Current Concepts Review

Operative Treatment of Osteochondral Lesions of the Talus

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- Osteochondral lesions of the talus are common injuries in recreational and professional athletes, with up to 50% of acute ankle sprains and fractures developing some form of chondral injury. Surgical treatment paradigms aim to restore the articular surface with a repair tissue similar to native cartilage and to provide long-term symptomatic relief.
- Arthroscopic bone-marrow stimulation techniques, such as microfracture and drilling, perforate the subchondral plate with multiple openings to recruit mesenchymal stem cells from the underlying bone marrow to stimulate the differentiation of fibrocartilaginous repair tissue in the defect site. The ability of fibrocartilage to withstand mechanical loading and protect the subchondral bone over time is a concern.
- Autologous osteochondral transplantation techniques replace the defect with a tubular unit of viable hyaline cartilage and bone from a donor site in the ipsilateral knee. In rare cases, a graft can also be harvested from the ipsilateral talus or contralateral knee. The limitations of donor site morbidity and the potential need for an osteotomy about the ankle should be considered. Some anterior or far posterior talar lesions can be accessed without arthrotomy or with a plafondplasty.
- Osteochondral allograft transplantation allows an osteochondral lesion with a large surface area to be replaced with a single unit of viable articular cartilage and subchondral bone from a donor that is matched to size, shape, and surface curvature. The best available evidence suggests that this procedure should be limited to large-volume cystic lesions or salvage procedures.
- Autologous chondrocyte implantation techniques require a two-stage procedure, the first for chondrocyte harvest and the second for implantation in a periosteum-covered or matrix-induced form after in vivo culture expansion. Theoretically, the transplantation of chondrocyte-like cells into the defect will result in hyaline-like repair tissue.

Osteochondral lesions of the talus present a difficult clinical problem to orthopaedic surgeons. Ankle sprains are a common injury, with up to two million acute sprains occurring each year in the United States alone[1,2]. Approximately one-half of these acute ankle sprains are likely to result in some form of cartilage injury[3]. Ankle fractures also present a substantial risk for chondral injury, with rates reported to be as high as 73% (sixty-one of eighty-four acute ankle fractures)[4]. Clinically effective cartilage repair techniques are paramount in providing symptomatic relief and returning the patient to sports and activities of daily living.

The operative treatment paradigms for osteochondral lesions of the talus are controversial and a subject of frequent debate. A Cochrane review performed by Loveday et al. concluded that there was a lack of evidence to determine which

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operative treatment strategy is most beneficial in treating osteochondral lesions of the talus in adults[5]. Treatment techniques include arthroscopic bone-marrow stimulation, tissue transplantation, and other cell-based techniques. Biological adjuncts to cartilage repair are also becoming increasingly investigated and utilized. In this review, we provide, where possible, an evidence-based critical discussion of the basic science, indications, advantages, outcomes, and limitations associated with these operative treatment and augmentation strategies for osteochondral lesions of the talus.

Arthroscopic Bone-Marrow Stimulation

Arthroscopic bone-marrow stimulation involving drilling and microfracture is the most commonly utilized primary treatment strategy for symptomatic osteochondral lesions of the talus that are ≤15 mm in diameter[6-13]. This treatment is low-cost, technically undemanding, and minimally invasive, with low complication rates and minimal postoperative pain. Bone-marrow stimulation should be accompanied by excision and curettage of the defect site, such that the calcified layer is removed at the foundation and a stable margin of healthy cartilage is achieved[14,15].

The primary objective of bone-marrow stimulation is to breach the subchondral plate at multiple 3 to 4-mm intervals, thereby allowing pluripotent mesenchymal stem cells to accumulate into the base of the defect site from the underlying bone marrow (Figs. 1-A, 1-B, and 1-C)[13]. Intraoperatively, the release of fatty droplets from the fracture apertures can be utilized as a clinical indicator that adequate depth has been achieved. The subsequent formation of a fibrin clot initiates an inflammatory response, during which the release of cytokines and growth factors stimulates tissue healing[16-19]. Mesenchymal stem cells begin to differentiate into chondrocyte-like cells that ultimately form a repair tissue expressing mainly type-II collagen in a proteoglycan matrix at six to eight weeks after injury[20-22]. However, the ensuing surface fibrillation, proteoglycan depletion, and chondrocyte death result in a biological shift to fibrocartilaginous repair tissue exhibiting primarily type-I collagen at one year[21-24]. Type-I collagen retains inherently different biological and mechanical properties compared with hyaline cartilage, and it may degenerate over time[21].

Outcomes of Arthroscopic Bone-Marrow Stimulation

Currently, no study, to our knowledge, has described the long-term outcomes (i.e., at ten years or more) after arthroscopic bone-marrow stimulation of the talus. Likewise, we are not aware of Level-I clinical trials comparing bone-marrow stimulation with other cartilage repair techniques. A systematic review by Zengerink et al.[12] concluded that excision, curettage, and bone-marrow stimulation represented the treatment strategy of choice for primary osteochondral lesions of the talus, with an 85% success rate in a total of 386 patients.

The lesion size best suited for treatment with arthroscopic bone-marrow stimulation has not been established. However, strong associations have been reported between smaller lesion size and a successful clinical outcome. Chuckpaiwong et al. performed an analysis of 105 patients followed prospectively for a mean of 31.6 months and reported no treatment failures in lesions with a size of <15 mm, irrespective of lesion location[25]. Conversely, there was only one successful outcome in thirty-two patients with a lesion size of >15 mm. Choi et al. also evaluated the effect of lesion size on clinical outcome in 117 patients and found the lowest clinical failure rate to be associated with a defect area of <100 mm^2 (5.2% of fifty-eight ankles)[26]. Analyses by several authors have noted that age and a history of trauma have no effect on overall outcome[25-30].

One prospective randomized study (Level-II evidence) compared the outcomes of microfracture with those of alternative cartilage repair techniques. Gobbi et al. randomized thirty-two patients (thirty-three ankles) to receive microfracture, osteochondral autologous transplantation, or chondroplasty, all performed arthroscopically[31]. At a mean follow-up of fifty-three months, no significant difference was detected among treatment groups with respect to the American Orthopaedic Foot & Ankle Society (AOFAS) Ankle-Hindfoot Scale or the Single Assessment Numeric Evaluation rating[32,33]. The microfracture and chondroplasty groups, however, had lower Numeric Pain Intensity Scores in comparison with the osteochondral autologous transplantation group twenty-four hours postoperatively. There were several limitations to this study, including the fact that patients were not truly randomized but assigned a treatment according to the treating surgeon. There were also differences between treatment groups with regard to lesion size, patient sex, and age, yet it appears that outcomes for reparative and restorative strategies are both good.

Several authors have reported good results following arthroscopic bone marrow stimulation[28,34,35]. Lee et al.[35] reported good to excellent results after microfracture in 89% of thirty-five patients under fifty years of age and with lesions of <1.5 cm^2. Becher and Thermann, in a prospective study of thirty patients treated with arthroscopic microfracture and followed for a mean of twenty-four months[28], reported that 83% had excellent or good results according to the Hannover Scoring System[36]. However, all patients had fibrillation and fissuring on magnetic resonance imaging (MRI) at the time of the final follow-up.

In addition to these encouraging results, there are also several reports of poorer outcomes after arthroscopic bone-marrow stimulation[37-41]. Kumai et al., in a study of eighteen ankles treated with arthroscopic drilling and followed for a mean of 4.6 years, reported that thirteen patients (72%) had good clinical results and five (28%) had fair results[37]. While Schuman et al. found good to excellent results in 82% of patients at a mean of 4.8 years of follow-up, 45% reported being limited or not able to return to sporting activities after surgery[38]. Recently, Cuttica et al. assessed edema on follow-up MRI studies after microfracture in twenty-nine patients with thirty osteochondral lesions of the talus[40]. At a mean of 81.5 weeks after surgery, sixteen ankles (53%) had a fair or poor outcome, with better results seen in patients with a lower grade of edema intensity.

To our knowledge, Lee et al. were the first to report a case series using second-look arthroscopy, which was performed on twenty ankles one year after microfracture[42]. Despite good to

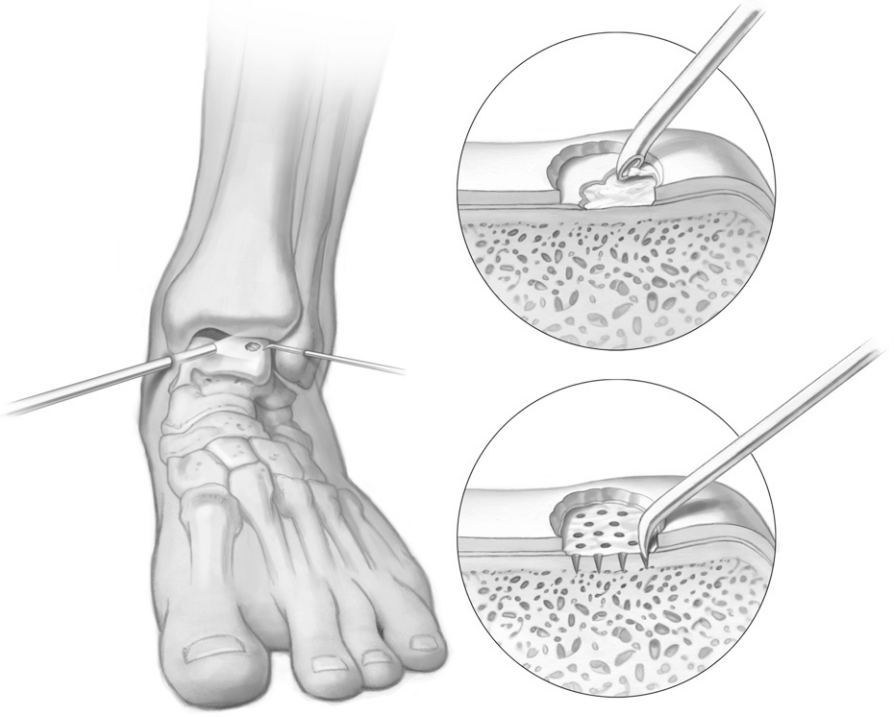


Fig. 1-A

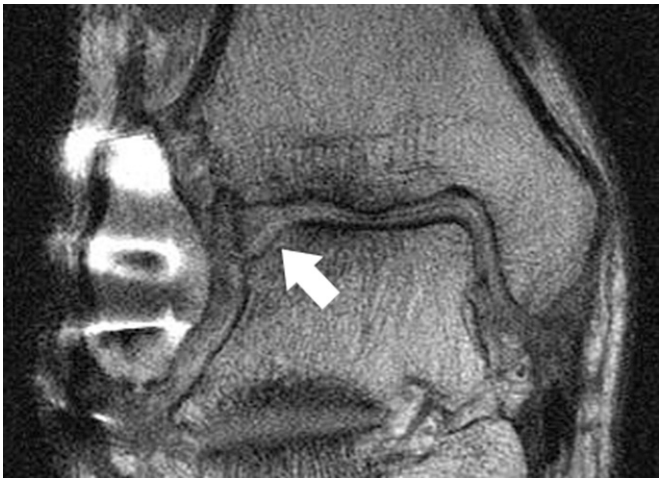


Fig. 1-B

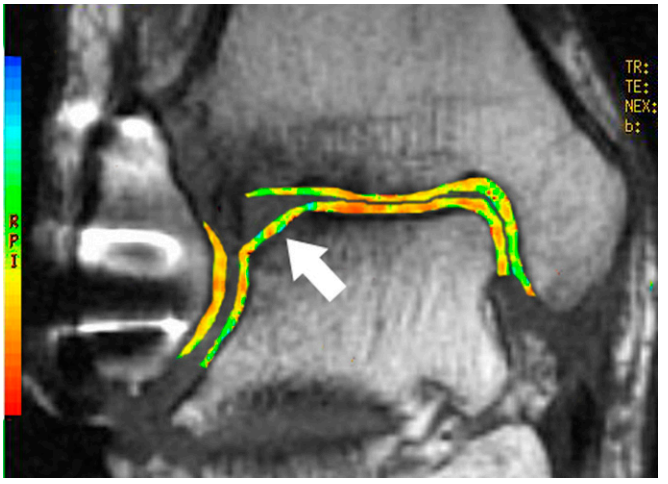


Fig. 1-C

Figs. 1-A, 1-B, and 1-C Arthroscopic bone-marrow stimulation for the repair of symptomatic osteochondral lesions of the talus. **Fig. 1-A** After curettage and debridement of the defect, removal of the calcified layer at the base of the defect is of critical importance in the procedure in order to facilitate clot adhesion[15]. Bone-marrow stimulation is then accomplished by perforating the subchondral bone at 3 to 4-mm intervals in the base of the defect to stimulate the formation of a fibrocartilaginous repair tissue. **Fig. 1-B** Coronal cartilage-sensitive fast spin-echo MRI study, acquired twenty-five months following microfracture of the lateral margin of the talar dome, demonstrates depression of the subchondral plate and overlying high-signal-intensity repair cartilage (arrow). Hardware is evident in the distal aspect of the fibula from a previous open reduction and internal fixation. **Fig. 1-C** Corresponding coronal quantitative T2 map demonstrates diffuse prolongation of T2 values and loss of color stratification at the site of cartilage repair (arrow), representing immature repair cartilage. Normal cartilage typically demonstrates T2 stratification, with lower values (i.e., red-orange) near the subchondral plate and progressively higher values (i.e., yellow-green) toward the articular surface. Abnormal cartilage (either damaged cartilage or fibrocartilaginous repair tissue) typically demonstrates prolongation of T2 relaxation values (i.e., yellow-green-blue) and loss of T2 stratification. (Figs. 1-B and 1-C reproduced, with permission of Sage Publications, from: Murawski CD, Foo LF, Kennedy JG. A review of arthroscopic bone marrow stimulation techniques of the talus: the good, the bad, and the causes for concern. Cartilage. 2010;1[2]:137-44. All rights reserved. Copyright [2010]. http://online.sagepub.com.)

excellent AOFAS scores for 90% of the ankles, the repair tissue in eight ankles (40%) was graded as abnormal (grade III) according to the International Cartilage Repair Society system[43,44], while seven ankles (35%) demonstrated incomplete healing (stage D) according to the Ferkel and Cheng classification system[45]. Separately, Ferkel et al. retrospectively evaluated fifty patients, including forty-four who had drilling and six who had an abrasion arthroplasty, with a mean follow-up of seventy-one months[46]. Thirty-four percent of the patients demonstrated advancement by at least one grade of arthritis on radiographs, and a subset of seventeen patients demonstrated a 35% decline in the modified Weber score[47] over five years. Collectively, therefore, these data are concerning and suggest deterioration of the fibrocartilage infill and declining outcome scores over time. While arthroscopic bone-marrow stimulation remains a technically undemanding and viable primary treatment strategy for small osteochondral lesions of the talus, size guidelines that facilitate symptomatic relief in the long term are not yet established.

Tissue Transplantation

Autologous Osteochondral Transplantation

Autologous osteochondral transplantation involves transplanting one or more tubular units of cartilage and bone harvested from the ipsilateral knee to a defect site in the talus (Figs. 2-A, 2-B, and 2-C). Mosaicplasty is one form of autologous osteochondral transplantation and consists of multiple circular plugs, often of varying sizes, arranged in a side-by-side configuration. Historically, autologous osteochondral transplantation has been indicated in patients with highly cystic lesions or secondarily after failed index procedures, whereas several recent studies have advocated its use in large primary lesions as well[12,48-50]. The inherent advantages of this technique include replacing the defect with viable hyaline cartilage, without the need for a two-stage procedure. Despite this, however, there are disadvantages, including the need for graft harvest and the associated donor site morbidity, differences in surface curvature between the graft and host tissues, the poor potential for spontaneous healing at the cartilage interface of the graft, and the possible need for an osteotomy. On the basis of the exact location of the lesion, various osteotomies, including plafondplasty as well as osteotomy of the medial malleolus, the lateral aspect of the tibia, and the fibula, can be performed. A fibular osteotomy can be combined with lateral ligament release, depending on the approach required[51].

Placing the donor graft(s) in the most congruent position possible to avoid surface incongruities on the talus should be considered of critical importance to the surgeon when performing this procedure. Two recent studies have investigated the effect of graft height on contact mechanics in cadaveric ankles[52,53]. In one of these studies, Fansa et al. transplanted a graft harvested from the ipsilateral knee to the centromedial aspect of the talus in the most congruent position possible relative to the surrounding cartilage[53]. Utilizing a six-degrees-of-freedom robotic arm, the authors demonstrated a restoration of force measurements on the medial one-third of the talus to within an insignificant 6% of normal.

Outcomes of Autologous Osteochondral Transplantation

To our knowledge, the largest case series of autologous osteochondral mosaicplasties to date was reported by Hangody et al. and included the cases of 1097 patients, ninety-eight of whom had the procedure performed in the talus[54]. The authors reported that 93% of the patients had good to excellent clinical results in the talus on the basis of evaluation with the Hannover Scoring System[36]. Long-term donor-site knee pain was present in 3% of the overall population. Similarly, Kennedy and Murawski also reported good functional results at a mean follow-up of 28.02 months postoperatively in seventy-two patients who underwent autologous osteochondral transplantation[49]. Three patients (4%) reported donor-site knee pain after the operation, and one patient required the decompression of a cyst that had developed beneath the graft site two years after the operation.

The role of autologous osteochondral transplantation procedures in returning patients to sporting activities has also been investigated. Paul et al. reported on 131 patients who were followed retrospectively for a mean of sixty months postoperatively[55]. The authors found that, while patients were able to return to sporting activities, they tended to modify the level of activity, particularly if they competed in high-impact or contact sports.

The results after medial malleolar osteotomy have also been reported. Lamb et al. recently described the results of a chevron-type medial malleolar osteotomy in sixty-two patients[56]. At a median follow-up duration of 34.5 months after surgery, fifty-eight patients (94%) were asymptomatic at the site of the osteotomy, with a median time to radiographic healing of six weeks (range, four to six weeks). Quantitative T2-mapping MRI revealed that relaxation times in the deep half of the repair tissue at the osteotomy interface were restored relative to those of normal tibial cartilage, while those in the superficial half indicated a more fibrocartilaginous repair.

Two studies have evaluated donor-site knee pain after osteochondral graft harvest. Paul et al. evaluated graft harvest from an asymptomatic knee in 112 patients with a minimum follow-up of two years (mean, fifty-five months)[57]. Patients were evaluated using the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Lysholm knee score[58,59]. The mean WOMAC and Lysholm scores were 5.5% and 89 points, respectively, at the time of final follow-up, and a higher body mass index (BMI) negatively influenced outcome scores. Reddy et al., in a retrospective evaluation of eleven patients with a mean follow-up of forty-seven months after the operation, reported a final mean Lysholm score of 81 points[60]. The number of grafts obtained had no effect on clinical outcome.

Autologous osteochondral transplantation of the talus has the potential to provide good clinical outcomes in the short to medium-term time periods, with results that do not appear to decrease over time. Emphasis should be placed on implanting the donor graft(s) in the most congruent position possible relative to the native cartilage. An osteotomy may be required to access the talar dome, but it does not appear to be a reported cause for concern. However, donor-site knee pain is a concern in some series.

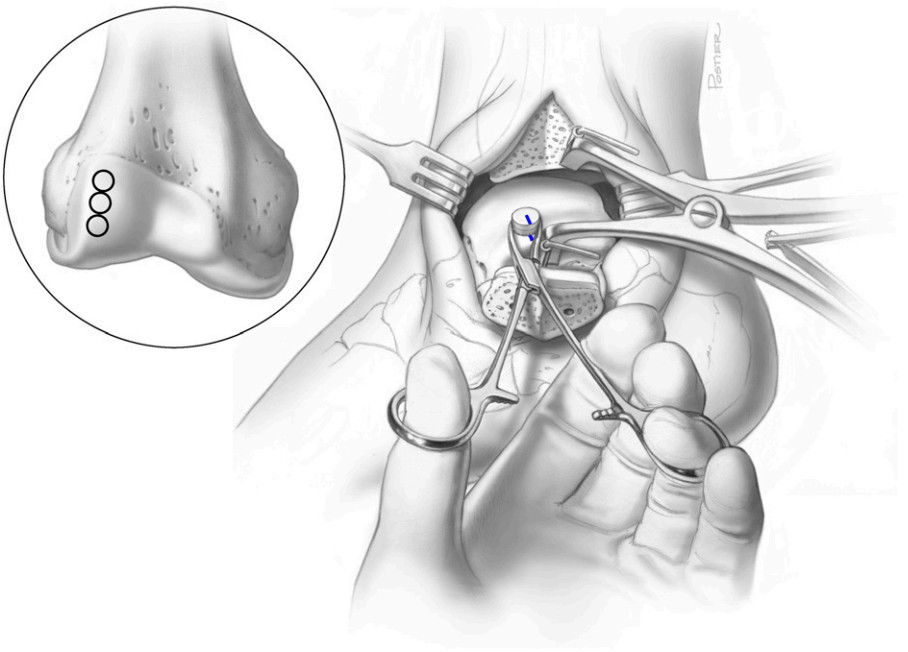
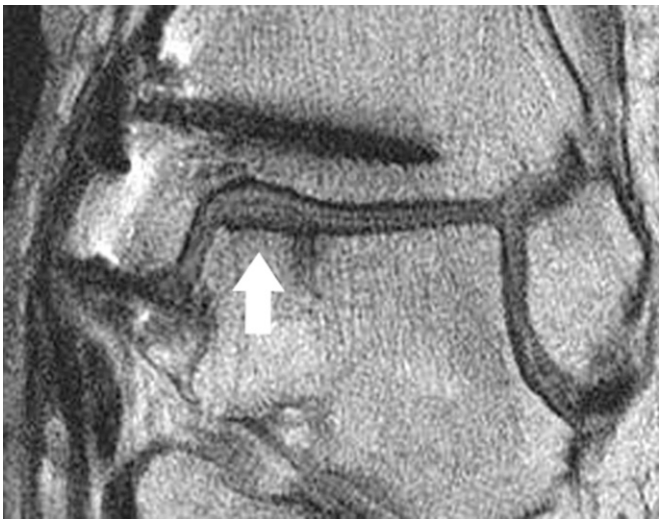


Fig. 2-A



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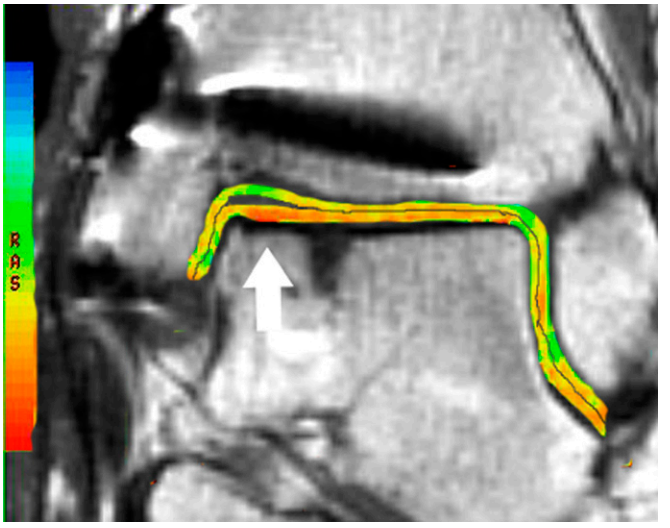

Fig. 2-C

Figs. 2-A, 2-B, and 2-C Autologous osteochondral transplantation for the replacement of an osteochondral lesion of the talus. **Fig. 2-A** One or more tubular units of viable hyaline cartilage and bone (circles in inset) are harvested from the ipsilateral knee and transplanted into the defect site of the talus in a press-fit configuration. Placing the graft in the most congruent position possible relative to the surrounding native articular surface of the talus should be considered crucial. The blue lines are used for alignment of the plug with the native surface of the talus. (Reproduced, with permission of Sage Publications, from: Kennedy JG, Murawski CD. The treatment of osteochondral lesions of the talus with autologous osteochondral transplantation and bone marrow aspirate concentrate: surgical technique. Cartilage. 2011;2:327-36. All rights reserved. Copyright [2011]. http://online.sagepub.com.) **Fig. 2-B** Coronal cartilage-sensitive fast spin-echo MRI study of an autologous osteochondral plug (arrow) transplanted into the medial margin of the talar dome demonstrates good fill of the cartilage defect and restoration of the radius of curvature of the articular surface by repair cartilage, which maintains gray-scale stratification and is flush with the adjacent native cartilage. There is good osseous incorporation of the graft. **Fig. 2-C** Corresponding coronal quantitative T2 map demonstrates normal color stratification of T2 values at the site of cartilage repair (arrow), similar to that of native cartilage. Placing the graft in a congruent position resulted in a step-off in the bone at the graft site relative to the surrounding bone as a result of thicker cartilage in the knee compared with the ankle. (Figs. 2-B and 2-C reproduced, with permission of Sage Publications, from: Murawski CD, Foo LF, Kennedy JG. A review of arthroscopic bone marrow stimulation techniques of the talus: the good, the bad, and the causes for concern. Cartilage. 2010;1[2]:137-44. All rights reserved. Copyright [2010]. http://online.sagepub.com.)

Osteochondral Allograft Transplantation

Osteochondral allograft transplantation is a replacement procedure in which a cadaver graft of viable articular cartilage and its underlying subchondral bone are harvested to a specific size, depth, and orientation of curvature (Fig. 3). In comparison with the knee, the ankle is a highly congruent joint, and thus the graft must be matched meticulously to the native talus. The advantages of using osteochondral allograft include the transplantation of viable hyaline cartilage without the need for graft harvest from an asymptomatic knee, the ability to replace large defects with a single dowel of cartilage and bone, and the ability to fashion the graft to a specific fit and radius of curvature. However, the disadvantages of osteochondral allograft include a technically demanding process of graft preparation, high cost, limited availability, and the potential for disease transmission. Several types of osteochondral allografts exist and can be characterized on the basis of the methods of storage or preservation prior to use. Fresh allografts are the most commonly utilized in clinical practice, as both fresh-frozen and cryopreserved allograft have been reported previously to have decreased chondrocyte viability in the donor tissue[61,62]. Immediately after being harvested from the cadaver, grafts undergo a rigorous screening process based on guidelines set forth by the American Association of Tissue Banks, during which time they are maintained in a temperature-controlled environment (typically between 2° and 4°C)[63-65]. In this regard, an expedient yet thorough process is critical, as chondrocyte viability in fresh allograft decreases with time. Williams et al. investigated the effect of prolonged storage on osteochondral allografts and found that, while chondrocyte viability and viable cell density were not altered through fourteen days, a significant ($p < 0.001$) decline in viable chondrocytes to 70% of the original amount occurred at twenty-eight days[66]. Every effort should be made by the surgeon and patient to conduct the procedure at the earliest possible time following release of the allograft.

Outcomes of Osteochondral Allograft Transplantation

Presently, the evidence supporting the use of osteochondral allograft in the talus remains limited, with only a few retrospective and prospective case series available. Raikin prospectively evaluated fifteen patients with a mean follow-up of forty-four months (minimum, twenty-four months) after fresh bulk osteochondral allograft transplantation for large-volume, cystic osteochondral lesions of the talus that were >3000 mm^3 in size[65]. At the time of final follow-up, the mean AOFAS score had improved from 38 points preoperatively to 83 points postoperatively, while the visual analog scale (VAS) pain score decreased from a mean of 8.5 points preoperatively to 3.3 points postoperatively. Radiographic findings revealed evidence of collapse or resorption in ten ankles (67%) and joint space narrowing in nine ankles (60%). Two (13%) of the fifteen ankles required subsequent conversion to ankle arthrodesis.

The remaining literature for fresh osteochondral allograft transplantation of the talus comprises retrospective case series. El-Rashidy et al. evaluated thirty-eight patients with a mean follow-up duration of 37.7 months[64]. The mean AOFAS ankle-hindfoot score increased significantly from 52 points preoperatively to 79 points postoperatively. Graft failure, defined as the need for conversion to arthrodesis or arthroplasty, occurred in four patients. Fifteen patients in the cohort also underwent MRI follow-up after surgery. Graft subsidence was found in only one patient, who also had graft failure. However, graft incorporation was rated as fair or poor in twelve patients (80%), while one-third of the grafts were also graded as unstable according to the De Smet criteria, in which signs of instability on MRI have been found to include one or more high-signal lines, a focal defect, an articular fracture, and an adjacent cyst.

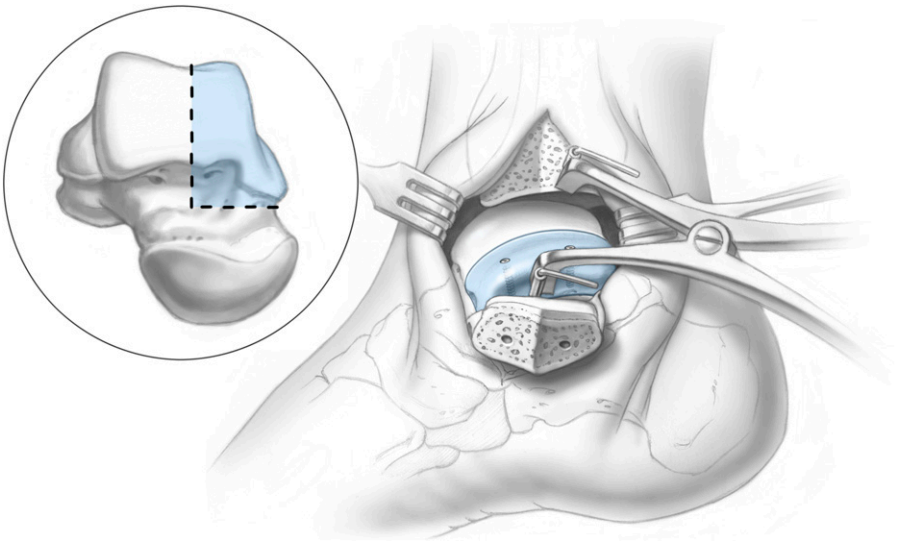

Fig. 3

A fresh osteochondral allograft is harvested from a donor talus matched to the size and radius of curvature of the native articular surface (left). The graft is then transplanted into the prepared talus and is typically secured using two bioabsorbable screws (right).

On the basis of the available evidence, patients for osteochondral allograft transplantation should be chosen carefully to include those needing salvage procedures or with large-volume, cystic lesions not amenable to arthroscopic bone-marrow stimulation or standard autograft procedures. When used in select patients, this procedure has the potential to reduce pain and improve function for those seeking to avoid or delay more permanent procedures, such as ankle arthrodesis or total ankle arthroplasty.

Autologous Chondrocyte Implantation

Autologous chondrocyte implantation was first developed by Brittberg et al., in 1994, as an innovative operative approach for treating cartilage defects of the knee[67]. In principle, the primary advantage of autologous chondrocyte implantation is that it involves the transplantation of viable, cultured chondrocytes into the defect, thereby facilitating a presumably hyaline-like repair tissue. However, a two-stage operation is required.

Periosteum-Covered Technique

The periosteum-covered, or first-generation autologous chondrocyte implantation, technique utilizes an injection of chondrocyte cell suspension under a sutured periosteal flap harvested from the distal end of the tibia. The limitations of this technique include a technically demanding procedure, the potential for cell dedifferentiation, cell leakage, uneven distribution of cells within the defect, delamination, and periosteal hypertrophy.

Matrix-Associated Technique

Matrix-induced autologous chondrocyte implantation, or the so-called second-generation autologous chondrocyte implantation technique, evolved in response to the complications associated with the first-generation technique. In the matrix-associated technique, harvested chondrocytes are typically cultured on a bioabsorbable, porcine type-I/III collagen membrane before implantation into the defect[68]. There are also various other types of matrices, including type-I collagen gel and hyaluronic acid-based membrane[69]. The advantages of the matrix-induced autologous chondrocyte implantation technique over the first-generation technique are that a periosteal graft harvest is avoided, there is a more even cell distribution, the procedure can be performed arthroscopically, and the culturing process is thought to prevent the dedifferentiation of chondrocytes. Presently, matrix-induced autologous chondrocyte implantation is not marketed in the United States.

Outcomes of Autologous Chondrocyte Implantation

The clinical outcomes after techniques of autologous chondrocyte implantation in the talus have been reported only in case series. In a recent meta-analysis of Level-I evidence, Niemeyer et al. evaluated the effectiveness of autologous chondrocyte implantation for osteochondral lesions of the talus[70]. In the review of sixteen studies meeting the inclusion criteria, the mean modified Coleman Methodology Score was 65 points and the overall clinical success rate was 89.9%. The Coleman Methodology Score has been used previously to evaluate studies of cartilage repair[71]. Definitive conclusions could not be reached because of a lack of controlled studies comparing autologous chondrocyte implantation techniques with other methods of cartilage repair.

Periosteum-Covered Technique

Giannini et al. reported the long-term, ten-year clinical and MRI results after periosteum-covered autologous chondrocyte implantation in ten patients[72]. The authors reported that the mean AOFAS score improved from 37.9 points preoperatively to 92.7 points postoperatively. Morphological MRI follow-up, using the Magnetic Resonance Observation of Cartilage Repair Tissue scoring system[73], revealed integration of the regenerated tissue, as well as subchondral edema in two patients (20%). Battaglia et al. recently reported the results of an arthroscopic autologous chondrocyte implantation technique in twenty patients with a mean age of thirty-five years and a mean follow-up duration of five years[74]. The mean AOFAS functional outcome score increased from 59 points preoperatively to 84 points postoperatively, while quantitative T2-mapping evaluation revealed a repair tissue similar to native cartilage covering 69% of the total defect area.

Matrix-Associated Technique

Giannini et al. reported what we believe is the largest case series, which involved forty-six patients undergoing matrix-induced autologous chondrocyte implantation in the talus for posttraumatic lesions[75]. The patients were followed prospectively for thirty-six months and demonstrated a significant improvement in the mean AOFAS score from 57.2 points preoperatively to 89.5 points postoperatively. The initial three patients in the series underwent second-look arthroscopy with tissue biopsy; subsequent histological examination revealed repair tissue similar to hyaline cartilage. Recently, Magnan et al. evaluated thirty patients with a mean lesion size of 2.36 cm^2 who were treated with matrix-induced autologous chondrocyte implantation[76]. The mean AOFAS score improved from 36.9 points preoperatively to 83.9 points at a mean follow-up of forty-five months (range, eighteen to ninety-six months). Only 50% of the patients returned to their previous sporting activities. In a separate study by Quirbach et al., who evaluated twelve patients after matrix-induced autologous chondrocyte implantation, T2 and T2* MRI relaxation times revealed a repair tissue that was not significantly different from the tissue in a healthy control group[77].

Despite promising results with the autologous chondrocyte implantation technique, including improved function in patients having a revision, definitive recommendations cannot be made. Patients should be counseled thoroughly with regard to the need for a two-stage procedure and other potential risk factors, such as those associated with periosteal harvest.

Biological Adjuncts to Cartilage Repair

Concentrated Bone-Marrow Aspirate

Bone-marrow aspirate contains a source of mesenchymal stem cells and growth factors and can be harvested intraoperatively using a simple, one-step aspiration technique from several sources, including the iliac crest, proximal or distal aspect of the tibia, and calcaneus[78]. While the site and aspirate volume may

play a role in the quantity of mesenchymal stem cells and progenitor cells, sex and age-related differences have also been reported[79,80].

The use of concentrated bone-marrow aspirate as an adjunct to microfracture has been investigated in a preclinical large-animal model. Fortier et al. created 15-mm, full-thickness defects on the lateral trochlear ridge of the stifle joint in twelve horses and treated them with microfracture and concentrated bone-marrow aspirate or microfracture alone[81]. The animals were killed at eight months, at which time histological data revealed greater type-II collagen, proteoglycan, and glycosaminoglycan content in the concentrated bone-marrow aspirate group. Clinically, several investigators have employed concentrated bone-marrow aspirate in uncontrolled studies; the usefulness of these studies in delineating the exact efficacy in the treatment of osteochondral lesions of the talus is therefore limited[49,82].

Hyaluronic Acid

Hyaluronic acid is a carbohydrate component contained within synovial fluid that confers its viscoelastic properties and experimentally enhances the proliferation of cultured chondrocytes in vitro[83,84]. To our knowledge, hyaluronic acid is the only biological adjunct for the treatment of osteochondral lesions of the talus that is supported by Level-I evidence. Recently, Doral et al. reported that three intra-articular hyaluronic acid injections performed weekly, beginning in the third postoperative week after arthroscopic debridement and microfracture, significantly improved clinical outcome compared with the microfracture-only control[83].

Overview

The surgical treatment of osteochondral lesions of the talus remains controversial among orthopaedic surgeons worldwide. Depending on lesion size, both arthroscopic bone-marrow stimulation and autologous osteochondral transplantation can be utilized as primary treatment strategies with good success (Table I). Osteochondral allograft transplantation and other cell-based techniques should only be utilized in carefully considered patients in whom other primary techniques have failed previously. Well-designed clinical trials of high methodological quality are required to substantiate these clinical guidelines. ■

TABLE I Grades of Recommendation for the Operative Treatment of Osteochondral Lesions of the Talus

	Grade*
Bone-marrow stimulation	B
Autologous osteochondral transplantation	B
Osteochondral allograft transplantation	C
Autologous chondrocyte implantation	C
Biological adjuncts	I

*Grade A indicates good evidence (Level-I studies with consistent findings) for or against recommending the intervention; Grade B, fair evidence (Level-II or III studies with consistent findings) for or against recommending the intervention; Grade C, conflicting or poor-quality evidence (Level-IV or V studies) not allowing a recommendation for or against the intervention; and Grade I, there is insufficient evidence to make a recommendation[85].

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References

1. Waterman BR, Belmont PJ Jr, Cameron KL, Deberardino TM, Owens BD. Epidemiology of ankle sprain at the United States Military Academy. Am J Sports Med. 2010;38(4):797-803.

2. Soboroff SH, Pappius EM, Komaroff AL. Benefits, risks, and costs of alternative approaches to the evaluation and treatment of severe ankle sprain. Clin Orthop Relat Res. 1984;(183):160-8.

3. Saxena A, Eakin C. Articular talar injuries in athletes: results of microfracture and autogenous bone graft. Am J Sports Med. 2007;35(10):1680-7.

4. Leontaritis N, Hinojosa L, Panchbhavi VK. Arthroscopically detected intra-articular lesions associated with acute ankle fractures. J Bone Joint Surg Am. 2009;91(2):333-9.

5. Loveday D, Clifton R, Robinson A. Interventions for treating osteochondral defects of the talus in adults. Cochrane Database Syst Rev. 2010;(8):CD008104.

6. Amendola A, Panarella L. Osteochondral lesions: medial versus lateral, persistent pain, cartilage restoration options and indications. Foot Ankle Clin. 2009;14(2):215-27.

7. 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):106-12.

8. Giannini S, Vannini F. Operative treatment of osteochondral lesions of the talar dome: current concepts review. Foot Ankle Int. 2004;25(3):168-75.

9. van Bergen CJ, de Leeuw PA, van Dijk CN. Treatment of osteochondral defects of the talus. Rev Chir Orthop Repara- trice Appar Mot. 2008;94:398-408.

10. van Dijk CN, van Bergen CJ. Advancements in ankle arthroscopy. J Am Acad Orthop Surg. 2008;16(11):635-46.

11. Lahm A, Erggelet C, Steinwachs M, Reichelt A. Arthroscopic management of osteochondral lesions of the talus: results of drilling and usefulness of magnetic resonance imaging before and after treatment. Arthroscopy. 2000;16(3):299-304.

12. Zengerink M, Struijs PA, Tol JL, van Dijk CN. Treatment of osteochondral lesions of the talus: a systematic review [Review]. Knee Surg Sports Traumatol Arthrosc. 2010;18(2):238-46.

13. Murawski CD, Foo LF, Kennedy JG. A review of arthroscopic bone marrow stimulation techniques of the talus: the good, the bad, and the causes for concern. Cartilage. 2010;1(2):137-44.

14. Takao M, Uchio Y, Kakimaru H, Kumahashi N, Ochi M. Arthroscopic drilling with debridement of remaining cartilage for osteochondral lesions of the talar dome in unstable ankles. Am J Sports Med. 2004;32(2):332-6.

15. Frisbie DD, Morisset S, Ho CP, Rodkey WG, Steadman JR, McIlwraith CW. Effects of calcified cartilage on healing of chondral defects treated with microfracture in horses. Am J Sports Med. 2006;34(11):1824-31.

16. Mankin HJ. The response of articular cartilage to mechanical injury. J Bone Joint Surg Am. 1982;64(3):460-6.

17. DePalma AF, McKeever CD, Subin DK. Process of repair of articular cartilage demonstrated by histology and autoradiography with tritiated thymidine. Clin Orthop Relat Res. 1966;48:229-42.

18. Buckwalter JA, Mow VC, Ratcliffe A. Restoration of injured or degenerated articular cartilage. J Am Acad Orthop Surg. 1994;2(4):192-201.

19. Tang QO, Shakib K, Heliotis M, Tsiridis E, Mantalaris A, Ripamonti U, Tsiridis E. TGF-beta3: A potential biological therapy for enhancing chondrogenesis. Expert Opin Biol Ther. 2009;9(6):689-701.

20. Cheung HS, Lynch KL, Johnson RP, Brewer BJ. In vitro synthesis of tissue-specific type II collagen by healing cartilage. I. Short-term repair of cartilage by mature rabbits. Arthritis Rheum. 1980;23(2):211-9.

21. Furukawa T, Eyre DR, Koide S, Glimcher MJ. Biochemical studies on repair cartilage resurfacing experimental defects in the rabbit knee. J Bone Joint Surg Am. 1980;62(1):79-89.

22. Hjertquist SO, Lemperg R. Histological, autoradiographic and microchemical studies of spontaneously healing osteochondral articular defects in adult rabbits. Calcif Tissue Res. 1971;8(1):54-72.

23. Shapiro F, Koide S, Glimcher MJ. Cell origin and differentiation in the repair of full-thickness defects of articular cartilage. J Bone Joint Surg Am. 1993;75(4):532-53.

24. Mitchell N, Shepard N. The resurfacing of adult rabbit articular cartilage by multiple perforations through the subchondral bone. J Bone Joint Surg Am. 1976;58(2):230-3.

25. 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):106-12.

26. 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):1974-80.

27. Becher C, Driessen A, Hess T, Longo UG, Maffulli N, Thermann H. Microfracture for chondral defects of the talus: maintenance of early results at midterm follow-up. Knee Surg Sports Traumatol Arthrosc. 2010;18(5):656-63.

28. Becher C, Thermann H. Results of microfracture in the treatment of articular cartilage defects of the talus. Foot Ankle Int. 2005;26(8):583-9.

29. Robinson DE, Winson IG, Harries WJ, Kelly AJ. Arthroscopic treatment of osteochondral lesions of the talus. J Bone Joint Surg Br. 2003;85(7):989-93.

30. 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):419-24.

31. 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):1085-92.

32. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int. 1994;15(7):349-53.

33. Williams GN, Taylor DC, Gangel TJ, Uhorchak JM, Arciero RA. Comparison of the single assessment numeric evaluation method and the Lysholm score. Clin Orthop Relat Res. 2000;(373):184-92.

34. Van Buecken K, Barrack RL, Alexander AH, Ertl JP. Arthroscopic treatment of transchondral talar dome fractures. Am J Sports Med. 1989;17(3):350-5, discussion :355-6.

35. Lee KB, Bai LB, Chung JY, Seon JK. Arthroscopic microfracture for osteochondral lesions of the talus. Knee Surg Sports Traumatol Arthrosc. 2010; 18(2):247-53.

36. Thermann H. Treatment of osteochondritis dissecans of the talus: a long-term follow-up. Sports Med Arthrosc. 1994;(2):284-288

37. Kumai T, Takakura Y, Higashiyama I, Tamai S. Arthroscopic drilling for the treatment of osteochondral lesions of the talus. J Bone Joint Surg Am. 1999;81(9): 1229-35.

38. 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):364-8.

39. Hunt SA, Sherman O. Arthroscopic treatment of osteochondral lesions of the talus with correlation of outcome scoring systems. Arthroscopy. 2003;19(4): 360-7.

40. Cuttica DJ, Shockley JA, Hyer CF, Berlet GC. Correlation of MRI edema and clinical outcomes following microfracture of osteochondral lesions of the talus. Foot Ankle Spec. 2011;4(5):274-9.

41. Robinson DE, Winson IG, Harries WJ, Kelly AJ. Arthroscopic treatment of osteochondral lesions of the talus. J Bone Joint Surg Br. 2003;85(7):989-93.

42. Lee KB, Bai LB, Yoon TR, Jung ST, Seon JK. Second-look arthroscopic findings and clinical outcomes after microfracture for osteochondral lesions of the talus. Am J Sports Med. 2009;37(Suppl 1):63S-70S.

43. Brittberg M, Peterson L. Introduction of an articular cartilage classification. ICRS Newsletter. 1998;1:5-8.

44. Peterson L, Minas T, Brittberg M, Nilsson A, Sjögren-Jansson E, Lindahl A. Two- to 9-year outcome after autologous chondrocyte transplantation of the knee. Clin Orthop Relat Res. 2000;(374):212-34.

45. Ferkel RD, Cheng JC. Ankle and subtalar arthroscopy. In: Kelkikian AS, editor. Operative treatment of the foot and ankle. NewYork: Appleton & Lange; 1999.

46. Ferkel RD, Zanotti RM, Komenda GA, Sgaglione NA, Cheng MS, Applegate GR, Dopirak RM. Arthroscopic treatment of chronic osteochondral lesions of the talus: long-term results. Am J Sports Med. 2008;36(9):1750-62.

47. Finsen V, Saetermo R, Kibsgaard L, Farran K, Engebretsen L, Bolz KD, Benum P. Early postoperative weight-bearing and muscle activity in patients who have a fracture of the ankle. J Bone Joint Surg Am. 1989;71(1):23-7.

48. 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):614-9.

49. Kennedy JG, Murawski CD. The treatment of osteochondral lesions of the talus with autologous osteochondral transplantation and bone marrow aspirate concentrate: surgical technique. Cartilage. 2011;2:327-36.

50. Imhoff AB, Paul J, Ottinger B, Wörtler K, Lämmle L, Spang J, Hinterwimmer S. Osteochondral transplantation of the talus: long-term clinical and magnetic resonance imaging evaluation. Am J Sports Med. 2011;39(7):1487-93.

51. Garras DN, Santangelo JA, Wang DW, Easley ME. A quantitative comparison of surgical approaches for posterolateral osteochondral lesions of the talus. Foot Ankle Int. 2008;29(4):415-20.

52. Latt LD, Glisson RR, Montijo HE, Usuelli FG, Easley ME. Effect of graft height mismatch on contact pressures with osteochondral grafting of the talus. Am J Sports Med. 2011;39(12):2662-9.

53. Fansa AM, Murawski CD, Imhauser CW, Nguyen JT, Kennedy JG. Autologous osteochondral transplantation of the talus partially restores contact mechanics of the ankle joint. Am J Sports Med. 2011;39(11):2457-65.

54. Hangody L, Vásárhelyi G, Hangody LR, Sükösd Z, Tibay G, Bartha L, Bodó G. Autologous osteochondral grafting—technique and long-term results. Injury. 2008;39(Suppl 1):S32-9.

55. Paul J, Sagstetter M, Lämmle L, Spang J, El-Azab H, Imhoff AB, Hinterwimmer S. Sports activity after osteochondral transplantation of the talus. Am J Sports Med. 2012;40(4):870-4.

56. Lamb J, Murawski CD, Deyer TW, Kennedy JG. Chevron-type medial malleolar osteotomy: a functional, radiographic and quantitative T2-mapping MRI analysis [Epub ahead of print]. Knee Surg Sports Traumatol Arthrosc. 2012.

57. Paul J, Sagstetter A, Kriner M, Imhoff AB, Spang J, Hinterwimmer S. Donor-site morbidity after osteochondral autologous transplantation for lesions of the talus. J Bone Joint Surg Am. 2009;91(7):1683-8.

58. McConnell S, Kolopack P, Davis AM. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC): a review of its utility and measurement properties. Arthritis Rheum. 2001;45(5):453-61.

59. Lysholm J, Gillquist J. Evaluation of knee ligament surgery results with special emphasis on use of a scoring scale. Am J Sports Med. 1982;10(3):150-4.

60. Reddy S, Pedowitz DI, Parekh SG, Sennett BJ, Okereke E. The morbidity associated with osteochondral harvest from asymptomatic knees for the treatment of osteochondral lesions of the talus. Am J Sports Med. 2007;35(1):80-5.

61. Bedi A, Feeley BT, Williams RJ 3rd. Management of articular cartilage defects of the knee [Review]. J Bone Joint Surg Am. 2010;92(4):994-1009.

62. Enneking WF, Campanacci DA. Retrieved human allografts: a clinicopathological study. J Bone Joint Surg Am. 2001;83-A(7):971-86.

63. 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):648-54.

64. 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):1634-40.

65. Raikin SM. Fresh osteochondral allografts for large-volume cystic osteochondral defects of the talus. J Bone Joint Surg Am. 2009;91(12):2818-26.

66. Williams SK, Amiel D, Ball ST, Allen RT, Wong VW, Chen AC, Sah RL, Bugbee WD. Prolonged storage effects on the articular cartilage of fresh human osteochondral allografts. J Bone Joint Surg Am. 2003;85-A(11):2111-20.

67. Brittberg M, Lindahl A, Nilsson A, Ohlsson C, Isaksson O, Peterson L. Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. N Engl J Med. 1994;331(14):889-95.

68. Jones CW, Willers C, Keogh A, Smolinski D, Fick D, Yates PJ, Kirk TB, Zheng MH. Matrix-induced autologous chondrocyte implantation in sheep: objective assessments including confocal arthroscopy. J Orthop Res. 2008; 26(3):292-303.

69. Haleem AM, Chu CR. Advances in tissue engineering techniques for articular cartilage repair. Oper Tech Orthop. 2010;20(2):76-89.

70. Niemeyer P, Salzmann G, Schmal H, Mayr H, Südkamp 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. 2012;20(9):1696-703.

71. Jakobsen RB, Engebretsen L, Slauterbeck JR. An analysis of the quality of cartilage repair studies. J Bone Joint Surg Am. 2005;87(10):2232-9.

72. Giannini S, Buda R, Grigolo B, Vannini F. Autologous chondrocyte transplantation in osteochondral lesions of the ankle joint. Foot Ankle Int. 2001;22(6): 513-7.

73. Marlovits S, Singer P, Zeller P, Mandl I, Haller J, Trattnig S. Magnetic resonance observation of cartilage repair tissue (MOCART) for the evaluation of autologous chondrocyte transplantation: determination of interobserver variability and correlation to clinical outcome after 2 years. Eur J Radiol. 2006;57(1):16-23.

74. Battaglia M, Vannini F, Buda R, Cavallo M, Ruffilli A, Monti C, Galletti S, Giannini S. Arthroscopic autologous chondrocyte implantation in osteochondral lesions of

the talus: mid-term T2-mapping MRI evaluation. Knee Surg Sports Traumatol Arthrosc. 2011;19(8):1376-84.

75. Giannini S, Buda R, Vannini F, Di Caprio F, Grigolo B. Arthroscopic autologous chondrocyte implantation in osteochondral lesions of the talus: surgical technique and results. Am J Sports Med. 2008;36(5):873-80.

76. 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. Epub 2012 Apr 17.

77. Quirbach S, Trattnig S, Marlovits S, Zimmermann V, Domayer S, Dorotka R, Mamisch TC, Bohndorf K, Welsch GH. Initial results of in vivo high-resolution morphological and biochemical cartilage imaging of patients after matrix-associated autologous chondrocyte transplantation (MACT) of the ankle. Skeletal Radiol. 2009;38(8):751-60.

78. Murawski CD, Duke GL, Deyer TW, Kennedy JG. Bone marrow aspirate concentrate (BMAC) as a biological adjunct to osteochondral lesions of the talus. Tech Foot Ankle Surg. 2011;10(1):18-27.

79. Muschler GF, Boehm C, Easley K. Aspiration to obtain osteoblast progenitor cells from human bone marrow: the influence of aspiration volume. J Bone Joint Surg Am. 1997;79(11):1699-709.

80. Payne KA, Didiano DM, Chu CR. Donor sex and age influence the chondrogenic potential of human femoral bone marrow stem cells. Osteoarthritis Cartilage. 2010;18(5):705-13.

81. Fortier LA, Potter HG, Rickey EJ, Schnabel LV, Foo LF, Chong LR, Stokol T, Cheetham J, Nixon AJ. Concentrated bone marrow aspirate improves full-thickness cartilage repair compared with microfracture in the equine model. J Bone Joint Surg Am. 2010;92(10):1927-37.

82. 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):3307-20.

83. Doral MN, Bilge O, Batmaz G, Donmez G, Turhan E, Demirel M, Atay OA, Uzumcugil A, Atesok K, Kaya D. Treatment of osteochondral lesions of the talus with microfracture technique and postoperative hyaluronan injection. Knee Surg Sports Traumatol Arthrosc. 2012;20(7):1398-403.

84. Kawasaki K, Ochi M, Uchio Y, Adachi N, Matsusaki M. Hyaluronic acid enhances proliferation and chondroitin sulfate synthesis in cultured chondrocytes embedded in collagen gels. J Cell Physiol. 1999;179(2):142-8.

85. Wright JG, Einhorn TA, Heckman JD. Grades of recommendation. J Bone Joint Surg Am. 2005 Sep;87(9):1909-10.