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Review article

Acetabular cartilage repair: state of the art in surgical treatment

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ABSTRACT

Hip preservation has emerged as a developing surgical subspecialty with a variety of tools to address hip joint pain and dysfunction. Cartilage tears and delamination are caused by injury to the hip and can ultimately progress to osteoarthritis. It has been established that the acetabulum is particularly at risk of cartilage injury secondary to trauma, hip dysplasia and hip impingement. In spite of the high frequency of acetabular cartilage lesions based on our experience and the literature, there is no consensus as to the optimal treatment of these lesions. This review article highlights the challenges in treating cartilage injuries of the acetabulum with a particular emphasis on published studies and technical considerations in performing these procedures.

INTRODUCTION

Open hip preservation surgery has blossomed into its own specialty over the last 30 years based on the pioneering developments from several centers in Europe, Asia and North America [1–7]. During the same time span, arthroscopic techniques have migrated from the knee and shoulder to the hip. One particular condition that has lagged behind in the hip, particularly on the acetabular side, has been the availability of cartilage restoration treatment options. Cartilage repair in the acetabulum is complicated by the physical depth of the acetabulum, the powerful and large muscles covering the hip, the structural complexity of the acetabular labrum, the high degree of constraint of the hip joint, the limited thickness of the acetabular cartilage and the high eventual mechanical loads seen by the treated cartilage. In contrast to the acetabulum, cartilage lesions of the femoral head have been more widely studied and reported on in the literature [8–15].

A major achievement in the exploration of the hip was the development of a safe technique for surgical dislocation by Ganz *et al.* in the 1990s [4, 6]. This technique allowed for both the evaluation and the repair of native hips with cartilage delamination, cartilage loss and even some types of early arthrosis. Unfortunately, the treatments offered were limited to bone recontouring on the acetabular and femoral side, microfracture and labral debridement and repair.

In parallel with the developments in open surgery, hip arthroscopy has benefited from the understanding of the joint through the work of Ganz *et al.* in combination with the advancements in endoscopic instrumentation and visualization. Hip arthroscopy allows for a magnified view of the intraarticular structures and has gradually become the more common method for assessing and treating cartilage lesions of the hip joint. In assessing cartilage lesions of the acetabulum, standard scoring systems, such as the Outerbridge [16] or ICRS [17] classification, can be used to describe the degree of cartilage loss. More recently, hip-specific cartilage scoring systems, such as the Konan classification [18], have been developed which better capture the nuances of cartilage injury, particularly on the acetabulum. Cartilage lesions in the acetabulum can span the spectrum from subtle delamination lesions (Konan grade 1, ICRS 2, Fig. 1A) to the full-thickness cartilage loss seen in osteoarthritis (Konan grade 4, ICRS 4, Fig. 1B) [17–19].

A number of cartilage restoration techniques have been utilized in the acetabulum. Many of these same techniques

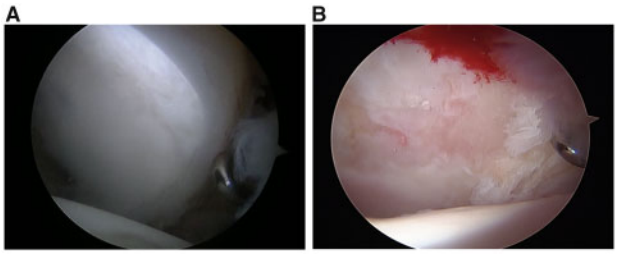

Fig. 1. Arthroscopic view of the hip showing the range of cartilage injuries from subtle delamination (**A**) to full-thickness cartilage loss and osteoarthritis (**B**).

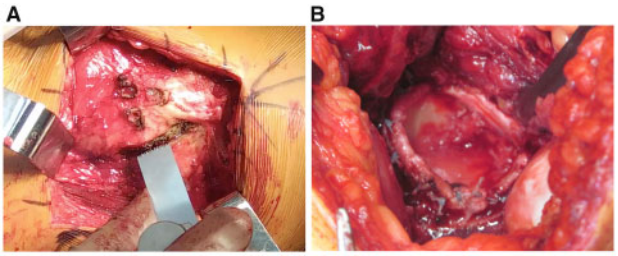

Fig. 2. (**A**) Approach for the surgical dislocation approach involving a trochanteric flip osteotomy performed from posterior to anterior after predrilling three fixation holes for 4.5 mm cortical screws with a 3.2 mm drill. (**B**) Circumferential exposure of the entire acetabulum with this approach allowing for cartilage treatment and labral reconstruction shown here.

have been well-described in treating knee cartilage lesions with favorable outcomes [20–31]. There is less data available in treating cartilage lesions of the hip, especially those in the acetabulum where most lesions are noted based on our experience and that of other centers [19, 32–34]. The objective of this review is to highlight the challenges in treating cartilage injuries of the acetabulum, review published studies on this topic and discuss the technical considerations in performing these procedures.

SURGICAL TREATMENT OPTIONS

Open versus arthroscopic approaches

The surgical treatment of acetabular cartilage lesions has been divided into open and arthroscopic techniques. Arthroscopic techniques have the advantages of relatively little pain compared with open surgery, excellent visualization but limitations of direct access to the lesions due to the obligatory use of portals and cannulas rather than direct handling of the injured region. Open approaches include the direct anterior approach through the Smith-Petersen interval or the open surgical dislocation as described by Ganz [4, 6]. The direct anterior approach is minimally invasive and passes through an internervous plane between the distributions of the superior gluteal nerve (Tensor Fascia Latae muscle) and the femoral nerve (sartorius muscle). Unfortunately, this approach does require significant traction application during dislocation and the potential for iatrogenic injury during this exposure. Furthermore, this approach provides less global access to the entire acetabular rim relative to the surgical dislocation approach. In the case of open treatment of acetabular cartilage lesions, surgical dislocation with a trochanteric osteotomy is the most versatile approach (Fig. 2A). The surgical dislocation allows circumferential access to the acetabulum and labrum while neutralizing the forces of the abductor muscles on the femur through the greater trochanteric osteotomy (Fig. 2B).

The surgical dislocation approach preserves the tenuous blood supply of the femoral head, the medial femoral circumflex artery. The posterior approach and direct lateral approaches (Hardinge) are not used in our practice due to the anatomical risks they pose to the medial femoral circumflex artery and to the abductor muscles, respectively.

Cartilage repair techniques

The specific repair technique used for acetabular cartilage lesions depends on the available tissue. If there is simply a delamination of the articular cartilage from the rim, the options would include removal of the cartilage tissue, or alternatively, repair of the tissue. For repair of the tissue, there are three general categories, namely, to repair the tissue primarily, to facilitate a biologically favorable environment for cartilage repair, and to transplant an anatomically and histologically mature tissue to the area of injury. Each of these categories of repair depends on factors, such as the general health of the joint, the age of the patient, the size of the lesion and the involvement of the underlying bone.

Suture of the cartilage flap

Cartilage delamination flaps can be repaired surgically with suture. The suture technique can be performed using suture anchors at the rim and passing the sutures around the cartilage and labrum as a unit. Due to the poor tensile properties of the cartilage, the sutures can cut through the cartilage tissue leading to linear fissures. We have also noted that in most situations, the cartilage does not have tensile properties that are amenable to suture fixation, leading to the suture cutting through the cartilage upon tensioning (Fig. 3A and B). The problem of cutting through of sutures at the chondrolabral junction may be ameliorated by the use of recently available suture tape by several manufacturers.

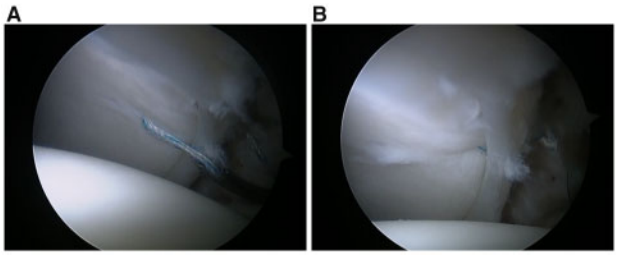

Fig. 3. Arthroscopic view of suture stabilization of the articular cartilage of the acetabulum in a collegiate track athlete. A suture anchor with a #1 non-absorbable suture has been placed at the edge of the acetabulum along a region with cartilage delamination. The suture is passed through the cartilage with a small diameter suture passing device (Nanopass, Stryker, Kalamazoo, MI, USA). (**A**) The suture is wrapped around both the labrum and cartilage. (**B**) A locking sliding knot is used to stabilize both the labral tissue and the cartilage. Any residual tissue on the labrum and cartilage can be addressed with a radiofrequency probe.

In spite of this problem, the stabilization of the labrum often improves the stability of the adjacent cartilage and due to its intimate contact with the labrum. In many cases, the cartilage will be mechanically more stable when the adjacent labrum is repaired back to bone. A second technique has been described by Kaya *et al.* [35] utilizes all-suture anchors that are placed within the more medial aspect of the acetabular lesion. The sutures are then passed laterally over the cartilage lesion toward the rim. The sutures are then fixed to the acetabular rim with additional knotless suture anchors. A case report conducted by Sekiya *et al.* [36] in which the authors used a polydioxanone smooth suture for cartilage repair to the labrum without incorporating the suture into an anchor. They showed that the suture technique can provide a positive outcome for a young, active patient. One additional concern with any cartilage repair suture technique is the risk of abrasion of the femoral head by the sutures within the acetabulum, even with smooth sutures or tape.

Fixation with fibrin glue

Fibrin is a non-globular protein involved in blood clotting. Polymerized fibrin, together with platelets, forms a hemostatic clot over a wound site. Recently, fibrin glue has become another effective treatment for cartilage damage of the hip. It is used in conjunction with microfracture to bond delaminated articular cartilage to the underlying subchondral bone. Because it acts as a scaffold for cells and has the potential to stimulate the release of growth factors, it promotes the repair of many tissues, preventing chondral damage from progressing. Fibrin also accelerates sprouting of capillary vessels and the ingrowth of mesenchymal stem cells [37, 38]. Taken together, these characteristics of fibrin allow it to facilitate early regeneration and more organized repair in comparison to untreated defects. The use of fibrin glue is also advantageous because it is faster than many of the other techniques, relatively cost-effective at a cost of approximately US $160 per 2 ml, and can be carried out arthroscopically.

Stafford *et al.* [37] showed that the use of fibrin glue is both safe and effective for cartilage repair. In their study, the modified Harris Hip Score (mHHS) [39, 40] improved from 61.9 pre-operatively to 79.4 post-operatively with a mean follow-up time of 28 months. Although this result is promising, there are also conflicting reports in the literature that show either no positive effect or even delayed healing of critical-sized defects [41, 42].

Cassar-Gheiti *et al.* [43] assessed the biomechanical stability of the acetabular articular surface using a physiological human cadaveric model. Among the techniques used in this study was fibrin glue. They found that while fibrin glue in comparison to other techniques such as a suture technique was easier to perform, in isolation, it did not provide sufficient fixation to repair chondral flaps on the acetabular surface. Furthermore, the stability of the flap repair was unsatisfactory. Fibrin glue represents a potentially viable method of enhancing the repair of articular cartilage hip damage. However, due to the variance in technique and sparse studies assessing its efficacy, more consistent methods and data are needed to confidently determine whether its use in articular cartilage repair of the acetabulum is beneficial.

Microfracture

Microfracture is a surgical technique that traces back over 60 years ago as a drilling procedure [44] and popularized more recently by Steadman [28, 29, 45]. The technique of microfracture is to demarcate a cartilage defect and then perforate the underlying bone, allowing the bone marrow and progenitor cells within it to fill the defect. Microfracture is routinely performed in the knee, but its use in the hip has only recently become common [46, 47] (Fig. 4). The microfracture technique involves the creation of several holes in the subchondral bone at evenly spaced distances to allow bleeding and migration of bone marrow nucleated cells and growth factors into the defect [47]. These cellular elements and growth factors eventually produce the fibrocartilaginous tissue that fills the defect [46]. Although microfracture awls have been developed and used extensively in the acetabulum, the angle of entry is quite unfavorable to address the lateral rim of the acetabulum where most defects occur. When awls are used, one

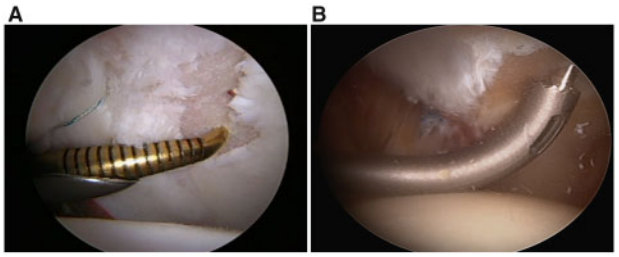

Fig. 4. A curved, sharp awl is used for microfracture of the acetabulum in a hip with a peripheral cartilage lesion. (**A**) Due to the unfavorable angle of entry, the slotted cannula is used as a fulcrum to direct the awl into the bone rather than across the bone. (**B**) A curved drill is used to achieve a perpendicular angle of entry for acetabular microfracture.

method to address the difficulty of perpendicular access to the defect has been to use a slotted cannula as a buttress under the microfracture awl during impaction (Fig. 4A).

The microfracture technique has been improved to a great degree using curved drills that have recently become available [46] (Fig. 4B). These allow a directional change between the cannula and the angle of drilling with less risk of damage to the subchondral bone that the traditional microfracture awls. The concern about using powered drills is that they may lead to thermal necrosis of the bone.

Another disadvantage of microfracture in the acetabulum is that the native cartilage is thinner and there are often un-contained lesions with no firm shoulders to which the microfracture tissue can heal.

Philippon *et al.* [48] performed hip arthroscopy on 122 patients with femoroacetabular impingement with a minimum 2-year follow-up. Of this group, 47 required microfracture (8 femoral, 30 acetabular and 9 both surfaces). There was no difference in mHHS in the patients treated with or without microfracture (81 versus 86, respectively, $P = 0.215$). Ten patients required total hip replacement at a mean of 16 months after the procedure. The patients undergoing microfracture of both surfaces were significantly more likely to require a total hip replacement.

Karthikeyan *et al.* [49] performed acetabular microfracture in 20 patients and then evaluated them by second-look arthroscopy. At an average follow-up of 17 months, 19 of 20 patients had a mean fill of 96% of the lesions with macroscopically healthy repair tissue. The remaining patient had a 25% fill of the lesion with poor quality tissue. They showed a general improvement based on the Nonarthritic Hip Score [50] by specifying statistical significance.

Domb *et al.* [51] reported on a cohort of 79 patients with full-thickness (Outerbridge IV) cartilage lesions undergoing microfracture matched to a cohort of 158 patients with Outerbridge grade III or less cartilage lesions who did not undergo microfracture. They found improvement in both groups. The patients undergoing microfracture had equivalent outcomes at 2 years to those in the control groups based on their patient-reported outcomes (PRO) with the exception of the visual analog scale (VAS) which was significantly higher in the microfracture group. Satisfaction was significantly higher in the control group (7.2 for microfracture versus 8.04 for the control group). Both group's PROs increased at all time intervals. At 3 months and 1 year, there was no difference in the change from pre-operative PROs between the microfracture and control groups. However, at 2-year follow-up, the microfracture group had a significantly lower improvement in PROs relative to the control group. Lodhia *et al.* [52] presented data from the same center with an average follow-up of 32.7 months on 35 patients with microfracture for chondral defects compared with a control group of 70 patients that did not have a cartilage defect matched based on gender, age, Workman's compensation status, labral treatment and acetabular cross-over percentage. They found no significant difference in post-operative PRO scores between the groups except for the Hip Outcome Score-Activity of Daily Living (HOS-ADL) and VAS where the control group proved to have superior outcomes.

Hevesi *et al.* [53] performed a multicenter study on a total of 113 hips with acetabular labral articular disruption lesions with unipolar grade 3 or 4 acetabular cartilage delamination. This cohort was treated with debridement/abrasion (82 hips) or microfracture (31 hips). There was no difference in the size of the lesions. At 5 years, the cartilage treatment led to no difference in the PRO of the VAS, mHHS and Hip Outcome Score-Sports Specific Subscale (HOS-SSS) [54] and was found to not be predictive of revision surgery. One weakness of this study was that the determination of the final cartilage treatment was not established prospectively in a random manner which may lead to bias in the selection of the cartilage treatment technique.

McDonald *et al.* [55] studied return to play after microfracture in a retrospective study of 39 elite athletes undergoing arthroscopic microfracture and comparing them to 94 hips treated in elite athletes treated without microfracture . In the microfracture group, 79% returned to play at a high level in comparison to 84% in the control group. There was no difference in the rate of return between groups.

MacDonald *et al.* [56] performed a systematic review of articles involving microfracture as an adjunct to hip arthroscopy. They identified 12 articles involving 267 patients. Eleven of these studies demonstrated positive results with

hip arthroscopy with microfracture. Of all patients, 0.7% developed a complication and 1.1% required additional surgery at a mean follow-up of 29.5 months. There were major limitations to the conclusions of these studies based on the small size, loss of patients to follow-up, lack of long term follow-up and variations in rehabilitation protocols.

In conclusion, microfracture is a commonly used technique for acetabular cartilage repair because it is relatively inexpensive and easy to perform compared with other techniques [47]. However, there is concern about the lack of durability of the repair tissue, potential subchondral cyst formation and damage to the subchondral bone plate.

Augmented microfracture

Over the last two decades, several methods of augmentation of microfracture have been developed. The goal of these procedures is to provide a mechanical scaffold upon which the cells released from the subchondral bone can build the cartilage repair tissue. One strategy for augmented microfracture has been the use of extracellular matrix cartilage allografts (EMCAs). These are dessicated, particulated allograft cartilage tissue (BioCartilage®, Arthrex, Naples, FL, USA and Cartilage Allograft Matrix®, MTF, Edison, NJ, USA) that is rehydrated with blood or platelet-rich plasma. EMCAs were developed to address some of the concerns and limitations of microfracture, mainly in the knee. This includes unpredictable volume, poor outcome in larger defects and intraarticular osteophyte formation [57]. The dry nature of the matrix facilitates its 3–5-year storage time at ambient temperatures. The EMCA is then placed into a cartilage defect after the completion of microfracture [57]. The main advantage of EMCA is as a one-stage method to enhance traditional microfracture procedures [58]. EMCAs contain the extracellular matrix that is native to articular cartilage. They are believed to act as a scaffold over a microfractured defect to provide a tissue network and to improve the degree and quality of tissue healing within a properly prepared articular cartilage defect. For example, BioCartilage® has been shown to achieve higher degrees of Type II collagen, histological scores and graft integration into the surrounding cartilage in a large animal model [57].

In their preparation, EMCAs are mixed mechanically in a syringe with Platelet Rich-Plasma (PRP) in a 1:1 or 1:0.8 of matrix to PRP ratio. Then, a delivery needle is applied to the end of the syringe and the mixture is dispensed into the previously prepared defect. Once injected, the EMCA covered with fibrin glue.

There have been no large trials involving EMCAs in the treatment of acetabular cartilage lesions although case reports and anecdotal reports have been presented [59] (Fig. 5).

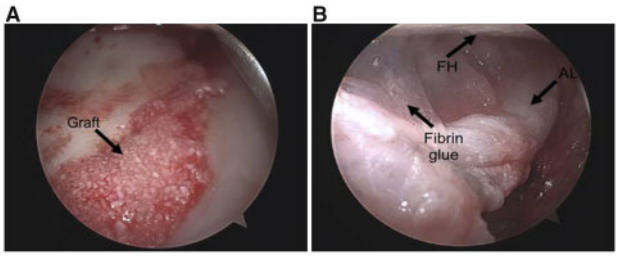

Fig. 5. Arthroscopic view of an acetabular cartilage lesion after application of a BioCartilage® graft. (**A**) The graft is slightly recessed relative to the surround articular cartilage to permit placement of fibrin glue. (**B**) Arthroscopic view of the repaired region showing the acetabular labrum (AL) and the femoral head (FH) after application of the fibrin glue. (With Permission, Schallmo *et al.*, *Arthroscopy Techniques*).

If extrapolation of animal and human knee data holds true for the acetabulum, EMCAs may prove to be one of the most practical methods of treating small acetabular defects.

This material represents a shelf-stable cartilage matrix with particular benefit in cases where microfracture alone is felt to be inadequate either due to the larger size of the lesion or due to the higher physical demands of the patient. Challenges remain for arthroscopic delivery in the hip due to the need for a dry field and the vertical orientation of the acetabular rim in supine and lateral decubitus hip arthroscopy.

Another promising technique in the treatment of cartilage lesions has been augmentation of microfracture with a chitosan-based scaffold. Chitosan is a common polysaccharide derived from the exoskeleton of crustaceans and has the advantages of biocompatibility, biodegradability and adhesivity. In this technique, a chitosan-based medical device, BST-CarGel® (Smith & Nephew, London, UK) is mixed with autologous whole blood and applied to the area of microfracture to stabilize the clot and enhance marrow repair.

In a randomized controlled study in the knee comparing microfracture with and without this matrix in 80 patients, it improved the filling from 85% to 93% but showed no difference in clinical outcome at 12 months [60]. The improvement in repair tissue was maintained at 5-year follow-up [61]. In the acetabulum, Tahoun reported on 23 patients treated with acetabular cartilage repair with this technique and achieved a result with 91% of patients meeting or exceeding a minimal clinically important difference [62] (Fig. 6).

Rhee *et al.* [63] demonstrated the safety and short-term efficacy of the BST-CarGel® treatment as an augmentation

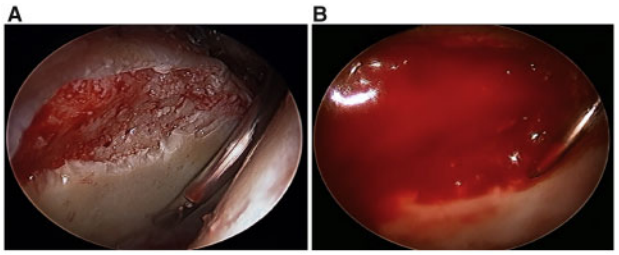

Fig. 6. (**A**) Arthroscopic view of a right hip viewed from the anterolateral portal with acetabular cartilage lesion subsequent to debridement and microfracture. (**B**) Same lesion after application of chitosan-blood mixture with a spinal needle. (With Permission, Tahoun *et al.*, *Arthroscopy*).

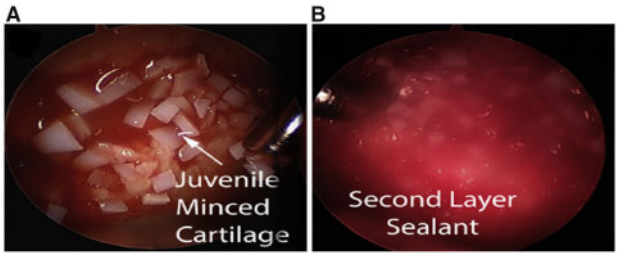

Fig. 7. Juvenile allograft cartilage is inserted through a curved drill guide into the defect after previously applying a layer of fibrin glue (**A**). A second layer of fibrin glue is applied over the allograft cartilage sealing it in place (**B**). (With Permission, Pascual-Garrido *et al.*, *Arthroscopy Techniques*).

to microfracture of the acetabulum. They evaluated 37 hips in patients with a mean age of 36 years at a mean follow-up of 12.7 months. Patient-reported outcomes improved for the group as a whole. There were no major adverse events except for two patients (5.4%) being readmitted for pain which the authors attributed to an inflammatory reaction to the BST-CarGel®.

Arthroscopic juvenile allograft cartilage transplantation

Particulated juvenile cartilage allograft (PCA) (DeNovo NT®, Zimmer, Warsaw, IN, USA) is a tissue used for cartilage repair in which allograft cartilage is obtained from allograft donors younger than 13 years. The PCA procedure is based on the principle that juvenile articular cartilage demonstrates improved healing potential compared with adult tissue and that it produces significantly more extracellular matrix than mature cartilage [64]. Furthermore, juvenile cartilage has been shown to produce Type II collagen *in vitro* and its clinical application is aimed to lead to improved tissue histology and durability [20, 64].

In the acetabulum, the PCA technique holds particular promise in that it is a one-stage procedure and that the handling of the allograft tissue is relatively straightforward. Arthroscopic management of fluid within the joint and efficient injection of fibrin glue makes this procedure challenging similarly to EMCA procedures. There is no need to violate the subchondral bone which can, in and of itself, potentially lead to joint pain. Disadvantages of the procedure are the relatively high cost of the graft, limited volume of graft available for larger lesions, and limited instrumentation available for the procedure. Additionally, the thin cartilage of the acetabulum does not provide the same degree of graft containment as seen in other sites such as the knee. Much like EMCAs, there are only case reports and technical descriptions of the use of PCAs in the acetabulum [65] (Fig. 7).

Autologous chondrocyte implantation

Autologous chondrocyte implantation (ACI) was one of the first tissue-engineered techniques utilized clinically. Brittberg *et al.* [30] published the first clinical trial using ACI in the knee in 1994. In 1997, this procedure was approved by the US FDA. Traditional ACI is a two-stage procedure. During the first stage, chondrocytes are harvested arthroscopically from one of the patient's joints and grown in a laboratory. During the second stage, the cells are implanted beneath a patch sewn over the defect in a water-tight manner. In the acetabulum, due to the minimal thickness of the cartilage and the presence of the femoral head, the traditional technique of a patch and suture is impractical if not impossible. However, a more efficient method of ACI has recently been developed which has been utilized in the hip. This technique is called the autologous matrix-induced three-dimensional chondrocyte transplantation using three-dimensional spheroids (ACT 3 D) (Fig. 8).

In this technique, cartilage is obtained from the femoral head at the planned site of femoral osteochondroplasty. That cartilage is removed and is cultured for 5–10 weeks and formed into cartilage spheroids. According to the original technique description published by Schubert *et al.* [26], the cartilage is minced and digested and then resuspended in culture with added human serum from the patient. The spheroids are generated by seeding the third generation chondrocytes on hydrogel-coated cell culture plates. After 1 week, 4–12 spheroids are transferred into each well to allow coalescence. After 2 weeks, the fused spheroids are used for the experiment. This technique is now commercially available in the European Union by CO.DON AG (Teltow, Germany) under the commercial name Spherox®. The results of the ACT 3D procedure in the hip have been reported in two papers. Körsmeier *et al.* [66] reported on the outcome of the procedure in 16 patients with an average defect size of 4.52 cm^2 (ranging

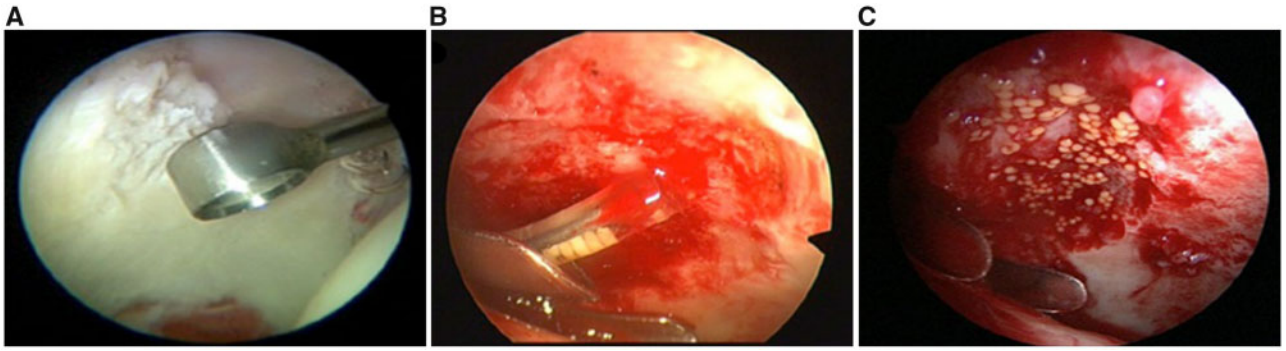

Fig. 8. (**A**) The lesion is debrided using a curette or shaver. (**B**) The spheroids are applied into the lesion using a flexible needle and spread out with a probe. (**C**) The spheroid fills the defect in a uniform manner. (With Permission, Körsmeier *et al.*, *Knee Surgery, Sports Traumatology, Arthroscopy*).

from 3 to 6 cm^2). The mean follow-up was 16 months. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Non-Arthritic Hip Score (NAHS) both increased significantly from the preoperative scores to latest follow-up with the greatest improvement noted in the first 6 weeks after the procedure. Schroeder *et al.* [67] published on a series of 20 patients treated with ACT 3D with an average defect size of 5.05 cm^2 (range 2–6) . Labral repair was performed in 18 cases. Cam decompression was performed as needed but the total number of hips undergoing this procedure was not specified. The average follow-up was 12 months. Three months post-operatively, the mHHS improved from a mean of 63 to a mean of 81 points and further to a mean of 93 points at 12 months ($P = 0.017$). Similar improvements were noted in the iHOT33 [68] scores. Krueger *et al.* [69] reported on the same series with 32 consecutive hips with a minimum 36-month follow-up with an average defect size of 4.9 cm^2 (range 2–6). At the 3-year follow-up, the mHHS scores had improved from 64 to 91 and from 44% to 86% for iHOT33 (both $P < 0.001$).

In summary, the use of ACT 3D holds promise in treating acetabular cartilage lesions. It is technically similar to the use of microfracture augmentation techniques but has the advantage of implantation of a more mature population of autologous chondrocytes. Disadvantages include the lack of availability in the United States, the risk of contamination in the laboratory prior to implantation, the need for two surgical procedures and higher costs.

Scaffold-based treatments: Matrix-Induced Autologous Chondrocyte Implantation and Autologous Matrix-Induced Chondrogenesis

Two recent procedures, Matrix-Induced Autologous Chondrocyte Implantation (MACI) and Autologous Matrix-Induced Chondrogenesis (AMIC), have been developed for cartilage repair in full-thickness, symptomatic chondral defects.

MACI is a variation of ACI where the cultured chondrocytes are seeded onto a matrix scaffold and placed into the joint with the scaffold rather than under a patch. The scaffold is usually fixed into place with a combination of fibrin glue and/or sutures. A recent systematic review of MACI in the knee has demonstrated significant improvements in clinical scores and total 'treatment failures' of only 9.7% among seven of the studies that reported them with a minimum follow-up of 5 years [25]. These failures included osteoarthritis progression, graft delamination and lack of clinical improvement. This technique holds promise as an autologous method of treatment of cartilage lesions without the challenges of suturing a patch to the surrounding tissue in a water-tight manner. The main disadvantage of the MACI technique is the high cost and the two surgical procedures required for the treatment.

To address these disadvantages, Behrens *et al.* [70] introduced a related technique called AMIC. In this technique, a one-stage procedure is performed with performance of a microfracture to open the subchondral bone and to release bone marrow-derived progenitor cells into the defect. The defect is then covered with a matrix scaffold, usually the same type of collagen I/III matrix as used in MACI. However, with AMIC, the patch does not contain any chondrocytes but is instead populated by the released bone marrow progenitor cells found in the joint or by the microfracture procedure [71] (Fig. 9).

Both AMIC and MACI are indicated for full-thickness symptomatic chondral defects. Contraindications include infections, inflammatory arthritis, tumors and a compromised joint space [72]. Both procedures have thus far had favorable outcomes in the hip. According to a study conducted by Mancini and Fontana [73], 57 consecutive patients with acetabular lesions were treated with MACI

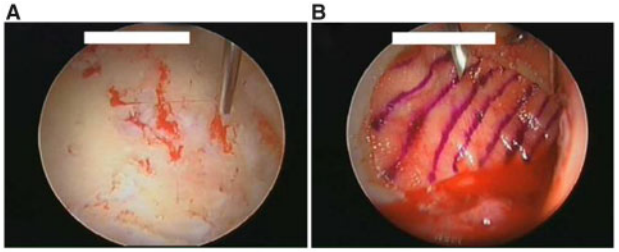

Fig. 9. An acetabular cartilage lesion is debrided and subsequently treated with microfracture (**A**). Next, the Chondro-Gide matrix is brought into the joint and placed to cover the defect. The matrix has a smooth and a rough surface. Markings are placed on the smooth surface so that the rough surface faces the subchondral bone (**B**). (With Permission, Fontana, *Arthroscopy Techniques*).

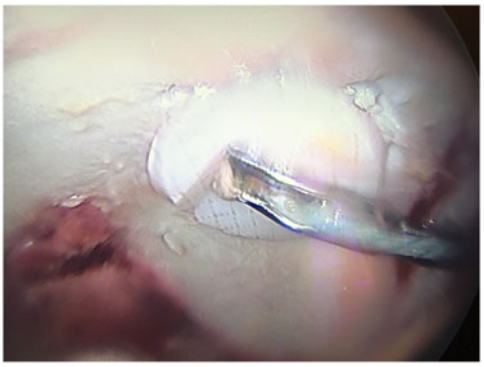

Fig. 10. Dry arthroscopy view of a fresh cryopreserved osteochondral allograft patch (Prochondrix, Allosource, Centennial, CO, USA) applied arthroscopically to the acetabular roof in a cadaveric specimen.

($n = 26$) or AMIC ($n = 31$) (Fig. 10). They were followed with the mHHS. The pre-operative mHHS were 46.5 ± 7 for the MACI group and 44.9 ± 5.9 for the AMIC group. These scores increased by 37.8 ± 5.9 and 39.1 ± 5.9 for the MACI and AMIC groups, respectively. There was no significant difference in outcome between the groups.

Another study conducted by Fontana and de Girolamo [74] compared outcomes of microfracture in 77 patients to AMIC in 70 patients. The treatment was determined based on insurance coverage of the collagen patch. The patients underwent concurrent treatment of femoroacetabular impingement. Microfracture was performed with a chondral pick for all patients. In the AMIC group, a collagen Type I/III matrix (Chondro-Gide®, Geistlich Pharma AC, Wolhusen, Switzerland) was cut to fit the lesion and applied with the porous side facing the bone. Traction was released and the stability of the patch was checked. If needed, fibrin glue can be used to augment the fixation of the scaffold. In both groups, the mHHS improved significantly at all time points. The mean mHHS in the microfracture decreased at between 4 and 5 years, while the improvement of the scores in the AMIC group continued. A subgroup from this series with 8-year follow-up consisted of 130 patients with 109 patients meeting the inclusion criteria for the study (59 AMIC versus 50 microfracture) [75]. At a minimum of 8 years, the results were superior for the AMIC group. A total of 11 patients undergoing total hip replacement in the microfracture group was compared with no patients in the AMIC group.

Thorey *et al.* [76] reported on a series of 62 patients with either isolated chondral lesions or chondral lesions associated with Cam type femoroacetabular impingement (FAI) treated with hip arthroscopy and the AMIC procedure. In those patients with impingement, the cartilage procedure was combined with femoral osteochondroplasty. At 2-year minimum follow-up, they achieved statistically significant improvements in the Hip disability and Osteoarthritis Outcome Score (HOOS) [77] (58.8 ± 7.4 pre-op to 90.6 ± 7.1 at latest f/u), mHHS (53.4 ± 6.6–82.4 ± 8.2 at latest f/u) and a significant decrease in the VAS from 4.9 ± 1.1 pre-operatively to 1.1 ± 0.8 at latest follow-up. Importantly, they excluded patients with coexisting chondral lesions of the femoral head, pincer or mixed type FAI and labral tears.

FUTURE DIRECTIONS

Osteochondral patches

Osteochondral allograft patches Cartiform® (Arthrex, Naples, FL, USA) and Prochondrix® (Allosource, Centennial, CO, USA) have recently been provided by tissue banks. These patches address some of the shortcomings of other types of cartilage repair. These grafts are osteochondral in nature but have only a thin layer of calcified cartilage on the non-articular side. They are cryopreserved, allowing them to be stored for long periods of time while maintaining chondrocyte viability. Finally, due to their mechanical flexibility, they can be contoured to complex surfaces such as the knee trochlea or acetabulum. The technique for these procedures typically requires the performance of a microfracture followed by application of the graft onto the cartilage defect. The grafts can then be secured either with suture anchors or with fibrin glue (Fig. 10).

We know of no peer-reviewed publications on the use of these types of grafts in the acetabulum. However, based on early reports, some of the challenges of these grafts in the acetabulum are the presence of a concave acetabular surface. The grafts often have a convex shape memory as they are often harvested from the condylar surface of the

knee. Other difficulties with these grafts include the increased thickness of the grafts relative to the acetabular cartilage and the difficulty in securing the grafts with suture anchors or with fibrin glue for durable fixation.

Fresh osteochondral allografting

Fresh osteochondral allografting is one of the oldest and most validated treatments for articular cartilage defects [23, 24, 27, 78, 79]. In fact, this procedure has demonstrated the long-term cell survival of the donor cell population in the recipient for nearly 30 years [80]. The chondrogenic potential and gene expression of transplanted chondrocytes have been confirmed *in vivo* [81]. In the acetabulum, it has had a limited role due to the difficulty in access as well as the high degree of precision involved in restoring the articular surface. Coring systems, as have been used in the femoral head and in the knee, have limited capacity to address the hemispherical surface of the lateral rim of the acetabulum where most lesions occur. Limited transplantation with wedge-shaped grafts may be an option in selected cases. New instrumentation has been developed to facilitate partial acetabular grafts that are wedge shaped. These grafts can be transplanted effectively with a surgical dislocation approach and are more suited to the acetabulum that the traditional allograft core grafts commonly used in the knee (Fig. 11).

In patients who are very young and who have large acetabular cartilage or structural defects and/or osteoarthritis, osteochondral transplantation of the entire acetabulum is an alternative to total hip replacement (Fig. 12). Oladeji *et al.* [15] reported on 10 patients treated with osteochondral allograft transplants of the hip, of which only one had full resurfacing of the femoral head and the acetabulum. That procedure was performed in a 22-year-old female patient

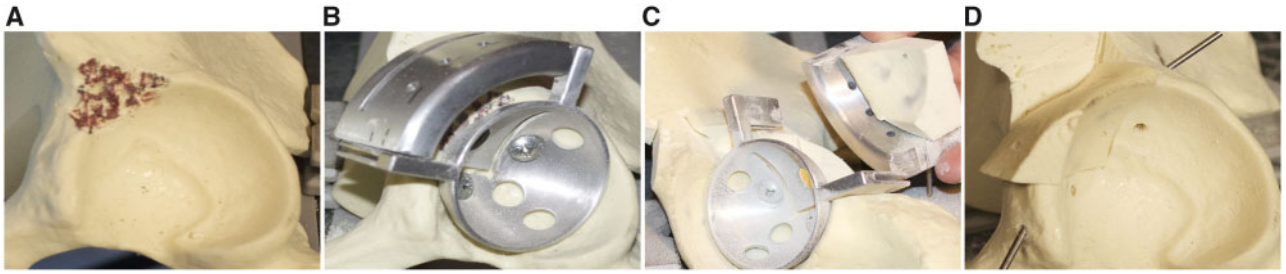

Fig. 11. A foam bone model (Sawbones, Vashon Island, WA, USA) is prepared with a structural defect in the anterior superior acetabulum involving the area commonly involved in femoroacetabular impingement (**A**). A size appropriate cutting tool is applied to the acetabulum for the purpose of transplantation of a 90° wedge of acetabular bone as an osteochondral allograft. A 90° wedge is removed with the tool (**B**). The same guide is applied to a second model, acting as a donor and harvesting a separate section of the acetabulum, in this case, the posterior wall segment. In this image that wedge has been removed and is shown to the right of the image (**C**). The osteochondral allograft wedge is next applied to the recipient site prepared in Fig. 11B. There is precise restoration of the entire segment of the acetabulum with no step-offs facilitating smooth joint function (**D**).

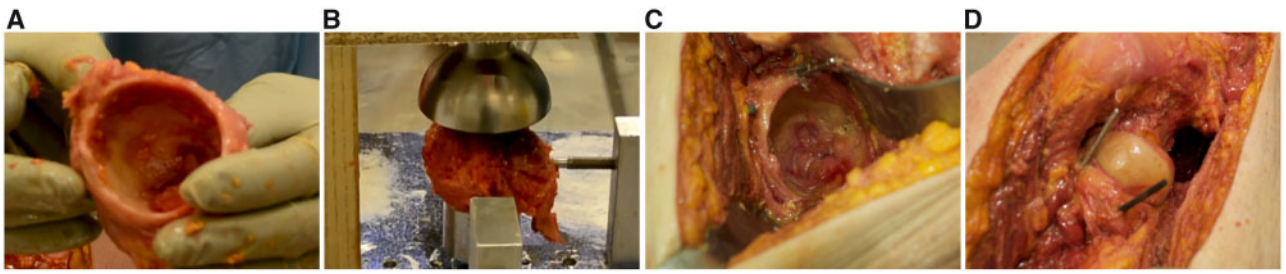

Fig. 12. Osteochondral allograft transplantation of the entire acetabulum can be performed by removing the entire acetabulum using cuts through the ilium, ischium and pubis on the donor (**A**). The sharp edges of bone are removed and the acetabular graft is placed on a work station with a hemispherical platform upon which the graft socket is placed. The graft is further secured with multiple pins from its periphery. An attached reverse hemispherical reamer is brought down onto the graft stopping at a desired distance above the hemispherical platform to establish a set thickness of the graft (**B**). The patient's diseased acetabulum is then reamed with standard hip replacement reamers and the prepared graft is impacted into position achieving press-fit into the patient's acetabular cavity (**C**). Additional fixation can be applied in the periphery of the graft shown with temporary pins and with the hip reduced (**D**).

with post-traumatic arthritis. The operative time for the procedure was over 350 min. At the latest follow-up, that patient had not required a total hip replacement.

In the acetabulum, osteochondral allografts are limited in a number of ways. First of all the grafts for this type of procedure are very expensive and difficult to obtain. Most tissue banks only provide these as a special order graft with limited availability. Due to the proximity to the bowel and risk of contamination with intestinal bacteria, acetabular grafts are not usually processed by tissue banks. Finally, most surgeons who perform this surgery have used instruments from total hip replacement or hip resurfacing that are not ideally suited to perform these procedures. These challenges must be considered in the setting of an alternative treatment, namely, total hip replacement, with excellent outcomes, even in young patients. Ongoing areas of research will be directed to methods of decontaminating these grafts while also developing new techniques and instrumentation for these challenging procedures.

Cost analysis

As described above, there are many options available in the treatment of acetabular cartilage lesions. These have been summarized in Table I. The choice of treatment modality is dictated to some extent by the age and activity level of the patient, the size and depth of the lesion, and the availability of the technique based on national and local regulations. In today's world of skyrocketing healthcare spending, it is necessary for surgeons and administrators to have some idea of the cost of the various treatments. The overall cost of any cartilage repair technique depends on a number of factors including the number of surgeries needed, the cost of the implant, the additional time needed for implantation and the need for arthroscopic versus open surgery with the open surgery often requiring an inpatient hospital stay with increased costs. We have sought to calculate the costs of the various treatment options based on the best available data. As noted in Table II, the treatment modalities with only one surgery and no implant have the lowest total cost. Adding a preliminary surgery to harvest cartilage from the knee for procedures, such as MACI or ACI adds an additional cost. We have set this cost to $3500 based on usual in-network rates of reimbursement by insurance plans in the United States although these costs can vary based on the geographic location of the procedure. For standard hip arthroscopy, we have set the cost at $8000 based on the same guidelines. Additional time used for the cartilage repair technique has been assigned a cost of $1000 per hour with most procedures requiring additional time, between 15 min such as for the cartilage suture technique, 30 min for repair using fibrin glue or microfracture and 45 min when using EMCAs, chitosan, PCAs, 3D ACT, MACI or AMIC. We have sought to obtain the costs of the various treatment options either from the manufacturer as in the case of BST-CarGel®, DeNovo®, Cartilage Allograft Matrix® and Spherox®. In other cases, the pricing was obtained by third party sellers for items such as BioCartilage®. In other, cases, information on pricing was available from government reports on pricing such as for MACI. For MACI, pricing was available from Australia in 2010 and from the United Kingdom in 2017 [82, 83]. We have converted those prices to the contemporary prices in the United States based on the exchange rates at the time. For MACI, we have selected the higher value as it was more recently obtained. Finally, we have obtained direct pricing information from our own cases for the use of specialize drills used from microfracture/drilling, fresh osteochondral allografts and for procedures involving a collagen patch as used in the AMIC technique. For inpatient procedures, such as fresh osteochondral allografting, we have set the cost of the surgical procedure at $20 000 to include an inpatient stay and the cost of the implant at $14 000 based on information from various vendors. These numbers can vary widely based on geographic location and the use of cash pay versus insurance contracted rates. Additionally, some procedures such as chitosan, AMIC, MACI are not necessarily approved by the US FDA for applications in the acetabulum.

CONCLUSION

Acetabular cartilage injuries can be caused by an array of factors that include trauma as well as morphological variations. Although the causes of these injuries are complex, evolving surgical techniques have led to promising results. Hip arthroscopy provides the best surgical route to treating limited acetabular cartilage injuries. For larger lesions, surgical hip dislocation is an excellent option. All of the techniques presented in this study offer a biologic solution to hip pathology in contrast to artificial bearing surface replacements, such as total hip resurfacing or standard hip replacement. The development of a biological solution in the hip reduces the inherent risks of total hip arthroplasty including early loosening, metal sensitivity and loss of bone stock for future surgeries, factors that are especially important for young, active patients. Regardless of the method selected, the goal of any cartilage repair technique should be restoration of articular surface congruity, the development of a durable biologically active surface, the decrease in joint inflammation and synovitis, and the preservation of normal joint kinematics to allow for smooth and pain-free range of motion.

Table I. Literature summary of studies reporting outcomes of acetabular cartilage repair

Reference	*Authors*	*Year*	*Number of subjects*	*Mean age*	*Genders*	*Diagnoses*	*Procedure*	*Mean follow-up time*	*Pre-op outcome measurement*	*Post-op outcome measurement*
[37]	Stafford *et al.*	2011	43	34.2	25 M, 18 F	Delaminated acetabular articular cartilage	Fibrin adhesive	28 months	mHHS: 61.9	mHHS: 79.4
[38]	Tzaveas and Villar	2010	19	36	5 M, 14 F	Acetabular chondral delamination	Excision of chondral flaps	12 months	mHHs: 58.3 ± 20.5	mHHs: 80.3 ± 21.3
[48]	Philippon *et al.*	2009	112 (39 microfracture of acetabulum ± femoral head)	40.6	50 M, 62 F	FAI and chondrolabral dysfunction	Microfracture	27.6 months	mHHS: 58	mHHS: 84.3, no difference in mHHS with or without microfracture
[49]	Karthikeyan *et al.*	2012	20	37	16 M, 4 F	Isolated full-thickness acetabular cartilage defects in patients with FAI	Microfracture, evaluated by second-look arthroscopy	21 months	NAHS: 55	NAHS: 78, 19 of 20 patients with 96% fill, one patient with 25% fill by second-look arthroscopy.
[51]	Domb *et al.*	2015	79 (for microfracture group); 158 (for non-microfracture group)	44	47 M, 32 F (for microfracture group); 94 M, 64 F (for non-microfracture group)	Full-thickness chondral defect	Microfracture	29.1 months (microfracture group); 27.7 (non-microfracture group)	Microfracture group—mHHS: 60.66 ± 17.4; NAHS: 55.85 ± 19.42; VAS: 5.84 ± 2.19 non-microfracture group—mHHS: 59.71 ± 14.48; NAHS: 54.86 ± 17.71; VAS: 6.0 ± 2.01	Microfracture group—mHHS: 77.91 ± 17.82; NAHS: 74.90 ± 20.29; VAS: 3.63 ± 2.50 Non-microfracture group—mHHS: 81.34 ± 17.70; NAHS: 79.26 ± 19.07; VAS: 2.82 ± 2.35 Patients undergoing microfracture had equivalent PRO scores compared with control group at 2 years. The change in PROs from pre-operatively to 2 years was lower in the microfracture group. The VAS scores and satisfaction

(continued)

Table I. (continued)

Reference	Authors	Year	Number of subjects	Mean age	Genders	Diagnoses	Procedure	Mean follow-up time	Pre-op outcome measurement	Post-op outcome measurement
										scores were lower in the microfracture group.
[52]	Lodhia *et al.*	2015	35 (for microfracture group); 70 (for non-microfracture group)	41.8 (28.5–53.9) microfracture group, 42.1 (24.2–61.3) non-microfracture group	23 M, 12 F microfracture group, 46 M, 24 F non-microfracture group	Full-thickness chondral defect	Microfracture	32.7 months (microfracture group), 30.3 months (non-microfracture group)	Microfracture group—mHHS: 61.76 ± 18.29; NAHS: 56.44 ± 20.15; HOS-ADL: 63.01 ± 20.03; HOS-SSS: 42.14 ± 24.18; VAS: 5.94 ± 2.40 Non-microfracture group—mHHS: 59.17 ± 15.32; NAHS: 56.06 ± 18.72; HOS-ADL: 61.63 ± 19.84; HOS-SSS: 37.59 ± 25.13; VAS: 6.06 ± 1.94	Microfracture group—mHHS: 77.02 ± 14.78; NAHS: 72.32 ± 16.14; HOS-ADL: 73.58 ± 19.14; HOS-SSS: 61.14 ± 26.09; VAS: 3.94 ± 2.29 Non-microfracture group—mHHS: 77.62 ± 18.45; NAHS: 77.18 ± 18.02; HOS-ADL: 81.97 ± 19.47; HOS-SSS: 63.65 ± 27.92; VAS: 2.94 ± 2.41 no difference in outcomes between pre-operative and latest follow-up except for HOS-ADL and VAS both of which were significantly better in the non-microfracture group.
[53]	Hevesi *et al.*	2019	113	32.8 for debridement, 39.1 for microfracture	34 F, 48 M debridement, 11 F, 20 M for microfracture	Grade 3 and 4 acetabular labrum articular disruption (ALAD) with large chondral flaps or full-thickness cartilage loss	Microfracture versus debridement/Abrasion	59 months	VAS 5.6 ± 2.3 for Debridement, 5.1 ± 2.6 for microfracture mHHS 64.9 ± 14.9 for Debridement, 65.5 ± 16.8 for Microfracture HOS-SSS 47.1 ± 26.1 for Debridement 45.6 ± 27.5 for Microfracture	VAS 2.0 ± 2.0 for Debridement, 2.6 ± 2.6 for microfracture mHHS 86.1 ± 15.5 for Debridement, 81.3 ± 18.4 for Microfracture HOS-SSS 72.5 ± 26.4 for Debridement 66.3 ± 26.5 for Microfracture
[55]	McDonald *et al.*	2013	39 hips (microfracture of grade IV chondral defect); 94 hips in 81 athletes	30.3 for treatment group; 28.5 for control group	120 M, 0 F	Grade IV chondral defect	Microfracture	3 seasons		77% returned to play in the microfracture group and 84% in the

(continued)

Table I. (continued)

Reference	Authors	Year	Number of subjects	Mean age	Genders	Diagnoses	Procedure	Mean follow-up time	Pre-op outcome measurement	Post-op outcome measurement
			(no grade IV chondral defect, no microfracture)							control group returned to play. No significant difference in return to play between the groups.
[56]	MacDonald *et al.*	2016	267 (systematic review, 12 publications)	38.3	202 M, 65 F	Chondral defects of the hip	Microfracture	29.5 months		Outcomes reported in literature are, in general, positive, with a very low percentage of patients requiring further surgery or experiencing complications
[62]	Tahoun *et al.*	2018	23	40.9	18 M, 5 F	Full-thickness cartilage lesion of acetabulum greater than 2 cm^2 with FAI	Microfracture-/chitosan-based scaffold	38 ± 7.0 months	NAHS 55.2 ± 13.4, IHOT33 43.1 ± 14.0	NAHS 85.6 ± 14.5, IHOT33 78.5 ± 15.6
[63]	Rhee *et al.*	2018	37	36.2	30 M, 7 F	Full-thickness acetabular cartilage defects larger than 2cm^2	Microfracture followed by application of BST-Cargel	12.72 months	iHOT 40.4 ± 19.7 HOS-ADL 60.6 ± 19.4 HOS-SP 36.9 ± 24.9	iHOT 59.1 ± 26.1 HOS-ADL 71.4 ± 22.9 HOS-SP 51.6 ± 31.0 (All parameters with statistically significant improvement from pre-op to latest follow-up)
[66]	Körsmeier *et al.*	2016	16	31.8	14 M, 2 F	Full-thickness cartilage defects of the hip joint	Autologous chondrocyte transplantation 3D	16.09 ± 5.3 months	NAHS pre-op: ~45 WOMAC pre-op ~56	NAHS at latest f/u: ~75, WOMAC at latest f/u ~92
[67]	Schroeder *et al.*	2016	20	33	16 M, 4 F	Full-thickness acetabular cartilage defects	Autologous chondrocyte transplantation 3D	12.05 months (range 6–24)	mHHS: 63, iHOT33 44	mHHS: 93, iHOT33 79 (12 month follow-up)
[69]	Krueger *et al.*	2018	32	33	28 M, 4 F	Full-thickness acetabular cartilage defects	Autologous chondrocyte transplantation 3D	36 months	mHHS: 64, iHOT33 44	mHHS: 91, iHOT33 86
[73]	Mancini and Fontana	2014	57	MACI 36.0 ± 9.3 years; AMIC 36.4 ± 10.3 years)	MACI (12 M, 14 F); AMIC (13 M, 18 F)	Acetabular chondral defects between 2 and 4 cm^2 due to femoral acetabular impingement	MACI (26) and AMIC (31)	60 months	MACI (mHHS: 46.5); AMIC (mHHS: 44.9)	MACI mHHS: 84.3; AMIC mHHS: 84.0
[74]	Fontana and de Girolamo	2015	147	Microfracture 39.3 years; AMIC 39.1 years	Microfracture (55 M, 22 F); AMIC (36 M, 34 F)	Acetabular grade III and IV chondral lesions	Microfracture (77) and AMIC (70)	6 months, 1, 2, 3, 4 and 5 years	Microfracture (mHHS: 47.1); AMIC (mHHS: 44.7)	Microfracture mHHS: 76.3; AMIC mHHS: 79.5 at 6 months. Microfracture results worsened over 5 years, AMIC was maintained at approximately same scores. Eight percent of Microfx patients

(continued)

Table I. (continued)

Reference	*Authors*	*Year*	*Number of subjects*	*Mean age*	*Genders*	*Diagnoses*	*Procedure*	*Mean follow-up time*	*Pre-op outcome measurement*	*Post-op outcome measurement*
										required THA, 0% of AMIC patients required THA
[75]	de Girolamo *et al.*	2018[109]		Microfracture 38.3 years; AMIC 39.3 years	37 M, 13 F for MFx and 27 M, 32 F for AMIC	Hip chondral lesions associated with FAI	Microfracture and AMIC	6 months and yearly for 8 years	mHHS: 46 ± 6.0 at 12 months	mHHS: 78 ± 8.8 at 12 months.
[76]	Thorey *et al.*	2019[62]		34.3 ± 5.4	28 M, 34 F	Acetabular chondral lesions 3.2 ± 0.9 cm^2, excluded those with coexisting chondral lesions of the femoral head, pincer or mixed type FAI, and labral tears	AMIC	25 months	HOOS: 58.8 ± 7.4, mHHS: 53.4 ± 6.6, VAS: 4.9 ± 1.1	HOOS: 90.6 ± 7.1, mHHS: 82.4 ± 8.2, VAS: 1.1 ± 0.8. All three scores showed significant improvement from pre-operative to latest follow-up

Table II. Cost analysis of acetabular cartilage repair techniques

Technique	*One/Two stage*	*Cell biopsy surgery (if needed) cost*	*Index procedure baseline cost*	*Index procedure implant or special equipment cost*	*Index procedure (additional time in hours)*	*Index procedure (additional time, $1000 per h)*	*Index procedure estimated cost*	*Total estimated treatment cost*	*Comments*
Standard techniques with minimal additional equipment									
Chondroplasty	One	0	$8000.00	$0.00	0.00	$0.00	$8000.00	$8000.00	0 USD due to routine use of shaver in hip arthroscopy procedures
Cartilage flap suture	One	0	$8000.00	$0.00	0.25	$250.00	$8250.00	$8250.00	0 USD due to likelihood of concurrent anchor placement for labral repair
Fixation with fibrin glue	One	0	$8000.00	$385.00	0.50	$500.00	$8885.00	$8885.00	Tisseel (Baxter) $160 USD/2 ml, Long applicator $65 (costs paid by our facility). Total $385.
Microfracture	One	0	$8000.00	$500.00	0.50	$500.00	$9000.00	$9000.00	$500 for rental use of microfracture drills at our facility.
Complex techniques with special implants									
Extracellular matrix cartilage allograft (EMCA) per ml	One	0	$8000.00	$1085.00	0.75	$750.00	$9835.00	$9835.00	Implant prices paid by our facility either through manufacturer or from 3rd party seller. $700 for implant, $385 for Tisseel and

(continued)

Table II. (continued)

Technique	*One/Two stage*	*Cell biopsy surgery (if needed) cost*	*Index procedure baseline cost*	*Index procedure implant or special equipment cost*	*Index procedure (additional time in hours)*	*Index procedure (additional time, $1000 per h)*	*Index procedure estimated cost*	*Total estimated treatment cost*	*Comments*
									applicator. Total $1085.
Chitosan	One	0	$8000.00	$2385.00	0.75	$750.00	$11 135.00	$11 135.00	$2600 (Canadian) per manufacturer, equivalent to $2000 USD as of 1/5/2020. $385 for Tisseel and applicator. Total $2385.
Particulated juvenile cartilage allograft (PCA) (per packet)	One	0	$8000.00	$5175.00	0.75	$750.00	$13 925.00	$13 925.00	Cost per manufacturer, $4790 per pack. $385 for Tisseel and applicator. Total $5175.
Three-dimensional spheroid autologous chondrocyte implantation	Two	$3500	$8000.00	$13 475.00	0.75	$750.00	$22 225.00	$25 725.00	Cost per manufacturer, 10 000 £ conversion to $13 090 as of 1/5/2020. $385 for Tisseel and applicator. Total $13 475.
Matrix-induced autologous chondrocyte implantation (MACI)	Two	$3500	$8000.00	$21 185.00	0.75	$750.00	$29 935.00	$33 435.00	16 000 £ (Equivalent to $20 800 at exchange rate of 0.77£ per USD in 7/2017). 11 400 AUD Dollars in 2010 (equivalent to $10 360 USD at exchange rate of 1.1 AUD per US $ in 1/2010), $385 for Tisseel and applicator.

(continued)

Table II. (continued)

Technique	*One/Two stage*	*Cell biopsy surgery (if needed) cost*	*Index procedure baseline cost*	*Index procedure implant or special equipment cost*	*Index procedure (additional time in hours)*	*Index procedure (additional time, $1000 per h)*	*Index procedure estimated cost*	*Total estimated treatment cost*	*Comments*
									Utilizing more up to date cost of $20 800, Tisseel with appilcator, $385. Total $21 185.
Autologous matrix-induced chondrogenesis (AMIC)	One	0	$8000.00	$885.00	0.75	$750.00	$9635.00	$9635.00	Cost for collagen patch at our facility $500, Tisseel with appilcator, $385. Total $885.
Osteochondral allograft flexible patches	One	0	$8000.00	$9171.00	0.75	$750.00	$17 921.00	$17 921.00	Cost per manufacturer, $8786, Tisseel with appilcator, $385. Total $9171.
Open procedures									
Osteochondral allograft transplantation	One	0	$20 000.00	$14 000.00	0.00	$0.00	$34 000.00	$34 000.00	

ALAD, acetabular labral articular disruption.

In summary, acetabular cartilage lesions pose a difficult clinical and surgical challenge. The currently available treatments include debridement, microfracture, augmented microfracture, ACI and osteochondral transplantation with particulated allograft tissue, osteochondral patches, and in the most involved cases, standard osteochondral allografts. Due to the lack of consensus, a simple algorithm for treatment is not currently available. The senior author treats smaller lesions with microfracture (up to 4 cm^2). For larger lesions, we prefer to augment the microfracture with EMCA. The options for treatment in the United States are more limited than in other parts of the world due to FDA regulations. We believe that no one technique has distinguished itself as the most effective. The use of injectable EMCAs and patch techniques, such as AMIC appear to have greater ease of use due to their low cost, history of clinical use in the hip and straightforward technique in contrast to osteochondral allografts or osteochondral patches. Osteochondral patches have the disadvantages of having to be ordered ahead of time, higher cost and difficulty in contouring to the surface of the acetabulum. Standard osteochondral allografts are useful only in cases of global damage to the acetabulum or in cases of structural trauma to the acetabulum.

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CONFLICT OF INTEREST STATEMENT

The senior author (AAJ) has developed techniques and instrumentation for osteochondral allograft transplantation in the acetabulum demonstrated in this manuscript in Figures 11 and 12. No other authors have any conflicts to declare.

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