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REVIEW ARTICLE

Surgical Management of Osteochondral Lesions of the Talus

[1]Samuel B Adams Jr MD, [2]Christopher E Gross MD, [3]David M Tainter MD, [4]Mark E Easley MD, [5]Selene G Parekh MD MBA

ABSTRACT

Osteochondral lesions of the talus (OLT) present a formidable treatment challenge to the orthopaedic surgeon. Historical cartilage repair strategies often result in the formation of fibrocartilage leading to suboptimal clinical results. With advances in regenerative medicine, modern surgical techniques are diverse and employ autograft, allograft and tissue-engineered constructs for cartilage repair. Fresh and particulated juvenile allograft transplantation have become popular options in the United States. Worldwide, both cellular and acellular tissue-engineered constructs are utilized. In all cases, there is still debate as to the optimal cell source and scaffold material and only short-term clinical results are available. This article will review these current as well as experimental techniques for cartilage repair of osteochondral lesions of the talus.

Keywords: Talus, Osteochondral, Lesion, Osteochondritis dissecans, Microfracture, OLT, Allograft, OATS, PJCAT, ACI, MACI, AMIC, Metal resurfacing, Cartilage.

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INTRODUCTION

Previously described as osteochondritis dissecans, osteochondral fracture, transchondral fracture and osteochondral defect, osteochondral lesion of the talus (OLT) refers to any pathology of the articular cartilage of the talus and corresponding subchondral bone. Osteochondral lesion of the talus is the preferred nomenclature; however, osteochondral lesion (OCL) of the talus is an acceptable alternative.

The poor intrinsic regenerative capacity of cartilage makes treating OLTs a particular challenge for orthopaedic surgeons. Historically, debridement and marrow stimulation to encourage cartilage repair was the mainstay of treatment. Unfortunately, this treatment often resulted in fibrocartilage formation leading to suboptimal clinical results. Innovations in cartilage repair have led to a plethora of modern surgical techniques; employing autograft, allograft and alternative cell sources for cartilage repair. Despite these recent advances, the paucity of comparative studies examining these techniques has led to a lack of consensus regarding surgical guidelines. This article will review the current techniques and supporting literature for surgical management of OLTs.

In general, operative treatment is indicated for lesions that remain symptomatic despite 3 to 6 months of nonoperative treatment or displaced OLTs of any chronicity. Many operative techniques have been described to treat OLTs; we will classify these treatment strategies as cartilage repair, regeneration or replacement.

[1-5]Department of Orthopaedic Surgery, Duke University Medical Center, Durham, NC, USA

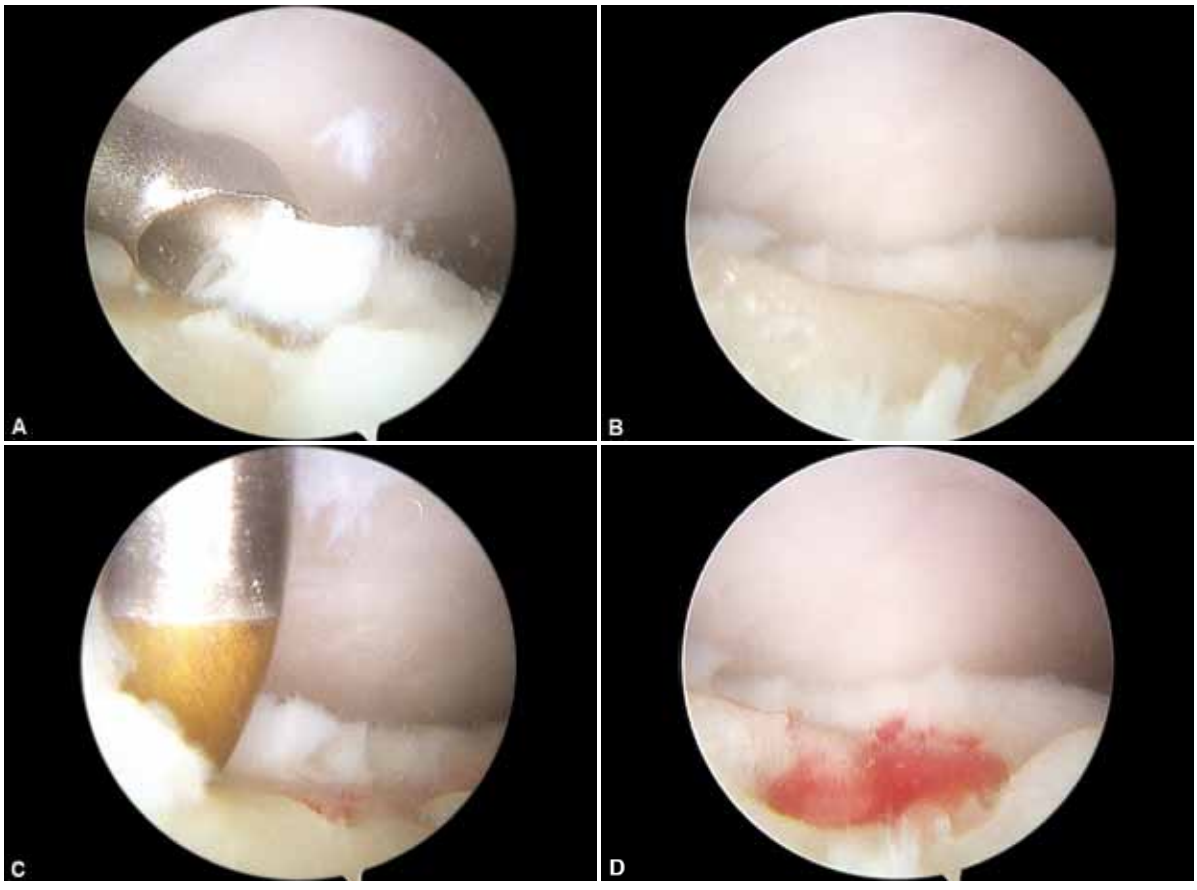
Corresponding Author: Samuel B Adams Jr, Assistant Professor, Department of Orthopaedic Surgery, Director of Foot and Ankle Research, Duke University Medical Center 4709 Creekstone Drive, Suite 200, Durham, NC 27703, USA Phone: 919-660-5010, e-mail: samuel.adams@duke.edu

CARTILAGE REPAIR STRATEGIES

Marrow Stimulation

Marrow stimulation (microfracture) is typically used as the initial operative management after failed conservative treatment. By perforating the subchondral bone, marrow stimulation allows the migration of bone marrow progenitor cells to infiltrate the lesion and attempt repair (Figs 1A to D). Unfortunately, the process typically yields a defect repaired with fibrocartilage, consisting of mainly type I collagen, instead of hyaline cartilage which is primarily composed of type II collagen. The fibrocartilage formed from this procedure has been shown to be biomechanically weaker than hyaline cartilage in the knee,[61] but this is believed to be a better alternative, regarding pain and function, than the exposed subchondral bone of the OLT.

Success rates for marrow stimulation range from 65 to 90%.[20,42,67,69,73,75] Historically, microfracture was applied to all OLTs; however, modern literature has been beneficial in providing guidelines as to the most appropriate lesions for marrow stimulation. Size, patient age, OLT chronicity, associated joint degeneration, presence of subchondral cysts, and lesion location and containment have been studied as prognostic factors with varying amounts of evidence regarding each characteristic. Osteochondral lesions of the talus size shows an inverse relationship with outcome after microfracture. Chuckpaiwong et al[17] studied 105 osteochondral lesions of the ankle (tibial



Figs 1A to D: (A and B) Debridement of medial talar dome OLT to stable margins, (C) microfracture performed and (D) marrow elements seen exiting microfracture holes

and talar) treated with ankle arthroscopy, debridement, and microfracture. Lesion size was overwhelmingly correlated with successful outcome. No treatment failures were reported when lesions had an average (longitudinal and transverse) diameter less than 15 mm, while only one (3%) patient had a successful outcome with a lesion ≥15 mm. A corroborative study by Choi et al[16] reported a cut-off of less than 150 mm^2 based on MRI imaging for successful clinical outcome.

One study by Kelberine and Frank[42] reported a more favorable outcome for lesions that were treated acutely rather than those that had become chronic. Another study noted that younger patients with traumatic lesions and a shorter interval between injury and surgery had improved results.[48] On the contrary, Choi et al[15] demonstrated that patient age was not a significant predictor of outcome, but increasing size and number of associated intra-articular lesions were predictors of poor outcome. Becher and Thermann[8] reported no correlation with outcome when comparing patient age, grade, or location of the defect. However, degenerative post-traumatic lesions with arthrosis had less satisfactory results. In summary, lesion chronicity and associated arthrosis may serve as prognostic factors for marrow stimulation.

Microfracture has been used in patients with Outerbridge grade 3 or 4 articular cartilage lesions.[18] In a study of 40 patients, the mean talar defect size was 70 mm^2. Patients who had previous ankle surgery had significantly lower outcome scores *vs* patients who did not have previous surgery. Days from surgery were negatively correlated with foot and ankle disability index activities of daily living score. Overall, patients had a high level of satisfaction and had reasonable outcome scores.

Marrow stimulation techniques have also been attempted in OLTs where the underlying bone shows evidence of cyst formation. Kumai et al[48] suggested that regardless of the treatment method, poor results are expected in the treatment of OLTs associated with subchondral cysts. A study by Robinson et al[67] reported a 53% poor outcome in debridement/curettage and drilling of OLTs with subchondral cysts. However, Han et al[39] performed arthroscopic microfracture or abrasion arthroplasty on 20 OLTs with subchondral cysts, and 18 OLTs without cysts. At a minimum follow-up of 2 years, the two groups showed no differences in American Orthopaedic Foot and Ankle Society (AOFAS) scores and the cystic areas significantly decreased at final postoperative follow-up. All of the cystic lesions in this study were less than 1.5 cm^2, as measured by anteroposterior radiographs. Saxena and Eakin[70] found reduced time to return to functional activity for noncystic lesions treated with microfracture than for cystic lesions treated with bone grafting (15 *vs* 19 weeks),

but functional scores showed no difference. In a study[10] of 13 patients with medial cystic OLTs who failed microfracture, a demineralized subchondral bone allograft was used to fill the defect. Pain, level of disability while descending stairs, and function improved significantly at 6 and 12 months. However, disability ascending stairs and walking up to 4 blocks remained the same from 6 to 12 months. There were no failures.

Location and containment of the OLT may also be implicated in the prognosis of marrow stimulation techniques. A recent study by Choi et al[14] reported on a series of 399 OLTs treated with marrow stimulation and subdivided the lesions into medial, lateral, contained (nonshoulder) and uncontained (shoulder) groups. The authors concluded that uncontained lesions showed a statistically significant worse clinical outcome than those patients with contained, nonshoulder lesions. Location (medial *vs* lateral) or size of the lesion failed to significantly alter these results. The authors concluded that when an uncontained lesion is suspected, more advanced surgical techniques should be considered.

There is a dearth of comparison studies between microfracture and other surgical strategies for the treatment of OLTs. In a small, prospective randomized trial of chondroplasty alone, microfracture, or osteochondral autograft for the treatment of OLTs in 31 patients by Gobbi et al[34] reported essentially no difference in outcome scores among the three treatment groups at 2 years.

Reports in the literature of second-look arthroscopy findings following marrow stimulation are rare. One series studied 20 ankles that had second-look arthroscopy done at 1 year after microfracture.[51] The International Cartilage Repair Society (ICRS) Score[80] and Ferkel and Cheng[23] staging were used to grade the cartilage. According to the ICRS grades, 60% of the lesions were grade I or II (normal or near normal) and 40% were grade III (abnormal). The Ferkel and Cheng staging revealed 35% of the lesions had incompletely healed.

Repeat debridement and marrow stimulation after failed initial surgical attempts may be beneficial. Ogilvie-Harris and Sarrosa[63] reported significant improvement at a mean 38 months in eight patients who underwent arthroscopic debridement to bleeding bone after previous open debridement. The authors concluded that the initial open procedures were likely inadequate and did not include debridement down to bleeding bone. Likewise, Savva et al[69] reported on 12 patients who underwent repeat debridement that showed improvement in AOFAS ankle-hindfoot scores at a mean of 5.9 years of follow-up. Mitchell et al[59] perform repeat debridement in athletes desiring an early return to sport and in lesions of $<1\ cm^2$.

Microfracture complications are rare but have been reported to include: superficial or deep infection, deep vein thrombosis, stiffness requiring manipulation, plantar fasciitis, complex regional pain syndrome, and saphenous and superficial peroneal nerve injury secondary to arthroscopic portal placement.[58]

Postoperative management is another area of contention. Traditionally, patients have been kept nonweight-bearing for a period of 6 to 8 weeks with good results.[23,24,34] Li et al[55] allowed 58 patients to immediately weight bear using a figure of eight splint after an arthroscopic microfracture procedure. All patients had excellent recovery with significant improvements in VAS and AOFAS ankle-hindfoot scores. Lee et al[50] recently conducted a prospective, randomized trial comparing early weight-bearing at 2 weeks to a protocol of nonweight-bearing for a 6 weeks period in patients treated with arthroscopic microfracture for small to medium sized OLTs. A total of 81 ankles with lesions less than 2.0 cm^2 were randomized to these two groups and followed for an average of 37 months. AOFAS, CAS, and ankle activity score (AAS) showed significant improvements from preoperative to final postoperative visits for both groups. None of the scores demonstrated a significant difference between the early weight-bearing and nonweight-bearing groups. Thus, early return to weight-bearing status may be warranted.

Retrograde Drilling

In unique cases of talar lesions where the subchondral bone appears cystic but the overlying cartilage is intact, retrograde drilling without microfracture has been performed with excellent clinical outcomes.[25, 44, 48] Kono et al[44] performed retrograde drilling for symptomatic OLTs on 11 patients. Second-look arthroscopy performed 1 year postoperatively demonstrated that none of the lesions had deteriorated. At 2-year follow-up, the AOFAS ankle-hindfoot score was also significantly improved in these patients. Recently, Anders et al[4] reported on 41 osteochondral lesions of the talus treated by arthroscopically guided retrograde drilling with autologous cancellous bone grafting. They reported an increase in AOFAS scores from 47.3 to 80.8 at a mean follow-up of 28 months. In addition, they found that patients with intact articular cartilage overlying the lesion had superior results when compared to those patients demonstrating small cracks or chondral fissures. The authors utilized a drill ranging from 7 to 9 mm in diameter to create a working portal to debride the lesion subchondrally. After removing the necrotic bone, the portal was back filled with an autologous cancellous bone cylinder in a press-fit manner. Open growth plates and those with first time surgical interventions were associated with better outcomes.

In a recent feasibility study[43] (electronic, four patients were successfully treated with MRI-guided retrograde

drilling. In this study, a 0.23 tesla open configuration MRI system was used. Instrument tracking was performed using an infrared navigation system. The most edematous portion of the OLT was targeted and approached from an oblique anterolateral direction. The mean time of the procedure was 48 minutes.

CARTILAGE REGENERATION STRATEGIES

Autologous Chondrocyte Implantation

Autologous chondrocyte implantation (ACI) is a staged procedure that often is used after failed conservative treatment or microfracture.[60] Ideal lesions should be focal and well circumscribed by a rim of intact cartilage. Hyaline cartilage is harvested during the first stage, usually from the anterior talus,[7] interchondylar notch or other nonweight-bearing portion of the ipsilateral knee.[60] Typically, 200 to 300 mg of cartilage is harvested and then cultured for 3 to 8 weeks to increase the number of chondrocytes, which can then be stored for >1 year.[60] In a second procedure, the cells are delivered into the OLT and a periosteal patch from the tibia is sewn into place to cover the defect.

Published reports of ACI typically describe favorable results. Nam et al[60] reported on 11 OLTs treated with ACI which had previously failed debridement, drilling, pinning or abrasion arthroplasty. The mean size of the OLTs was 273 mm^2 (80 to 500 mm^2). Extensive subchondral cysts were bone-grafted at the time of implantation in six patients. They reported significant improvement in the AOFAS ankle-hindfoot score and Tegner activity score at a mean follow-up of 38 months. Nine of the 11 (82%) patients reported good or excellent results and stated they would have the surgery again. Unlike the results for microfracture, OLT size or presence of a cyst had no impact on outcome of ACI in this study. The authors did, however, discourage ACI for OLTs with a cartilage defect of > 400 mm^2. Similarly, Baums et al[6] reported on 12 OLTs with a mean area of 2.3 cm^2 (1.0 to 6.25 cm^2) that showed significant improvement in the AOFAS ankle-hindfoot score at mean of 63 months follow-up. It should be noted that the study included an undisclosed number of patients who failed previous attempts at microfracture or drilling.

Whittaker et al[81] followed 10 ACI patients for 4 years. The mean size of these lesions was 1.95 cm^2 and eight of 10 patients had undergone prior arthroscopic debridement. Cartilage was harvested from the ipsilateral knee in all cases and 90% of the patients were 'pleased' or 'extremely pleased' with their final outcome. Second-look arthroscopy was performed in nine patients at a mean of 13 months showing that all lesions were macroscopically filled. Five of these patients had biopsies. Two biopsies yielded hyaline cartilage formation while three biopsies contained only fibrocartilage.

Kwak et al[49] reported on the long-term (average follow-up: 70 months) outcomes in 32 patients. There were 23 medial and six lateral lesions, with a mean size of 198 mm^2. Twenty patients underwent ACI of the talus alone and nine patients underwent ACI with bone grafting of subchondral cysts. At last follow-up, nine patients had excellent simplified symptomology scores, 14 had good, five had fair, and one had a poor outcome. The mean AOFAS and Tegner activity score improved. The mean Finsen score showed significant improvement from 13.7 to 5.1. Giannini et al[30] looked at lateral talar dome lesions in 46 patients at a mean of 71.2 years treated with ACI. There were three failures. At all time points, the mean AOFAS score was significantly improved. At 1 year follow-up, the mean AOFAS score was 86.8 ± 13.4; at 3 years, the mean score was 89.5 ± 13.4, and, at final follow-up, it was 92.0 ± 11.2.

Zengerink et al[82] reported their results on 11 patients who underwent ACI after prior failed surgical management. Lesion size was 13.1 by 20.7 mm on average and the mean follow-up period was 38 months (24-60 months). Ten of 11 patients reported improvement and nine patients had good to excellent outcomes. The AOFAS ankle-hindfoot score improved from 47.4 preoperatively to 84.3 postoperatively. Ten patients had second-look arthroscopy at a mean of 14.2 months after surgery showing complete defect coverage in all 10 patients. However, the repaired cartilage was noted to be softer than the surrounding native articular cartilage. The authors subjectively observed a correlation between increased firmness of the graft and time from implantation. Two patients had some degree of periosteal overgrowth.

Lee et al[53] studied factors influencing the results of ACI on 38 patients who received the procedure 1 year earlier. Employing second look arthroscopy, cartilage was assessed using a modified magnetic resonance scoring system (MOCART). Age, sex, location, depth, size, preoperative AOFAS score and additional procedures were assessed. They found that lesion size greater than 137.6 mm^2 and patient age less than 26 years correlated with significantly better modified MOCART scores.

The possibility of using the detached cartilage of the OLT has been studied as a cell source for ACI. Giannini et al[29] used detached OLT cartilage fragments as a cell source for ACI. Analysis of the cartilage fragments from 20 patients yielded a 99.9% chondrocyte viability rate and confirmed the presence of type-II collagen. Chondrocytes from 16 of the patients were expanded from their detached fragment and utilized during the ACI procedure. At a minimum of 12 months, all patients showed significant improvement in the AOFAS ankle-hindfoot

score. The extent of improvement in this group was statistically comparable to a group of patients receiving ACI with chondrocytes from the ipsilateral knee. However, Candrian et al[13] compared OLT fragment chondrocytes to normal ankle chondrocytes and found OLT chondrocytes contain significantly lower amounts of DNA, glycosaminoglycan (GAG), and collagen type II while showing statistically greater amounts of collagen type I. In addition, OLT chondrocytes had inferior cartilage-forming capacity. In another study of 151 patients whose damaged talar cartilage was harvested, the chondrocyte viability was 92% after 4 to 6 weeks of culturing.[45]

Matrix-induced Autologous Chondrocyte Implantation

Matrix-induced autologous chondrocyte implantation (MACI) or matrix-associated autologous chondrocyte transplantation (MACT) is essentially a second generation of ACI. The need for periosteal harvesting is eliminated by using a matrix, thereby theoretically reducing the operative time and potential postoperative complications. Additionally, the matrix may reduce technical errors reported in traditional ACI, notably cell leakage from under the periosteal flap, uneven distribution of the cells, or periosteal hypertrophy.[11]

Giza et al[33] reported on 10 patients treated with MACI through an anteromedial or anterolateral arthrotomy with plafondplasty and without a malleolar osteotomy. A type I/III collagen bilayer matrix was implanted with chondrocytes harvested from the perimeter of the OLT. The AOFAS ankle-hindfoot scores were significantly improved at 1 year, but at the 2-year mark, AOFAS scores showed an insignificant improvement over baseline. However, the SF-36 subscores of physical functioning and bodily pain showed significant improvement at 1 and 2 years. Subjectively, all patients were pleased with the procedure and no patient considered their outcome a failure.

Schneider and Karaikudi[72] performed open MACI on 20 patients. The perimeter of the OLT served as the donor site in all patients. A porcine collagen membrane was chosen as the matrix and seeded with 1×10^6 chondrocytes per cm^2. Grafts were secured with fibrin glue. AOFAS ankle-hindfoot scores showed significant improvement along with dramatic pain reduction. Two of the grafts failed. Second-look arthroscopy in six patients showed healed articular surfaces.

Magnan et al[57] evaluated 30 OLT patients at an average follow-up of 45 months after MACI. All lesions were between 1.5 and 4 cm^2. Patient age ranged from 17 to 49 years and all patients had pre- and postoperative MRI exams. Results were determined clinically using the AOFAS ankle-hindfoot and MOCART scoring systems and 56.7% of patients reported excellent outcomes, 36.7% as good and 6.6% as fair. Of note, 50% of patients returned to sporting activities at 8 weeks postoperatively. Magnetic resonance imaging (MRI) findings had no correlation with clinical results. Second-look arthroscopy and biopsy were performed in four patients with results showing formation of hybrid cells between native hyaline cartilage and fibrocartilage.

Apprich et al[5] used three Tesla MR imaging to compare MACI to microfracture in 20 patients with OLTs. Patients underwent MACI or microfracture and were matched by age, body mass index, and follow-up for comparison. The MOCART score and diffusion-weighted imaging (DWI) were used to assess patients' images. The authors observed no difference in postoperative MOCART scores between groups. Likewise, both groups showed significantly improved AOFAS ankle-hindfoot scores at final follow-up. The magnitude of improvement between groups was not significant. MACI repaired cartilage and healthy control cartilage demonstrated no significant difference in DWI diffusion quotient, radiographically indicating similar tissue. However, the DWI diffusion quotient did demonstrate a significant difference between microfracture repair tissue and control cartilage in favor of the latter. Therefore, the authors concluded that although clinically these techniques provided similar results, DWI indicated that quality of cartilage repair may be better with MACI.

A meta-analysis by Niemeyer et al[62] on the available data of ACI/MACI for OLTs systematically reviewed 16 studies that met their inclusion criteria. ACI and MACI were examined in 6 and 10 studies respectively. This analysis included 213 patients with a mean postoperative follow-up of 32 months and mean defect size of 2.3 cm^2. American Orthopaedic Foot and Ankle Society ankle-hindfoot was the most common of the various outcome measures used. The reported success rates ranged from 50 to 100%, with a mean of 89.9%. Unfortunately, all studies included in this meta-analysis were case series.

Anders et al[3] followed 22 consecutive patients treated with MACI. Nine lesions were post-traumatic in nature while 13 were from osteochondritis dessicans. Osteochondral lesions of the talus size ranged from 1 to 6 cm^2. The mean follow-up was 63.5 months with 21/22 patients available at 5 years. The authors observed significantly improved overall AOFAS scores, from 70.1 to 95.3, and significantly reduced visual analog pain score, from 5.7 to 0.9. Comparisons between traumatic and OD patients revealed no significant differences in average age, preoperative defect size and final AOFAS outcome scores.

Lee et al[51] studied a novel matrix-induced technique in 38 patients who received autologous chondrocyte implantation. All patients were followed for a minimum of 24 months. Thrombin and fibrin were mixed in a gel to form the cell matrix. Donor cartilage was harvested from the cuboid surface of the calcaneus. Second-look arthroscopy of 36 patients at 1 year showed normal or near normal cartilage in 75% of patients. American Orthopaedic Foot and Ankle Society ankle-hindfoot scores improved on average from 71 to 91 at 2 years. The authors reported no donor site morbidity.

Bone Marrow-derived Cell Transplantation and Platelet-Rich Plasma

Currently, this category of attempted cartilage regeneration entails autologous matrix-induced chondrogenesis (AMIC) and other 'one-step' techniques that utilize bone marrow derived cells and/or PRP. These techniques combine lesion debridement and microfracture with the addition of autologous iliac crest spongiosa bone, bone marrow aspirate concentrate, and/or platelet-rich plasma to the lesion using a collagen matrix carrier and fibrin glue to secure the carrier. This technique uses autologous tissue as a one-step surgical procedure that can be performed arthroscopically creating little to no donor site morbidity. As a relatively new technique, there are minimal outcome data.

Giannini et al[31] reported prospective data on 48 patients at a mean of 29 months follow-up after 'one-step' arthroscopic transplantation of bone marrow derived cells (BMDCs). Either a hyaluronic acid membrane or a porcine collagen powder was used as the scaffold. Scaffolds were prepared with 2 ml of concentrated bone marrow aspirate and 1 ml of platelet-rich fibrin gel (to provide growth factors) and then shaped to the appropriate size. Scaffolds were placed after microfracture was performed on the OLTs in a single arthroscopic operation. Qualitative *in vitro* analysis demonstrated BMDC viability in each of the scaffolds. There was significant improvement in AOFAS scores for both hyaluronic acid and porcine collagen scaffolds at 6, 12, 18 and 24 months. No difference in outcomes between scaffolds was observed. All patients demonstrated new tissue formation at the lesion site at 24 months after surgery as demonstrated by MRI. Second-look arthroscopy demonstrated normal appearing cartilage in three of five patients and hypertrophied cartilage in the remaining two patients. Various stages of tissue remodeling were seen on histologic examination of biopsied cartilage leading the authors to conclude that this arthroscopic one-step technique provides a safe alternative with similar outcomes to other techniques.

Giannini et al[27] later compared the results of 56 patients receiving ACI (arthroscopic or open-field) to 25 patients treated with one-step BMDC cell transplantation. Both the arthroscopic ACI group and the one-step technique group demonstrated significant improvement at 36 months. There was no difference in the magnitude of improvement among the groups was seen. Both MRI and second-look arthroscopy revealed moderate cartilage hypertrophy in a small number of lesions from both groups.

In 2012, Giannini published on 49 patients who received one step bone marrow derived cell transplantation analyzed with pre- and postoperative MRI with T2 mapping.[26] Subjects in this study were followed for 48 months and analysis took place with both clinical exam and MRI evaluation at specific intervals. The T2 mapping showed evidence of reparative tissue at the surgical site similar to that of hyaline cartilage in a mean of 78 ± 16% of the lesion area. American Orthopaedic Foot and Ankle Society scores in this group of patients showed improvement from 63.73 ± 14.13 to 82.19 ± 17.04 at 48 ± 6.1 months. Interestingly, the best results were seen at the 24 months follow-up with a decline in AOFAS scores seen at 36 and 48 months.

Valderrabano et al[77] also reviewed their results of AMIC-aided repair of 26 OLTs at a mean follow-up of 31 months. The AOFAS ankle score improved significantly from a preoperative mean of 60 point to 89 points postoperatively. The preoperative VAS score mean of 5 improved to an average of 1.6 postoperatively. The postoperative MOCART score averaged 62 points. In 35% of patients, there was complete filling of the defect at the level of the surrounding cartilage. Complete filling with a hypertrophic cartilage layer was found in half the patients. Nearly normal MRI signal intensity of the repaired cartilage compared to the native cartilage was seen in 69% while normal signal was seen in 15%.

Osteochondral lesions of the talus frequently occur after ankle sprains and, thus, in an inflammatory environment. In these instances, the level of PGE_2 is increased, which leads to chondrocyte apoptosis and may lead to the differentiation of bone marrow-derived cells to a fibroblastic phenotype.[56] Even the postsurgical joint microenvironment can have elevated levels of proinflammatory cytokines.[71] Therefore, Cadossi et al sought to alter the joint environment following BMDC implantation with a pulsed electromagnetic field in thirty patients. These patients were then randomized to serve as a control group or have the electromagnetic field applied for 4 hours a day for 60 days. Significantly, higher AOFAS scores were recorded at 6 and 12 months in the experimental group. At 60 days, 6 and 12 months follow-up, the experimental group had significantly lower pain. No significant difference was found in SF-36 between group.

CARTILAGE REPLACEMENT STRATEGIES

Osteochondral Autograft Transfer

Osteochondral autograft transfer (OAT) techniques are designed to deliver hyaline cartilage to an osteochondral defect. For lateral lesions, this may be accomplished by using a temporary external fixation device.[64] Cartilage plugs can be harvested from a nonweight-bearing portion of the ipsilateral knee, iliac crest,[54] the anterior talus or an allograft talus. In addition, Giannini et al[28] demonstrated that osteochondral autografts maintain the presence of type II collagen at their implantation site.

Several complications have, however, been reported with harvesting osteochondral plugs from the ipsilateral knee including persistent pain, pain on heavy exertion, patellar instability, giving way, difficulty kneeling or squatting and the need for additional surgery.[58]

Valderrabano et al[76] reported 72 months follow-up on 12 patients who underwent knee-to-ankle mosaicplasty for OLTs. These patients experienced significant pain relief and improvement in AOFAS ankle-hindfoot scores. Six patients reported knee pain while 10 patients developed recurrent ankle lesions and demonstrated some degree of joint degeneration. Gobbi et al[34] reported on a series of 12 patients who had osteochondral allografting with one to three plugs transferred from the lateral femoral condyle or trochlear notch. The mean lesion size was 3.7 cm^2 (1.2 to 5 cm^2). By final follow-up, AOFAS ankle-hindfoot scores significantly improved and no harvest site complications were reported.

Emre performed open mosaicplasty through a medial malleolar osteotomy on 32 patients.[22] Allograft was harvested from the lateral femoral condyle of the ipsilateral knee in all cases. Malleolar osteotomy was fixed with a screw in all cases and range of motion exercises were begun shortly after surgery with full weight-bearing allowed at 6 weeks once radiographs confirmed bony union. The mean size of the lesion treated was 1.18 cm^2 (0.4-1.8) and stages ranged from lesions contained only in the cartilage to those full thickness defects containing subchondral cysts and avascular necrosis. At latest follow-up, mean AOFAS ankle-hindfoot scores increased from 59 to 88. At final follow-up, two patients (6.2%) experienced pain at the donor knee. The authors of this study concluded that mosaicplasty is a viable option for larger more advanced osteochondral lesions of the talus. Scranton et al[74] reported 90% satisfaction in 50 patients at a mean of 36 months follow-up, after OAT for cystic OLTs. Similarly, Hangody and Fules[40] reported 94% good to excellent results after OAT mosaicplasty in 36 patients at a mean 4.2 years follow-up.

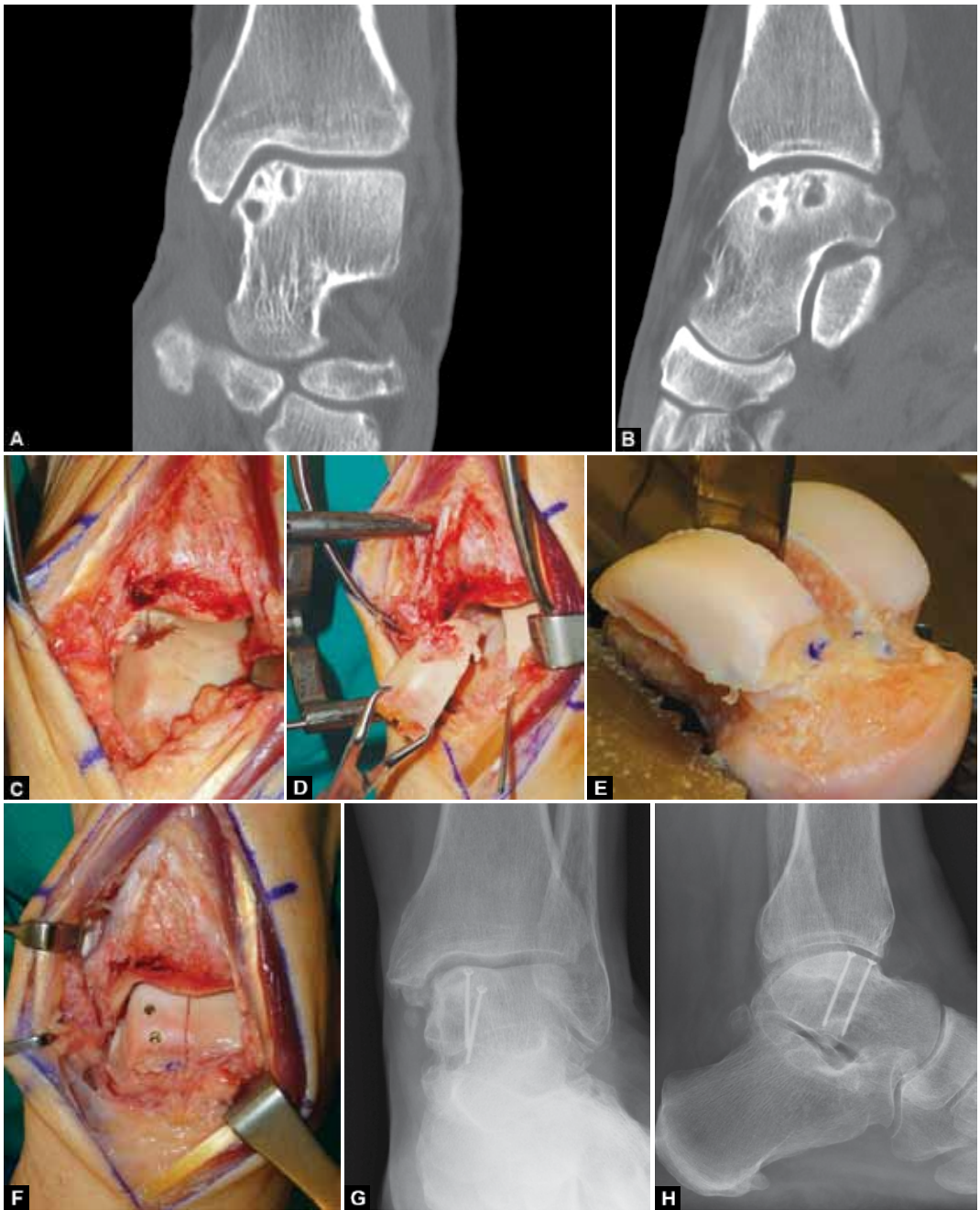
Sammarco et al[68] reported on 12 patients in which osteochondral plugs were harvested from the ipsilateral talus. The largest graft size was 8 mm in diameter taken from either the medial or lateral talar facet. Significant improvement in the AOFAS ankle-hindfoot score was observed at a mean follow-up of 25 months. The most common complaint was minimal aching over the anterior aspect of the ankle with no patient reporting decreased ability to participate in activities of daily living or sports. Kreuz et al[46] reported on a series of 35 patients who underwent ipsilateral talus articular facet osteochondral plug harvesting and implantation through a variety of approaches. No complications related to graft harvesting were seen and implantation was done via a medial malleolar osteotomy, a tibial wedge osteotomy or no osteotomy. Each graft was up to 10 mm in diameter with two patients requiring multiple plugs. Significant improvement in AOFAS ankle-hindfoot scores was seen at 48.9 months. The best results were seen in those patients who did not require an osteotomy.

Often times, larger lesions may need more than one graft to fill the defect. In a study of 28 patients who underwent autologous osteochondral transplantation,[38] fourteen patients with a mean defect size of 208 ± 54 mm^2 were treated with a double plug autograft transplantation. They were matched by age and sex to a control cohort of 28 patients who underwent a single plug transplantation for a mean defect size of 74 ± 26 mm^2. All patients with single and double-plug allografts had singficant increases in FAOS and SF-12 scores, though there was no difference between the groups. Mean MOCART scores did not show any significant difference between groups. The authors conclude that, in the intermediate term, double-plug allografts are as effective as single plug allografts in treating larger talar OLTs.

Osteochondral Allografts

Osteochondral allografting is typically performed on large talar shoulder lesions (Figs 2A to H). The grafts are obtained from human cadavers from licensed tissue banks. They may be fresh or fresh-frozen, although we recommend fresh grafts. The tissue bank delivers the entire talus that has been size-matched based on recipient radiographic parameters. Advantages of using osteochondral allografts include a single stage procedure with the ability to restore multiple dimensions of cartilage loss, treat large lesions, and eliminate donor site morbidity in the knee. Disadvantages include disease transmission, failure of the graft to incorporate and necessity for intra-articular hardware placement.

Very few studies exist on osteochondral allografting for OLTs. Gross et al[35] studied nine patients treated with fresh osteochondral allograft transplantation. Six of the nine remained *in situ* at a mean follow-up of



Figs 2A to H: Coronal (A) and sagittal (B) CT images demonstrating a large medial talar dome OLT, (C) intraoperative image demonstrating the extent of the lesion, (D) the lesion was removed, (E) the medial hemi-talus was measured and cut from the allograft, (F) the allograft was secured to the body of the talus, AP (G) and lateral (H) radiographs taken 2.5 years after allograft replacement

11 years. The three remaining patients' grafts demonstrated radiographic and intraoperative evidence of fragmentation or resorption and all went on to ankle fusion. Raikin[65] reported on a series of six patients with bulk allografting of OLTs with an average size of 4.38 cm^3 showing satisfactory results in five of the six patients at 2 years. More recently, Raikin[66] published on 15 patients with large, cystic OLTs with a mean size of just over 6 cm^3 (3 to 10 cm^3). At 54 months, 13 allografts remained *in situ* with significant improvement in the AOFAS ankle-hindfoot score. Evidence of collapse, resorption or joint space narrowing was observed in all patients and the two failed grafts underwent ankle arthrodesis.

Adams et al[2] reported on eight talar shoulder lesions treated with fresh allograft transplantation. All grafts were still in place and patients experienced significant pain reduction with improvement in functional outcomes scoring. However, 50% of patients required additional surgical procedures including debridement and revision medial malleolar osteotomy. El-Rashidy et al[21] retrospectively reviewed 38 patients after fresh osteochondral allograft transplantation to the talus. At a mean of 37 months follow-up, AOFAS ankle-hindfoot scores were significantly improved. Seven patients had second-look arthroscopy revealing one graft with 5 to 6 mm area of denuded cartilage, one graft with diffuse

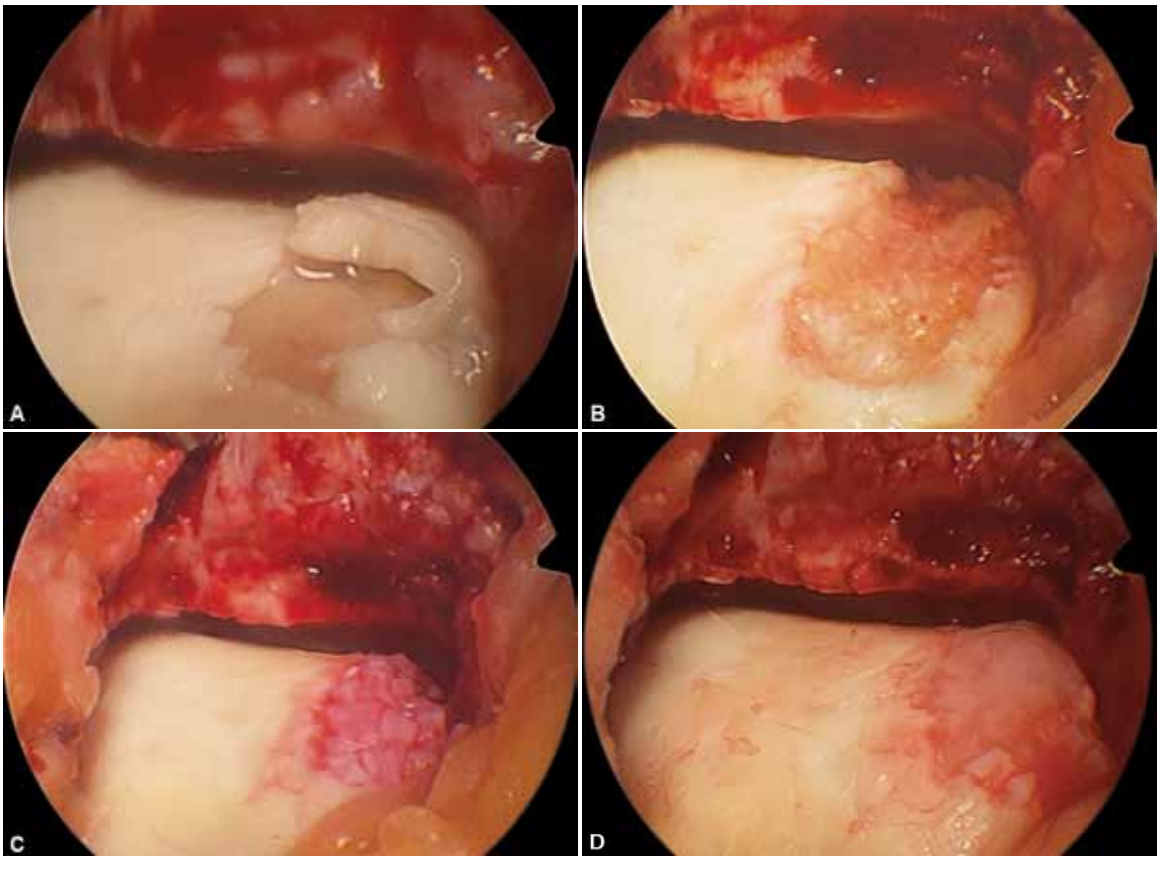
cartilage degeneration, and three loose grafts. Hahn et al reported on 18 patients who underwent fresh talar allograft implantation.[37] Of the 13 patients who returned for follow-up (mean, 48 months), there was a 100% graft incorporation rate on plain radiographs. There was a significant improvement between the patients' preoperative and postoperative pain and activity abilities as measured with the foot function index and AOFAS ankle-hindfoot scores. There were no failures.

Haene studied the use of fresh allograft as the treatment of 17 uncontained large OLTs.[36] Fresh talar allografts were obtained within 24 hours of donor death and stored at 2°C until implantation (less than 7 days in all cases). At final follow-up, five ankles were considered failures with two going on to arthrodesis, two showing failure of graft incorporation (on CT evaluation), and one patient dropping out of the study due to persistent symptoms. Degenerative changes were seen in seven ankles. Only four patients were symptom-free.

Bugbee et al[12] investigated 84 ankles treated with a bipolar osteochondral allograft of the tibiotalar joint at a mean duration of follow-up of 5.3 years. Thirty-six (42%) ankles had further surgery since implantation. The survivorship of the allograft was 76% at 5 years and 44% at 10 years. Twenty-five ankles (29%) were considered clinical failures as they underwent graft-related reoperations. Ten patients underwent revision allografts, seven had an ankle fusion, six underwent conversions to total ankle arthroplasty, and two underwent below-the-knee amputations. Despite the high clinical failure rate, 92% of patients were satisfied with the index procedure, 83% had improved function, and 85% had less pain.

Particulated Juvenile Cartilage Allograft Transplantation

Particulated juvenile cartilage allograft transplantation (PJCAT) is the newest technique available for treatment of OLTs. It entails transplantation of multiple fresh juvenile cartilage allograft pieces containing live cells within their native extracellular matrix (Figs 3A to D). A fibrin adhesive is utilized to secure the tissue firmly inside the prepared lesion. Currently, only DeNovo® NT Natural Tissue Graft (Zimmer, Inc, Warsaw, IN) is available for this procedure. The United States Food and Drug Administration considers this product a minimally manipulated tissue. The cartilage pieces are obtained from deceased donors ranging in age from newborn to age 13 in compliance with good tissue practice. All tissue is screened for disease (each lot of tissue comes from a single donor) and no stillborn or fetal tissue is used. A major advantage of this technique is that the particulated nature of the graft obviates the need for perpendicular access,



Figs 3A to D: (A) Unstable medial talar dome OLT, (B) the lesion was debrided to stable margins, (C) particulated juvenile cartilage allograft chips were placed into the lesion bed and (D) the cartilage chips were covered with fibrin glue

thereby eliminating the use of malleolar osteotomies and potential associated complications. It can also be delivered all arthroscopically.[1] Additional advantages of this technique are its shallow learning curve, no graft contouring, no donor site morbidity and a single surgery. The disadvantages of this technique are the lack of long-term results, the limited supply of juvenile donor cartilage, and the risks of disease transmission. Recently, Coetzee et al[19] presented a retrospective case series of 23 patients (24 ankles) treated with PJCAT at a mean follow-up of 16.2 months. The mean lesion surface size was 125 mm^2 (50-300 mm^2) with a mean depth of 7 mm (3-20 mm). All lesions had at least one dimension greater than or equal to 10 mm. The lesions were accessed via an open approach in 12 cases, an arthroscopic approach in three cases, and through an extended portal open approach in nine cases. Bone grafting was performed on lesions deeper than 5 mm. The mean postoperative 100 mm VAS for pain was 24 (0-93) and the mean AOFAS ankle-hindfoot score was 85 (23-100). The mean foot and ankle ability measure (FAAM) for activities of daily living was 55.1 (52-58) and the mean FAAM for sports was 63.4 (52-75). The mean postoperative SF-12 physical composite score was 46.4 (42-51). The authors note that these outcomes scores are similar to published reports on patients who were treated with bone marrow stimulation, autologous chondrocyte implantation, and matrix-induced autolgous chondrocyte implantation. Five patients required reoperation to remove symptomatic osteotomy hardware. One patient required an additional procedure to treat anterior impingement. At the time of two of these procedures, the juvenile cartilage was minimally debrided. Additionally, during three reoperations, the International Cartilage Repair Society (ICRS) cartilage repair assessment (protocol A) was used to assess the repair tissue. The three lesions were assessed at grade 2 (nearly normal repair). There was one partial graft delamination (~25% of the graft) that was diagnosed at 16 months. The original lesion size of this patient was 180 mm^2.

Kruse et al[47] presented one case of arthroscopically performed PJCAT to an OLT in a 30-year-old female with a full thickness posteromedial lesion that measured 7 × 5 mm. At 2 years following surgery, the patient was found to pain free with no activity limitations.

Bleazey and Brigido[9] retrospectively reported on a series of seven patients treated with a cylindrical allograft plug and PJCAT. The surgical technique was performed through a medial malleolar or fibular osteotomy in all patients. The lesion was assessed and then a size-matched reamer was used to ream past the subchondral plate into the cancellous bone. A cylindrical sponge allograft of matched diameter was then inserted and recessed to the level of the subchondral plate. Next, *ex vivo*, the particulated cartilage and fibrin glue were mixed into a size-matched mold to form the graft. Next the graft was secured with additional fibrin glue. All patients demonstrated significant improvement in each category of a custom 10-point scale that assessed ability to ambulate up stairs, down stairs and four city blocks. The greatest improvement was in the ability to walk four city blocks. All patients would have the surgery performed again. However, all patients were followed for only 6 months.

Indications for this procedure technique have yet to be completely defined. However, Giza et al[32] state that the ideal patient is a young patient (less than 50 years old) who has a failed a previous microfracture. The authors use PJCAT for lesions that have failed previous debridement and marrow stimulation techniques or on primary lesions that are greater than 15 mm in diameter. We are moving toward performing the majority of PJCATs arthroscopically even in cases when bone graft is needed.[1] However, in cases with larger defect that would require significant bone grafting, the authors prefer a structural allograft.

Metal Resurfacing Implants

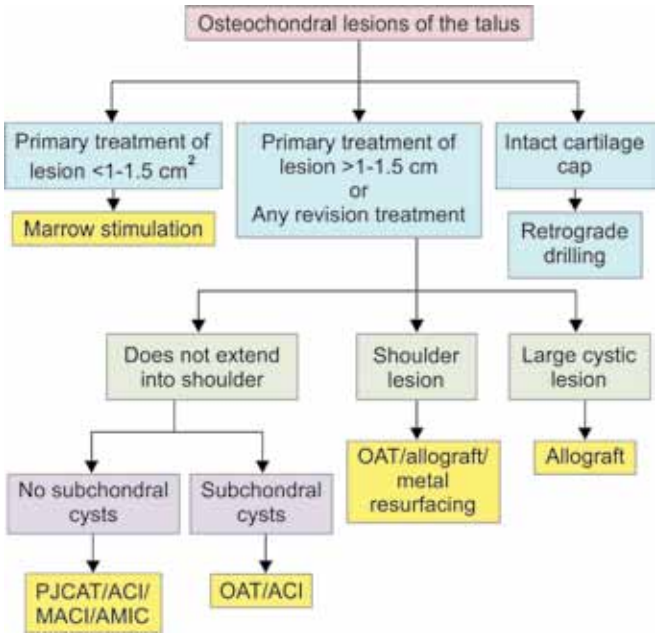
A talar metallic inlay implant has been developed for treatment of localized OLTs of the medial dome.[79] This implant consists of 15 different offset sizes that are designed to reduce pain and decrease cyst formation. The optimal implantation depth is 0.5 mm below the level of the articular surface in order to decrease the chances of protrusion, which leads to increased tibial contact pressures. If the implant was too deep, adjacent cartilage may collapse.[41]

Only one study has looked at the outcomes following implantation of this device.[78] van Bergen et al prospectively studied 20 patients treated with this metallic inlay device for a mean of 3 years. Postoperatively, there was statistically significant reduction of pain at rest and while walking, stair climbing and running. The median AOFAS ankle-hindfoot score significantly improved from 62 to 87 at final follow-up. The mean short-form 36 physical component scale improved significantly while the mental component scale did not change significantly. One patient required additional surgery for the osteochondral defect. On plain X-rays, progressive degeneration of the opposite tibial plafond was seen in two patients.

CONCLUSION

Osteochondral lesions of the talus remain a treatment challenge despite the many surgical treatment strategies

Flow Chart 1: Basic algorithm the authors use to decide on surgical management of OLTs. Treatment choice must be based on available data, availability/approval and surgeon comfort



available. In general, treatment options can be classified as cartilage repair, regeneration or replacement but not all treatment options are available worldwide. The multitude of approaches is in part due to the variable characteristics of OLTs and the lack of treatment comparison studies. Although the majority of reports in the literature are level IV evidence studies, results are generally favorable but firm treatment recommendations are unable to be made. A basic algorithm that the authors use for surgical treatment of OLTs is outlined in Flow Chart 1. However, the final decision on treatment strategy must be based on available data, availability/approval and surgeon comfort.

REFERENCES

1. Adams SB Jr, Demetracopoulos CA, Parekh SG, Easley ME, Robbins J. Arthroscopic particulated juvenile cartilage allograft transplantation for the treatment of osteochondral lesions of the Talus. Arthrosc Tech 2014;3(4):e533-537.
2. Adams SB Jr, Viens NA, Easley ME, Stinnett SS, Nunley JA 2nd. Midterm results of osteochondral lesions of the talar shoulder treated with fresh osteochondral allograft transplantation. J Bone Joint Surg Am 2011;93(7):648-654.
3. Anders S, Goetz J, Schubert T, Grifka J, Schaumburger J. Treatment of deep articular talus lesions by matrix associated autologous chondrocyte implantation—results at 5 years. Int Orthop 2012;36(11):2279-2285.
4. Anders S, Lechler P, Rackl W, Grifka J, Schaumburger J. Fluoroscopy-guided retrograde core drilling and cancellous bone grafting in osteochondral defects of the talus. Int Orthop 2012;36(8):1635-1640.
5. Apprich S, Trattnig S, Welsch GH, et al. Assessment of articular cartilage repair tissue after matrix-associated autologous chondrocyte transplantation or the microfracture technique in the ankle joint using diffusion weighted-imaging at 3 tesla. Osteoarthritis Cartilage 2012.
6. Baums MH, Heidrich G, Schultz W, Steckel H, Kahl E, Klinger HM. Autologous chondrocyte transplantation for treating cartilage defects of the talus. J Bone Joint Surg Am 2006;88(2):303-308.
7. Baums MH, Heidrich G, Schultz W, Steckel H, Kahl E, Klinger HM. The surgical technique of autologous chondrocyte transplantation of the talus with use of a periosteal graft. Surgical technique. J Bone Joint Surg Am 2007;89(Suppl 2 Pt.2):170-182.
8. Becher C, Thermann H. Results of microfracture in the treatment of articular cartilage defects of the talus. Foot & Ankle International 2005;26(8):583-589.
9. Bleazey S, Brigido SA. Reconstruction of complex osteochondral lesions of the talus with cylindrical sponge allograft and particulate juvenile cartilage graft: provisional results with a short-term follow-up. Foot Ankle Spec 2012;5(5): 300-305.
10. Brigido SA, Protzman NM, Galli MM, Bleazey ST. The role of demineralized allograft subchondral bone in the treatment of talar cystic OCD Lesions that have failed microfracture. Foot Ankle Spec 2014;7(5):377-386.
11. Brittberg M, Peterson L, Sjogren-Jansson E, Tallheden T, Lindahl A. Articular cartilage engineering with autologous chondrocyte transplantation. A review of recent developments. J Bone Joint Surg Am 2003;85-A(Suppl 3): 109-115.
12. Bugbee WD, Khanna G, Cavallo M, McCauley JC, Gortz S, Brage ME. Bipolar fresh osteochondral allografting of the tibiotalar joint. J Bone Joint Surg Am 2013;95(5):426-432.
13. Candrian C, Miot S, Wolf F, et al. Are ankle chondrocytes from damaged fragments a suitable cell source for cartilage repair? Osteoarthritis Cartilage 2010;18(8):1067-1076.
14. Choi WJ, Choi GW, Kim JS, Lee JW. Prognostic Significance of the containment and location of osteochondral lesions of the Talus: Independent adverse outcomes associated with uncontained lesions of the talar shoulder. Am J Sports Med 2012.
15. Choi WJ, Kim BS, Lee JW. Osteochondral lesion of the talus: could age be an indication for arthroscopic treatment? Am J Sports Med 2012;40(2):419-424.
16. Choi WJ, Park KK, Kim BS, Lee JW. Osteochondral lesion of the talus: is there a critical defect size for poor outcome? Am J Sports Med 2009;37(10):1974-1980.
17. Chuckpaiwong B, Berkson EM, Theodore GH. Microfracture for osteochondral lesions of the ankle: outcome analysis and outcome predictors of 105 cases. Arthroscopy 2008;24(1): 106-112.
18. Clanton TO, Johnson NS, Matheny LM. Outcomes following microfracture in grade 3 and 4 articular cartilage lesions of the Ankle. Foot Ankle Int 2014;35(8):764-770.
19. Coetzee JC, Giza E, Schon LC, et al. Treatment of osteochondral lesions of the talus with particulated juvenile cartilage. Foot Ankle Int 2013;34(9):1205-1211.
20. Donnenwerth MP, Roukis TS. Outcome of arthroscopic debridement and microfracture as the primary treatment for osteochondral lesions of the talar dome. Arthroscopy 2012;28(12):1902-1907.
21. El-Rashidy H, Villacis D, Omar I, Kelikian AS. Fresh osteochondral allograft for the treatment of cartilage defects of the talus: a retrospective review. J Bone Joint Surg Am 2011;93(17):1634-1640.

22. Emre TY, Ege T, Cift HT, Demircioglu DT, Seyhan B, Uzun M. Open mosaicplasty in osteochondral lesions of the talus: a prospective study. J Foot Ankle Surg 2012;51(5):556-560.
23. Ferkel RD CJ. Operative Treatment of the Foot and Ankle. New York: Appleton-Croft; 1999.
24. Ferkel RD, Zanotti RM, Komenda GA, et al. Arthroscopic treatment of chronic osteochondral lesions of the talus: long-term results. Am J Sports Med 2008;36(9):1750-1762.
25. Geerling J, Zech S, Kendoff D, et al. Initial outcomes of 3-dimensional imaging-based computer-assisted retrograde drilling of talar osteochondral lesions. Am J Sports Med 2009;37(7):1351-1357.
26. Giannini S, Buda R, Battaglia M, et al. One-step repair in talar osteochondral lesions: 4-year clinical results and T2-mapping capability in outcome prediction. Am J Sports Med 2012.
27. Giannini S, Buda R, Cavallo M, et al. Cartilage repair evolution in post-traumatic osteochondral lesions of the talus: from open field autologous chondrocyte to bone-marrow-derived cells transplantation. Injury 2010;41(11):1196-1203.
28. Giannini S, Buda R, Grigolo B, Vannini F. Autologous chondrocyte transplantation in osteochondral lesions of the ankle joint. Foot Ankle Int 2001;22(6):513-517.
29. Giannini S, Buda R, Grigolo B, Vannini F, De Franceschi L, Facchini A. The detached osteochondral fragment as a source of cells for autologous chondrocyte implantation (ACI) in the ankle joint. Osteoarthritis Cartilage 2005;13(7):601-607.
30. Giannini S, Buda R, Ruffilli A, et al. Arthroscopic autologous chondrocyte implantation in the ankle joint. Knee Surg Sports Traumatol Arthrosc 2014;22(6):1311-1319.
31. Giannini S, Buda R, Vannini F, Cavallo M, Grigolo B. One-step bone marrow-derived cell transplantation in talar osteochondral lesions. Clin Orthop Relat Res 2009; 467(12):3307-3320.
32. Giza E, Delman C, Coetzee JC, Schon LC. Arthroscopic treatment of talus osteochondral lesions with particulated juvenile allograft cartilage. Foot Ankle Int 2014;35(10): 1087-1094.
33. Giza E, Sullivan M, Ocel D, et al. Matrix-induced autologous chondrocyte implantation of talus articular defects. Foot Ankle Int 2010;31(9):747-753.
34. Gobbi A, Francisco RA, Lubowitz JH, Allegra F, Canata G. Osteochondral lesions of the talus: randomized controlled trial comparing chondroplasty, microfracture, and osteochondral autograft transplantation. Arthroscopy 2006;22(10):1085-1092.
35. Gross AE, Agnidis Z, Hutchison CR. Osteochondral defects of the talus treated with fresh osteochondral allograft transplantation. Foot Ankle Int 2001;22(5):385-391.
36. Haene R, Qamirani E, Story RA, Pinsker E, Daniels TR. Intermediate outcomes of fresh talar osteochondral allografts for treatment of large osteochondral lesions of the talus. J Bone Joint Surg Am 2012;94(12):1105-1110.
37. Hahn DB, Aanstoos ME, Wilkins RM. Osteochondral lesions of the talus treated with fresh talar allografts. Foot Ankle Int 2010;31(4):277-282.
38. Haleem AM, Ross KA, Smyth NA, et al. Double-plug autologous osteochondral transplantation shows equal functional outcomes compared with single-plug procedures in lesions of the talar dome: A minimum 5-year clinical follow-up. Am J Sports Med 2014;42(8):1888-1895.
39. Han SH, Lee JW, Lee DY, Kang ES. Radiographic changes and clinical results of osteochondral defects of the talus with and without subchondral cysts. Foot Ankle Int 2006;27(12): 1109-1114.
40. 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-A(Suppl 2):25-32.
41. Jackson DW, Lalor PA, Aberman HM, Simon TM. Spontaneous repair of full-thickness defects of articular cartilage in a goat model. A preliminary study. J Bone Joint Surg Am 2001; 83-A(1):53-64.
42. Kelberine F, Frank A. Arthroscopic treatment of osteochondral lesions of the talar dome: a retrospective study of 48 cases. Arthroscopy 1999;15(1):77-84.
43. Kerimaa P, Ojala R, Sinikumpu JJ, et al. MRI-guided percutaneous retrograde drilling of osteochondritis dissecans of the talus: a feasibility study. Eur Radiol 2014;24(7):1572-1576.
44. Kono M, Takao M, Naito K, Uchio Y, Ochi M. Retrograde drilling for osteochondral lesions of the talar dome. Am J Sports Med 2006;34(9):1450-1456.
45. Kreulen C, Giza E, Kim J, Campanelli V, Sullivan M. Viability of talus osteochondral defect cartilage for chondrocyte harvesting: results of 151 patients. Foot Ankle Int 2014;35(4):341-345.
46. Kreuz PC, Steinwachs M, Erggelet C, Lahm A, Henle P, Niemeyer P. Mosaicplasty with autogenous talar autograft for osteochondral lesions of the talus after failed primary arthroscopic management: a prospective study with a 4-year follow-up. Am J Sports Med 2006;34(1):55-63.
47. Kruse DL, Ng A, Paden M, Stone PA. Arthroscopic De Novo NT((R)) juvenile allograft cartilage implantation in the talus: a case presentation. J Foot Ankle Surg 2012;51(2):218-221.
48. Kumai T, Takakura Y, Higashiyama I, Tamai S. Arthroscopic drilling for the treatment of osteochondral lesions of the talus. J Bone Joint Surg 1999;81(9):1229-1235.
49. Kwak SK, Kern BS, Ferkel RD, Chan KW, Kasraeian S, Applegate GR. Autologous chondrocyte implantation of the ankle: 2- to 10-year results. Am J Sports Med 2014;42(9):2156-2164.
50. Lee DH, Lee KB, Jung ST, Seon JK, Kim MS, Sung IH. Comparison of early versus delayed weightbearing outcomes after microfracture for small to midsized osteochondral lesions of the talus. Am J Sports Med 2012;40(9):2023-2028.
51. Lee KB, Bai LB, Yoon TR, Jung ST, Seon JK. Second-look arthroscopic findings and clinical outcomes after micro-fracture for osteochondral lesions of the talus. Am J Sports Med 2009;37(Suppl 1):63S-70S.
52. Lee KT, Kim JS, Young KW, et al. The use of fibrin matrix-mixed gel-type autologous chondrocyte implantation in the treatment for osteochondral lesions of the talus. Knee Surg Sports Traumatol Arthrosc 2012.
53. Lee KT, Lee YK, Young KW, Park SY, Kim JS. Factors influencing result of autologous chondrocyte implantation in osteochondral lesion of the talus using second look arthroscopy. Scand J Med Sci Sports 2011.
54. Leumann A, Valderrabano V, Wiewiorski M, Barg A, Hintermann B, Pagenstert G. Bony periosteum-covered iliac crest plug transplantation for severe osteochondral lesions of the talus: a modified mosaicplasty procedure. Knee Surg Sports Traumatol Arthrosc 2014;22(6):1304-1310.
55. Li S, Li H, Liu Y, Qu F, Wang J, Liu C. Clinical outcomes of early weight-bearing after arthroscopic microfracture during

the treatment of osteochondral lesions of the talus. Chin Med J (Engl) 2014;127(13):2470-2474.

56. Lima EG, Tan AR, Tai T, et al. Differences in interleukin-1 response between engineered and native cartilage. Tissue Eng Part A 2008;14(10):1721-1730.
57. Magnan B, Samaila E, Bondi M, Vecchini E, Micheloni GM, Bartolozzi P. Three-dimensional matrix-induced autologous chondrocytes implantation for osteochondral lesions of the talus: midterm results. Adv Orthop 2012;2012:942174.
58. McGahan PJ, Pinney SJ. Current concept review: osteochondral lesions of the talus. Foot Ankle Int 2010;31(1):90-101.
59. Mitchell ME, Giza E, Sullivan MR. Cartilage transplantation techniques for talar cartilage lesions. J Am Acad Orthop Surg 2009;17(7):407-414.
60. Nam EK, Ferkel RD, Applegate GR. Autologous chondrocyte implantation of the ankle: a 2- to 5-year follow-up. Am J Sports Med 2009;37(2):274-284.
61. Nehrer S, Spector M, Minas T. Histologic analysis of tissue after failed cartilage repair procedures. Clin Orthop Relat Res 1999(365):149-162.
62. Niemeyer P, Salzmann G, Schmal H, Mayr H, Sudkamp NP. Autologous chondrocyte implantation for the treatment of chondral and osteochondral defects of the talus: a meta-analysis of available evidence. Knee Surg Sports Traumatol Arthrosc 2011.
63. Ogilvie-Harris DJ, Sarrosa EA. Arthroscopic treatment after previous failed open surgery for osteochondritis dissecans of the talus. Arthroscopy 1999;15(8):809-812.
64. Orr JD, Dutton JH, Nelson JR, Hsu JR. Indications for and early complications associated with use of temporary invasive distraction for osteochondral graft transfer procedures for treatment of lateral osteochondral lesions of the talus. Foot Ankle Int 2014;35(1):50-55.
65. Raikin SM. Stage VI: massive osteochondral defects of the talus. Foot Ankle Clin 2004;9(4):737-744.
66. Raikin SM. Fresh osteochondral allografts for large-volume cystic osteochondral defects of the talus. J Bone Joint Surg Am 2009;91(12):2818-2826.
67. Robinson DE, Winson IG, Harries WJ, Kelly AJ. Arthroscopic treatment of osteochondral lesions of the talus. J Bone Joint Surg Br 2003;85(7):989-993.
68. Sammarco GJ, Makwana NK. Treatment of talar osteochondral lesions using local osteochondral graft. Foot Ankle Int 2002;23(8):693-698.
69. Savva N, Jabur M, Davies M, Saxby T. Osteochondral lesions of the talus: results of repeat arthroscopic debridement. Foot Ankle Int 2007;28(6):669-673.
70. Saxena A, Eakin C. Articular talar injuries in athletes: results of microfracture and autogenous bone graft. Am J Sports Med 2007;35(10):1680-1687.
71. Schmal H, Mehlhorn A, Stoffel F, Kostler W, Sudkamp NP, Niemeyer P. In vivo quantification of intraarticular cytokines in knees during natural and surgically induced cartilage repair. Cytotherapy 2009;11(8):1065-1075.
72. Schneider TE, Karaikudi S. Matrix-Induced Autologous Chondrocyte Implantation (MACI) grafting for osteochondral lesions of the talus. Foot Ankle Int 2009;30(9):810-814.
73. Schuman L, Struijs PA, van Dijk CN. Arthroscopic treatment for osteochondral defects of the talus. Results at follow-up at 2 to 11 years. J Bone Joint Surg Br 2002;84(3):364-368.
74. Scranton PE Jr, Frey CC, Feder KS. Outcome of osteochondral autograft transplantation for type-V cystic osteochondral lesions of the talus. J Bone Joint Surg Br 2006;88(5):614-619.
75. Tol JL, Struijs PA, Bossuyt PM, Verhagen RA, van Dijk CN. Treatment strategies in osteochondral defects of the talar dome: a systematic review. Foot Ankle Int 2000;21(2):119-126.
76. Valderrabano V, Leumann A, Rasch H, Egelhof T, Hintermann B, Pagenstert G. Knee-to-ankle mosaicplasty for the treatment of osteochondral lesions of the ankle joint. Am J Sports Med 2009;37(Suppl 1):105S-111S.
77. Valderrabano V, Miska M, Leumann A, Wiewiorski M. Reconstruction of osteochondral lesions of the talus with autologous spongiosa grafts and autologous matrix-induced chondrogenesis. Am J Sports Med 2013;41(3):519-527.
78. van Bergen CJ, van Eekeren IC, Reilingh ML, Sierevelt IN, van Dijk CN. Treatment of osteochondral defects of the talus with a metal resurfacing inlay implant after failed previous surgery: a prospective study. Bone Joint J 2013;95-B(12): 1650-1655.
79. van Bergen CJ, Zengerink M, Blankevoort L, van Sterkenburg MN, van Oldenrijk J, van Dijk CN. Novel metallic implantation technique for osteochondral defects of the medial talar dome. A cadaver study. Acta Orthop 2010;81(4):495-502.
80. van den Borne MP, Raijmakers NJ, Vanlauwe J, et al. International Cartilage Repair Society (ICRS) and Oswestry macroscopic cartilage evaluation scores validated for use in Autologous Chondrocyte Implantation (ACI) and microfracture. Osteoarthritis Cartilage 2007;15(12):1397-1402.
81. Whittaker JP, Smith G, Makwana N, et al. Early results of autologous chondrocyte implantation in the talus. J Bone Joint Surg Br 2005;87(2):179-183.
82. Zengerink M, Szerb I, Hangody L, Dopirak RM, Ferkel RD, van Dijk CN. Current concepts: treatment of osteochondral ankle defects. Foot Ankle Clin 2006;11(2):331-359.