contrast, restorative surgical techniques attempt complete reconstruction of the cartilage microarchitecture.

Reparative or Marrow Stimulating Techniques

Reparative or marrow stimulating techniques include drilling of the defect, abrasion arthroplasty, and microfracture techniques. All of these procedures rely upon the penetration of the subchondral bone and exposing the underlying vascular, cancellous bone. This technique allows for the release of blood and mesenchymal cells, which leads to the formation of reparative tissue.

In 1959, Pirdie first described the drilling of areas of denuded articular cartilage to stimulate the reparative process.[11] However, rabbit models demonstrated that these

repairs deteriorated early after a one-year period.[12] In the 1980s, Johnson introduced abrasion arthroplasty, where a motorized burr was used arthroscopically to remove 1 mm to 3 mm of bone.[13] However, the investigators questioned the traumatic nature of removing so much subchondral bone. In fact, a retrospective study by Bert and Maschka showed 33% of patients had postoperative functional outcomes that resulted in worse function than preoperatively.[14] Steadman and associates then introduced the technique of microfracture, in 1997, based on the same principles as drilling and abrasion, but without the bone removal or risk of thermal necrosis.[15]

Microfracture

Microfracture involves a systematic removal of all covering calcified cartilage with a curette. All loose or marginally attached cartilage should be debrided back to a stable rim to form a perpendicular edge. These perpendicular edges form a "well shouldered" lesion, providing a pool that, in turn, helps hold the marrow clot and decrease shear forces across the lesion. Starting at the periphery and working towards the center of the defect, angled awls are then used to perforate the subchondral bone, making holes 3 mm to 4 mm apart. The arthroscopic fluid pump pressure is reduced and direct observation of the release of marrow droplets and blood into the defect is performed (Fig. 1). Steadman and coworkers advocate that the postoperative rehabilitation protocol should include toe-touch weightbearing (TTWB) for 6 to 8 weeks, with continuous passive motion (CPM) begun immediately postoperatively until full passive range of motion (PROM) of the knee is achieved.[16]

Steadman and colleagues, recently, published an average 11-year follow-up of a select group of microfracture patients.[16] Seventy-two traumatic articular injuries of the knee were prospectively followed in patients under 4 years of age, with no concurrent injuries. At 7 years postoperative, 80% of patients rated themselves as improved compared to preoperative status. They also noted that age was a prognostic indicator, with patients less than 35 years old having higher success rates than older cohorts. However, this study reported no histologic results and the average size of the lesions was relatively small (2.7 cm^2).

Repair tissue after microfracture has been described as a mixture of hyaline and fibrocartilage. In a recent study, microfracture patients were taken back to the operating room at 2 years postoperatively for biopsies of the lesions.[17] Only 11% of lesions had a large amount of hyaline cartilage, but 69% of lesions contained predominantly fibrocartilage. This repair tissue has more poor quality stiffness and inferior wear characteristics than does hyaline cartilage; however, the investigators maintained that this tissue remodels over time and becomes more stable.[16]

Critics of microfracture point out that the success reported by Steadman and associates may, in part, be attributed to the rigid postoperative rehabilitation protocol. In contrast, some surgeons perform microfracture without the follow-up use of CPM, and patients are made weightbearing as tolerated (WBAT) after surgery. This raises the question as to whether the same success can be achieved. Marder and coworkers recently reported a retrospective review of 50 patients who underwent microfracture.[18] Patients were grouped into those who were made TTWB for 6 weeks with the use of CPM and those who achieved WBAT with no CPM use. The study failed to show a significant difference in functional outcome scores at 2 years. The investigators stated that a well shouldered lesion would protect the repair tissue during weightbearing and, therefore, did not advocate CPM or weightbearing restrictions on these patients.

Restorative Techniques

The goal of restorative surgical technique is the restoration of the biomechanical and physiologic functions of cartilage by the complete reconstruction of its microarchitecture. These techniques include osteochondral autograft transfer, autologous chondrocyte implantation, and osteochondral allograft transplantation.

Osteochondral Autograft Transfer

Osteochondral autograft transfer (OATS) was first reported by Outerbridge and colleagues in 1995.[19] OATS involves the transfer of osteochondral plugs from relatively non-weightbearing regions of the knee to restore damaged articular cartilage. This technique, however, is limited by the amount of donor tissue available. Although there are reports of treating large lesions with this technique, the ideal lesion is between 1 cm^2 and 4 cm^2. Additionally, lesions deeper than 10 mm are not amenable to OATS alone, since plugs may not be long enough for adequate fixation.

OATS can be performed in open surgery through a small arthrotomy or arthroscopically. However, some lesions are

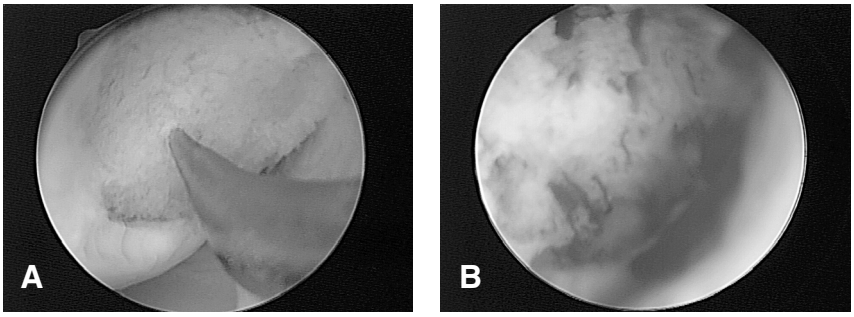

Figure 1 Microfracture technique.

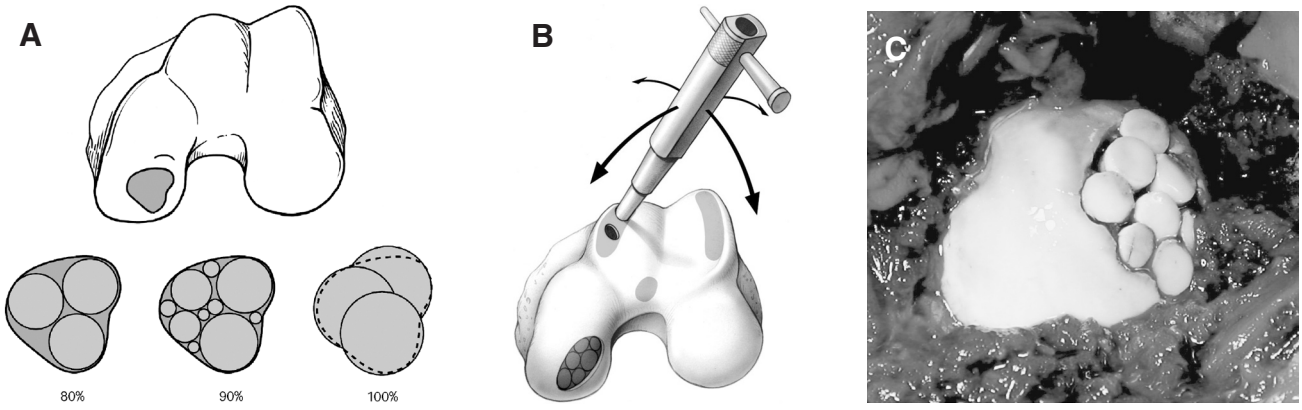

Figure 2 Osteochondral autograft transfer includes (**A**) sizing of the lesion to assist in increasing the filling area and (**B**) removal of the autograft from the donor site. **C**, Post-implantation picture showing maintenance of joint congruity. (From Hangody L, Rathonyi GK, Duska Z, et al. Autologous osteochondral mosaicplasty. Surgical technique. J Bone Joint Surg Am. 2004 Mar;86(Suppl 1):65-72. Copyright © 2004, reprinted with permission from The Journal of Bone and Joint Surgery, Inc.)

more amenable to an open procedure, as the site may be inaccessible because of a posterior location or because of an inability to flex the knee sufficiently. After the lesion is identified, the edges are debrided back to stable, healthy cartilage. The base of the lesion is abraded down to subchondral bone and the number of grafts needed is determined, at this time, by using a drill guide to size the lesion. Using variable sized plugs, the filling area can be increased to 90% to 100% (Fig. 2A).

The peripheral parts of both femoral condyles at the level of the patellofemoral joint can serve as donor sites. Notch area grafts are also available but less favorable, due to the concave hyaline cartilage surface. The appropriately measured tubular chisel is introduced perpendicular to the donor site. Nonperpendicular harvests may result in step-offs on the reconstructed surface and should be avoided. The chisel is tapped into the donor site for approximately 15 mm to 25 mm. The chisel is removed by careful toggling without rotation in order to avoid breakage of the plug (Fig. 2B). The graft is then pushed out of the chisel from the osseous end to avoid damage to the harvested cartilage.

The insertion of the graft is aided with a universal drill guide. The guide is tapped perpendicular to the base of the defect. A tunnel is created with an appropriately sized drill. A dilator is then used to create a conical-shaped recipient tunnel. Next, the graft is inserted through the guide to match the surface of the graft to the surrounding articular surface. The graft is secured in this press-fit manner, and no further fixation is required. Once all grafts have been inserted, the knee should be placed through a full ROM to ensure graft congruity with the joint surface and their press-fit stability (Fig. 2C).

The postoperative protocol most commonly described in the literature involves immediate active and passive ROM exercises with CPM assistance. A period of 3 to 4 weeks of strict non-weightbearing should be observed to avoid settling of the grafts. This is then followed by a 3 to 4 week period of progressive partial weightbearing.

In a prospective outcomes study, Jakob and associates followed 52 patients who underwent mosaicplasty for an average of 37-months.[20] Lesions sized up to 16 cm^2 were included. The study found that 86% of patients reported an increased level of knee function 2 years postoperatively. Ninety-two percent of patients reported increased knee function at latest follow-up. Biopsies were performed in four patients 4 to 41 months after surgery. Histologic examinations revealed that the transplanted cartilage retained its hyaline character. Complications included four graft failures, one postoperative hematoma requiring surgical drainage, and one case of arthrofibrosis.

In a case series of 37 young athletes with Outerbridge grade IV lesions and a two-year follow-up, investigators found 78.3% good to excellent functional outcomes after OATS.[21] Age was realized as a good prognostic indicator of success. Additionally, increasing size was associated with a poorer outcome. Twenty-seven (73%) patients were able to return to their preoperative level of sport activity, and five (14%) were able to return to sport at a lower level.

In the largest series to date, Hangody and Fules reported on the functional outcomes of over 800 mosaicplasties performed over 10 years.[22] They also included other joint surfaces, such as the talar dome, femoral head, capitellum, and humeral head. The majority of the lesions were on the femoral condyles, followed by the patellofemoral joint, talar dome, and tibial plateau. Good to excellent results were obtained in 92% of patients with femoral condyle lesions, 79% of patellofemoral lesions, and 87% of tibial lesions. Of note, however, 36 patients in the study had painful hemarthroses after the procedure. Eighty-three patients with mosaicplasty of the knee, in this series, underwent second-look arthroscopy. Sixty-nine of 83 patients demonstrated good gliding surfaces, viable transplanted cartilage, and a fibrocartilage covering of the donor sites. Fourteen patients showed signs of degenerative changes, ranging from mild to severe.

Donor site morbidity is of high concern during mosaicplasty. When harvesting graft tissue, causing further degen-

eration of the donor remains a concern. Therefore, the study looked at patients with talar, capitellar, femoral, and humeral head lesions who had knee surgery only for procurement of the osteochondral plugs. Ninety-five percent of these patients had no knee symptoms six weeks after surgery, and 98% had no symptoms one year after surgery.

In a study comparing OATS to microfracture, Gudas and coworkers performed a randomized controlled trial with 57 athletes.[23] Twenty-eight OATS and 29 microfractures were performed, with an average follow-up of 37 months. All lesions were 1 cm^2 to 4 cm^2. Results at 3 years demonstrated that 96% of the OATS group had good to excellent results, as compared to 57% of the microfracture group. When using return to sport as an outcome, comparison demonstrated that 93% of OATS patients were able to return to sport at 6 months, while only 52% of microfracture patients were able to return to sport at that time. Additionally, biopsies of the repair cartilage were performed at one year in 25 of the patients. Microfracture patients all had a fibrocartilaginous repair, while all OATS repairs retained their hyaline cartilage at one year.

Multiple histologic studies have shown that osteochondral autograft plugs retain their hyaline cartilage after implantation, which is an improvement over microfracture and the marrow stimulating techniques. However, Horas and colleagues recently showed that, although there is a seamless osseous integration of the plugs, a persistent gap remains at the level of the cartilage.[24] These gaps appear to be filled with fibrous tissue. This raises concern, since multiple persistent gaps might affect joint congruity and create a starting point for cartilage degeneration. On macroscopic examination, no signs of degeneration were observed and the graft cartilage appeared to be indistinguishable from the native cartilage.

OATS has the advantage of being a single-stage procedure. Additionally, the defect is repaired with hyaline cartilage, as compared to fibrocartilage in other modalities. There is no risk of disease transmission as seen with allografts, and it is a relatively low-cost procedure with no requirement of ordering grafts or implants. However, this procedure does carry risk of donor site morbidity, with the potential of degenerative changes from graft harvesting and postoperative hematoma formation. OATS can be a technically demanding procedure, as the surgeon needs to recreate the normal contour of the knee in three dimensions. OATS is also limited to the treatment of cartilage defects less than 4 cm^2, due to the limited amount of autologous tissue available. Finally, concerns remain over gaps existing between donor and host articular cartilage, as these may act as a starting point for degeneration.

Autologous Chondrocyte Implantation

ACI implantation was first reported by Brittberg and associates, in 1994, as an alternative for the treatment of articular cartilage injuries.[25] The investigators stated that this procedure produces a hyaline-like cartilage repair. It is a two-stage procedure, with the first step being the harvesting of chondrocytes from the patient's knee. The chondrocytes are then cultured and reimplanted back into the knee during a subsequent operation.

In a 2006 study, good prognostic indicators for a successful ACI procedure were reported, to include being under 20 years of age and having a single focal defect of the knee.[26] There was no relationship found between defect size and clinical outcome. Therefore, it seems that ACI is more amenable to larger defects than the previously described procedures. Additionally, patients who had symptoms for less than two years and higher preoperative functional scores demonstrated better clinical results than chronic lesions.

The first stage in ACI involves an arthroscopic evaluation of the focal chondral lesion. The surgeon should asses the size, containment, depth, and potential bone loss of the lesion. Lesions 3 mm to 6 mm deeper than the subchondral bone may require bone grafting prior to ACI. The opposing surface of the cartilage defect should be assessed for degeneration. Grade II lesions of the opposing surface are considered a relative contraindication to ACI.

The next step is the harvesting of the chondrocytes. This is performed with gouges or curettes. Again, as in OATS, cartilage is taken from lesser weightbearing regions of the knee. The preferred locations include the lateral edge of the intercondylar notch or the superomedial trochlea. The total size of the biopsy should be between 200 mg and 300 mg. The subchondral bone should be slightly penetrated during this procedure to allow a fibrocartilage repair of the donor site.

The cartilage specimens are sent to the laboratory in a sterile tube with culture medium. The harvested cartilage is enzymatically digested and the chondrocytes isolated. The cells are cultured for 2 weeks, which increases the number of cells by a factor of 30. Since the implanted cartilage cells need a stable environment in which to heal, predisposing factors such as meniscal pathology, ligamentous instability, and malalignment should be addressed prior to implantation.

The second stage of the procedure takes place 6 weeks to 18 months after the biopsy. However it can be delayed as long as 4 years. The first step in the second stage is defect preparation. Exposure is dependent upon defect location with common utilization of a medial or lateral parapatellar mini-arthrotomy (Fig. 3A).

All unstable and damaged cartilage is debrided back to a healthy, stable rim. Vertical walls are formed with a sharp blade to create a well-shouldered lesion. The thickness of the neighboring cartilage is very important, since it must be thick enough to accommodate suture fixation of the graft. Therefore, the walls must be minimally 2 mm to 3 mm thick.

In the case of ACI, care is taken to avoid penetration into the subchondral bone, as this would stimulate a fibrous response similar to microfracture or abrasion arthroplasty. The debrided defect should be made circular or oval, as this simplifies the suturing of the graft and the making of a water tight seal.

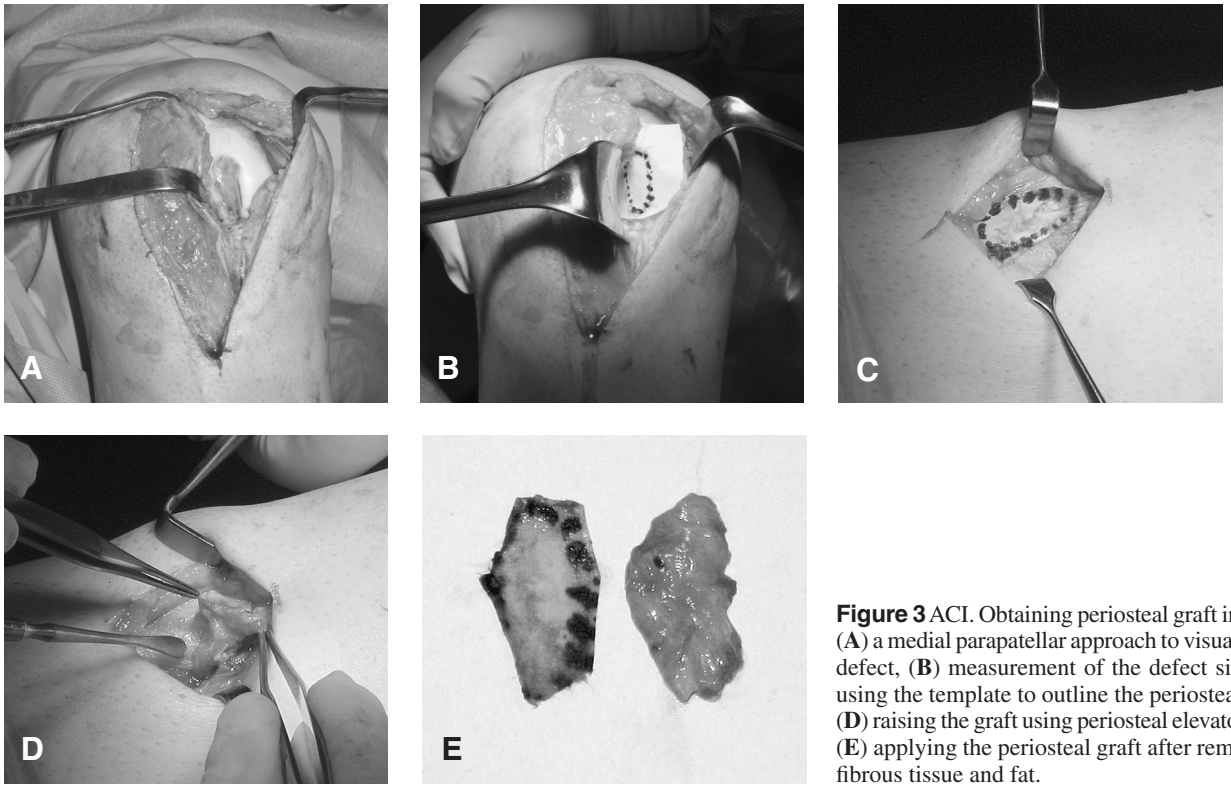

Figure 3 ACI. Obtaining periosteal graft includes (**A**) a medial parapatellar approach to visualize the defect, (**B**) measurement of the defect size, (**C**) using the template to outline the periosteal graft, (**D**) raising the graft using periosteal elevators, and (**E**) applying the periosteal graft after removal of fibrous tissue and fat.

Next, the periosteal flap that will cover the cartilage defect must be harvested. Tissue is easily accessed at the proximal medial tibia, distal to the pes anserine and medial collateral ligament (MCL) insertion. Overlying fibrous tissue and fat should be removed. Using an aluminum foil template, the size of the defect is then measured (Fig. 3B). The periosteal flap should be oversized by 1 mm to 2 mm. It is sharply incised at its margins. A periosteal elevator is used, taking care not to penetrate the flap (Fig. 3C-E).

With the cambium, or inner layer of the periosteum, facing the defect, the flap is sutured to the cartilage rim with 6-0 Vicryl suture. Anchoring begins in the corners and is continued around the periphery, leaving an opening superiorly for the injection of chondrocytes. Fibrin glue is utilized to fill the gaps between the sutures. The repair is then checked for water tightness by injecting saline into the pouch created (Fig. 4).

The suspension of chondrocytes returned from the laboratory is carefully injected into the defect using an 18-gauge Angiocath™ (Fig. 5). Care is taken to ensure the chondrocytes are evenly distributed throughout the defect. The superior opening is closed with suture and sealed with fibrin glue.

The postoperative protocol calls for early ROM, with the use of CPM 6 to 8 hours per day. The patient is made non-weightbearing for 6 weeks. Weightbearing is then progressed over the next 6 weeks, and the patient is made WBAT at 12 weeks. Patients are typically permitted to return to normal activities of daily living and light sport at 4 to 6 months postoperatively.

In a Swedish study, Peterson and coworkers evaluated the long-term durability of these procedures.[27] Sixty-one patients with focal cartilage defects of the knee underwent ACI and had an average follow-up of seven years. At 2 years, 50 (82%) patients had good to excellent clinical results. Additionally, 85% of patients with isolated femoral condyle lesions had good to excellent results. However, these outcomes were not as good in patellar lesions, where only 11 out of 17 patients (65%) had good to excellent results at 2 years. The outcomes seemed to improve over time, with 51 patients reporting good or excellent clinical results at latest follow-up (range 5 to 11 years.) Ten failures did occur; however, no failures occurred after 2 years. The investigators concluded that if ACI is successful, a long-lasting, durable repair is achieved.

Biopsy specimens were taken from 12 of the patients at a mean of 54 months postoperatively. Samples were stained for type II collagen, indicating a hyaline-like cartilage repair if more than 50% of the tissue stained positive. Eight patients had repairs with hyaline-like cartilage characteristics, while four were fibrous in nature. The investigators also noted that most grafts had a superficial fibrous covering that they believed was the remnant of the periosteal graft.

In a multicenter prospective study in the United States, Browne and colleagues studied 87 patients who underwent ACI.[28] Patients were followed for 5 years. The patients in this cohort had relatively large defects, measuring an average of 5 cm^2. Additionally, 70% of these patients already had one failed cartilage repair procedure, making this a challenging patient population. Sixty-two patients had improved

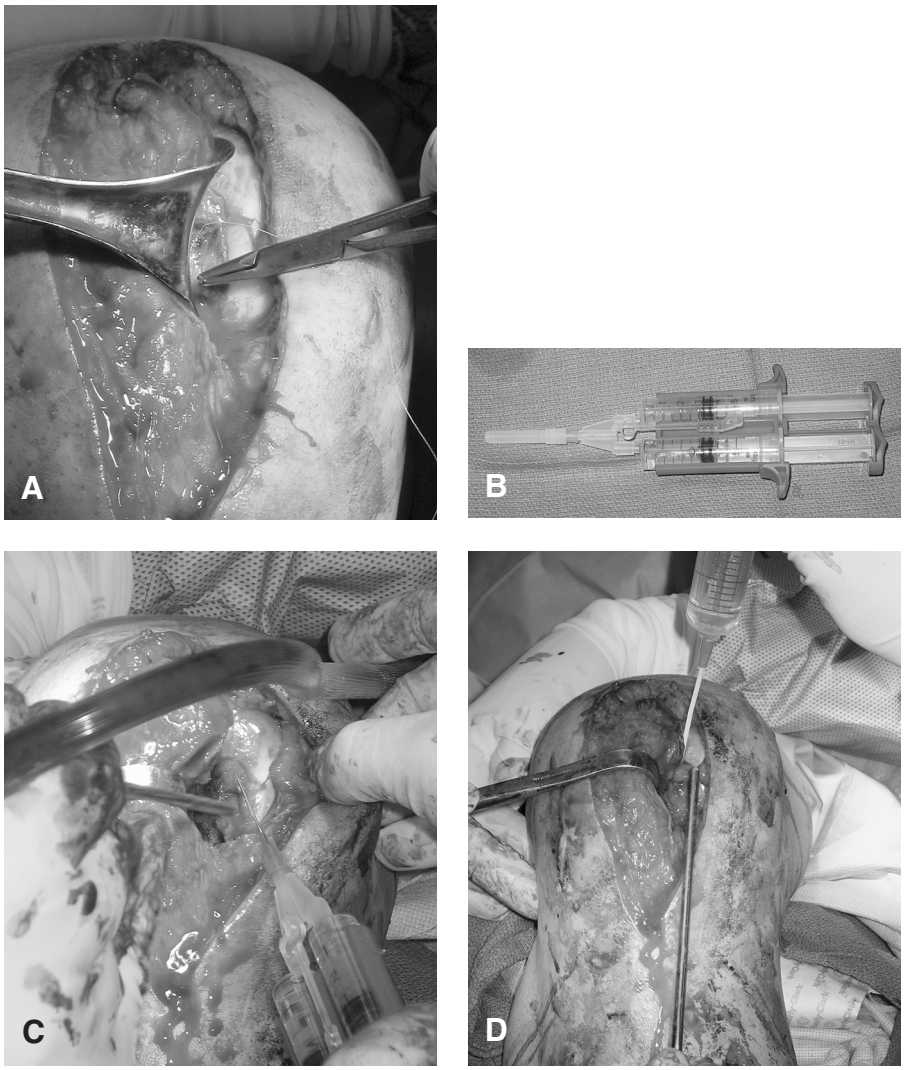

Figure 4 ACI. Fixation of the graft to the defect includes (**A**) suturing of the periosteal flap to the defect with 6-0 Vicryl sutures, (**B**) fibrin Glue, (**C**) application of the fibrin glue to margins of the repair, and (**D**) a water test.

functional outcomes at five years. Six patients remained unchanged and 19 patients reported worsened conditions. The study concluded that ACI proved to be an effective treatment for large articular defects that failed previous attempts at restoration.

Fu and associates compared ACI to debridement alone.[29] The study was a retrospective cohort with 96 patients and a minimum follow-up of three years. Though patients were not randomized, they had similar baseline functional scores. Patients in this study had predominantly large defects with an average size of 5 cm^2. Eighty-one percent of patents in the ACI group and 60% of patients in the debridement group reported functional improvement at recent follow-up. Additionally, scores for median overall condition, pain, and swelling were significantly better in the ACI group than in the debridement group. The failure rates of both groups remained equal. The study concluded that ACI is more efficacious than debridement in the treatment of larger cartilage lesions.

Comparing ACI to OATS, Bentley and coworkers conducted a prospective, randomized trial in 100 patients.[30] Mean follow-up was 19 months, and average lesion size was 5 cm^2. At one year, 88% of patients in the ACI group showed good to excellent functional scores, compared to 69% in the OATS group. Additionally, second look arthroscopy in 60 patients revealed that 82% of lesions treated by ACI had good or excellent repairs, as compared to only 34% in the OATS group.

Biopsies of 19 patients in the ACI group were taken at one year. Seven of these repairs demonstrated hyaline cartilage of normal appearance, seven demonstrated a mix of hyaline and fibrocartilage, and five demonstrated a mainly fibrocartilage repair. Of interest, one patient was biopsied at both one year and two years postoperatively. At 1 year, the repair showed a mixture of hyaline and fibrocartilage; whereas after 2 years, the repair was mainly hyaline cartilage. This supports the claim of Peterson and colleagues that these repairs can mature to hyaline-like cartilage as much as 2 years after implantation. No biopsies of the OATS group were performed. The investigators concluded that ACI was superior to OATS; however, this study was of larger lesions, approaching the recommended upper limit for OATS.

Horas and associates also performed a randomized controlled trial on 40 patients, comparing ACI to OATS.[24] The

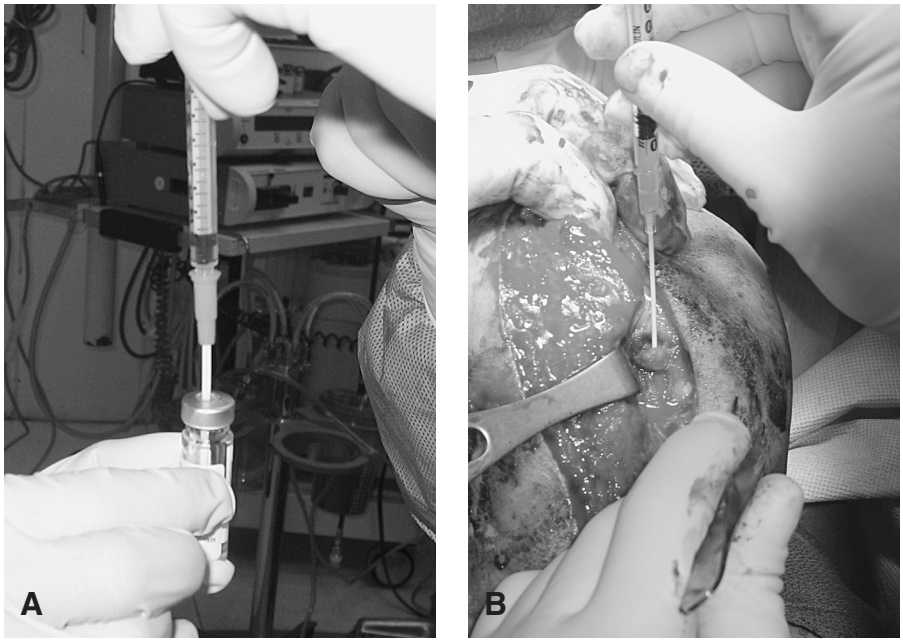

Figure 5 ACI. Injection of the chondrocytes includes (**A**) obtaining the chondrocytes, and (**B**) injecting the chondrocytes into the pouch, which is then closed superiorly.

average lesion size was smaller than the Bentley's study, being an average of 3.75 cm^2. Patients underwent the same postoperative rehabilitation protocol, with progressive, restricted weightbearing for 12 weeks, and immediate ROM exercises. At two years follow-up, Lysholm functional scores lagged behind in the ACI group, although both treatments resulted in improvement of symptoms.

Six patients in the ACI group were reexamined arthroscopically at 2 years, including biopsies. Macroscopic exam revealed the regenerate to have a rigid consistency with a rippled surface. In two patients, the regenerate grew over the surrounding normal cartilage. Histologic examination showed that the regenerate was adherent to the edges of the defect. However, the regenerated tissue was irregular and highly cellular. Staining of type II collagen was only positive in focal, deep areas of the regenerate, with the superficial layers remaining fibrous in nature.

As discussed earlier, arthroscopic examination of five patients who underwent OATS revealed macroscopically vital cartilage, with no degeneration and no differences between the transplanted and surrounding resident cartilage. Microscopic examination demonstrated that the plugs retained their hyaline cartilage and had seamless osseous integration. However, persistent gaps filled with fibrocartilage remained between the plugs and host cartilage. This study advocated the use of OATS over ACI in lesions smaller than 4 cm^2.

In a comparison between ACI and microfracture, Knutsen and coworkers performed a randomized controlled trial of 80 patients with focal chondral defects of the knee.[17] After two years, the investigators observed only subtle differences between the two groups. Both groups had significant clinical improvement. The SF-36 physical component score was significantly better in the microfracture group than in the ACI group. In the microfracture group, defects less than 4 cm^2 did better than larger lesions. This size dependency was not found in the ACI group. Younger and more active patients did better in both groups. Histologic exam revealed no significant differences between the two groups.

The reoperation rate was significantly higher in the ACI group in which 10 patients underwent additional surgery before two years, as compared to four patients in the microfracture group. These investigators noted that hypertrophy of the implanted tissue, which was hypothesized to be periosteum, was the major reason for reoperation. Overall, the study concluded that microfracture should be a first-line treatment in smaller focal defects, reserving ACI for lesions that failed microfracture and for those with bigger, noncontained defects.

Matrix Induced Chondrocyte Implantation

Reports of complications using periosteal patches, including graft hypertrophy, have led to interest in utilizing bioabsorbable covers as an alternative. One such technique is matrix-induced chondrocyte implantation (MACI). The MACI membrane consists of a porcine-derived collagen bilayer that is seeded with the patient's harvested chondrocytes. During implantation, the graft is secured to the defect by fibrin glue alone, without suture. These grafts have the potential benefits of decreased operating time, smaller incisions, and decreased pain. Additionally, since the grafts are seeded with chondrocytes, an even distribution of chondrocytes is ensured.

To study the outcomes of this new technology, Bartlett and colleagues recently published results of a randomized controlled trial between MACI and ACI in 91 patients.[31] At one year postoperatively, the investigators found no statistically significant difference between the two groups in functional outcomes, arthroscopic appearance of the repair, histologic grading, or postoperative complication rate. They

concluded, therefore, that MACI is a comparable procedure to ACI; however, further long-term studies are needed.

Osteochondral Allograft Transplantation

A special situation arises when a large defect exists with significant bone loss. A viable option in this situation is osteochondral allograft transplantation. The use of osteochondral allografts allows for the transfer of hyaline cartilage to repair the defect, while not being limited by its size. There is no donor site morbidity involved in the use of allografts. Additionally, allografts may be taken from younger, healthier patients in whom the quality of bone and cartilage is superior to that of the host. However, the use of osteochondral allografts is not without drawbacks. The use of fresh frozen allografts imparts a risk of disease transmission and an immunogenic response. Osteochondral allografts show a time-dependent loss of viable chondrocytes when refrigerated.[32] Therefore, allografts are of limited availability and should be transplanted within a narrow window of time.

Bugbee and associates reported the results of allograft transplantation in 97 knees, with an average follow-up of 50 months.[33] Of 61 knees that had allografting to one surface, the authors reported good to excellent results in 79% of patients. Of 30 knees that underwent allografting to two opposing surfaces, only 53% had good to excellent results. A study by Ghazavi and coworkers showed an 86% success rate of 127 knees treated with osteochondral allografts. They demonstrated that graft survivorship was 95% at 5 years, 71% at 10 years, and 66% at 20 years.[34]

Synthetic Mosaicplasty Implants

Recently, the use of synthetic implants for the repair of focal defects has been investigated. These synthetic scaffolds, frequently consisting of polylactides-*co*-glycolides, can be used either alone for a focal defect or as a delivery vehicle for chondrocytes or growth factors. They are designed to be multiphasic in nature and their degradation can be tailored. This multiphasic design allows one to address both the regeneration of articular cartilage, as well as the subchondral bone.

Niederauer and colleagues showed, in a goat model, that focal osteochondral defects treated with various implant constructs can be repaired with a hyaline-like cartilage.[35] Frenkel and associates illustrated, in a rabbit model, that multiphasic implants are capable of maintaining a hyaline-like cartilage at 24 weeks after implantation.[36] To our knowledge, no study has shown their efficacy in humans. Therefore, the role of these scaffolds in the treatment of ACL has yet to be determined.

Treatment Algorithm

Using the literature reviewed, a treatment algorithm can be produced for articular cartilage lesions (Fig. 6). The size of the lesion and patient characteristics, such as age and activity level, should guide the treatment plan. Marrow stimulating

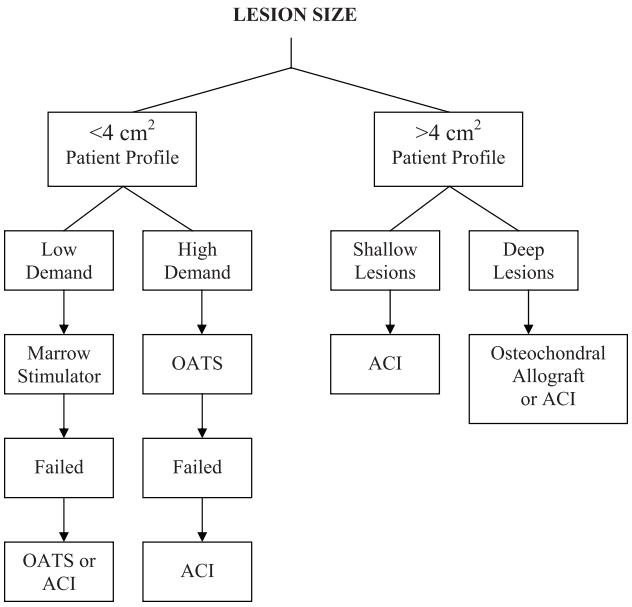

Figure 6 Treatment algorithm for articular cartilage defects: marrow stimulator OATS, osteochondral autograft transfer; ACI, autologous chondrocyte implantation.

techniques should serve as a first-line treatment in patients who have smaller lesions , under 4cm^2, and are relatively lower demand. More active patients with small lesions are more amenable to OATS. Additionally, OATS may serve as a second-line treatment in the setting of a failed microfracture. Large, shallow lesions should be treated primarily by ACI. Large lesions with significant extension into the subchondral bone may require osteochondral allografts. ACI may serve as a secondary treatment for both large and smaller lesions. The roles of MACI and synthetic scaffolds are yet to be determined.

Conclusion

Articular cartilage injuries have remained a challenge to the medical community for centuries. Initially, the treating surgeon should distinguish between arthritis and focal chondral injuries. Recent advances such as microfracture, OATS, and ACI are now available to the orthopaedist as treatment options. A treatment plan should be based on the pertinent criteria, including size of the lesion, patient age, activity level, and coexisting injuries.

References

1. Hunter W. Of the structure and disease of articulating cartilages. 1743. Clin Orthop Relat Res. 1995;(317):3-6.
2. Curl WW, Krome J, Gordon ES, et al. Cartilage injuries: A review of 31,516 knee arthroscopies. Arthroscopy. 1997;13:456-60.
3. Aroen A, Loken S, Heir S, et al. Articular cartilage lesions in 993 consecutive knee arthroscopies. Am J Sports Med. 2004;32:211-5.
4. Ochi M, Sumen Y, Kanda T, et al. The diagnostic value and limitation of magnetic resonance imaging on chondral lesions

in the knee joint. Arthroscopy. 1994;10:176-83.
5. Potter HG, Linklater JM, Allen AA, et al. Magnetic resonance imaging of articular cartilage in the knee. An evaluation with use of fast-spin-echo imaging. J Bone Joint Surg Am. 1998;80:1276-84.
6. Outerbridge RE. The etiology of chondromalacia patellae. J Bone Joint Surg Br. 1961;43:752-7.
7. Shelbourne KD, Jari S, Gray T. Outcome of untreated traumatic articular cartilage defects of the knee: A natural history study. J Bone Joint Surg Am. 2003;85(Suppl 2):8-16.
8. Linden B. Osteochondritis dissecans of the femoral condyles: A long-term follow-up study. J Bone Joint Surg Am. 1977;59:769-76.
9. Magnusson PB. Technique of debridement of the knee joint for arthritis. Surg Clin North Am. 1946;26:226-49.
10. Hubbard MJ. Articular debridement versus washout for degeneration of the medial femoral condyle. A five-year study. J Bone Joint Surg Br. 1996;78:217-19.
11. Pirdie KH. A method of resurfacing knee joints. J Bone Joint Surg Br. 1959;41:618-19.
12. Mitchell N, Shepard N. The resurfacing of adult rabbit articular cartilage by multiple perforations through the subchondral bone. J Bone Joint Surg Am. 1976;58:230-3.
13. Johnson LL. Arthroscopic abrasion arthroplasty historical and pathologic perspective: Present status. Arthroscopy. 1986;2:54-69.
14. Bert JM, Maschka K. The arthroscopic treatment of unicompartmental gonarthrosis: A five-year follow-up study of abrasion arthroplasty plus arthroscopic debridement and arthroscopic debridement alone. Arthroscopy. 1989;5:25-32.
15. Steadman JR, Rodkey WG, Singleton SB, Britts KK. Microfracture technique for full-thickness chondral defects: Technique and clinical results. Oper Tech Orthop. 1997;7:300-4.
16. Steadman JR, Briggs KK, Rodrigo JJ, et al. Outcomes of microfracture for traumatic chondral defects of the knee: Average 11-year follow-up. Arthroscopy. 2003:19:477-84.
17. Knutsen G, Engebretsen L, Ludvigsen TC, et al. Autologous chondrocyte implantation compared with microfracture in the knee. A randomized trial. J Bone Joint Surg Am. 2004;86:455-64.
18. Marder RA, Hopkins G Jr, Timmerman LA. Arthroscopic microfracture of chondral defects of the knee: A comparison of two postoperative treatments. Arthroscopy. 2005;21:152-8.
19. Outerbridge HK, Outerbridge AR, Outerbridge RE. The use of a lateral patellar autologous graft for the repair of a large osteochondral defect in the knee. J Bone Joint Surg Am. 1995;77:65-72.
20. Jakob RP, Franz T, Gautier E, Mainil-Varlet P. Autologous osteochondral grafting in the knee: Indication, results, and reflections. Clin Orthop Relat Res. 2002;(401)170-84.
21. Marcacci M, Kon E, Zaffagnini S, et al. Multiple osteochondral arthroscopic grafting (mosaicplasty) for cartilage defects of the knee: Prospective study results at 2-year follow-up. Arthroscopy. 2005;21:462-70.
22. Hangody L, Fules P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: Ten years of experimental and clinical experience. J Bone Joint Surg Am. 2003;85(Suppl 2):25-32.
23. Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. Arthroscopy. 2005;21:1066-75.
24. Horas U, Pelinkovic D, Herr G, et al. Autologous chondrocyte implantation and osteochondral cylinder transplantation in cartilage repair of the knee joint. A prospective, comparative trial. J Bone Joint Surg Am. 2003;85:185-92.
25. 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.
26. Krishnan SP, Skinner JA, Bartlett W, et al. Who is the ideal candidate for autologous chondrocyte implantation? J Bone Joint Surg Br. 2006;88:61-4.
27. Peterson L, Brittberg M, Kiviranta I, Akerlund EL, et al. Autologous chondrocyte transplantation. Biomechanics and long-term durability. Am J Sports Med. 2002;30:2-12.
28. Browne JE, Anderson AF, Arciero R, et al. Clinical outcome of autologous chondrocyte implantation at 5 years in US subjects. Clin Orthop Relat Res. 2005;(436):237-45.
29. Fu FH, Zurakowski D, Browne JE, et al. Autologous chondrocyte implantation versus debridement for treatment of full-thickness chondral defects of the knee: An observational cohort study with 3-year follow-up. Am J Sports Med. 2005;33:1658-66.
30. Bentley G, Biant LC, Carrington RW, et al. A prospective, randomised comparison of autologous chondrocyte implantation versus mosaicplasty for osteochondral defects in the knee. J Bone Joint Surg Br. 2003;85:223-30.
31. Bartlett W, Skinner JA, Gooding CR, et al. Autologous chondrocyte implantation versus matrix-induced autologous chondrocyte implantation for osteochondral defects of the knee: A prospective, randomised study. J Bone Joint Surg Br. 2005;87:640-5.
32. Malinin T, Temple HT, Buck BE. Transplantation of osteochondral allografts after cold storage. J Bone Joint Surg Am. 2006;88:762-70.
33. Bugbee WD, Convery FR. Osteochondral allograft transplantation. Clin Sports Med. 1999;18:67-75.
34. Ghazavi MT, Pritzker KP, Davis AM, et al. Fresh osteochondral allografts for post-traumatic osteochondral defects of the knee. J Bone Joint Surg Br. 1997:79:1008-1013.
35. Niederauer GG, Slivka MA, Leatherbury NC, et al. Evaluation of multiphase implants for repair of focal osteochondral defects in goats. Biomaterials. 2000;21:2561-74.
36. Frenkel SR, Bradica G, Brekke JH, et al. Regeneration of articular cartilage: Evaluation of osteochondral defect repair in the rabbit using multiphasic implants. Osteoarthritis Cartilage. 2005;13:798-807.