The Basic Science and Clinical Applications of Osteochondral Allografts

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Abstract

Indications for the use of osteochondral allografts for orthopaedic surgical applications are increasing with improved surgical techniques and advancing experience. Modern tissue banks have developed harvesting, processing, and storage methods that ensure an adequate, safe supply of grafts. Continued research is necessary to find a technique that maximizes chondrocyte viability and metabolism both during storage and implantation. The majority of published data on the use of osteochondral allografts has focused on the management of osteochondral defects about the knee. Successful outcomes following these procedures have led to increased interest in their application to pathology affecting other joints including the shoulder and ankle. The current paper aims to review the basic science and clinical applications of osteochondral allografts.

The use of allogeneic musculoskeletal tissue in orthopedic surgery has doubled in the last decade due to increased availability, improved screening and procurement protocols, and advancing surgical techniques. While concerns over the potential for disease transmission, cost, and issues with graft incorporation exist, the advantages of allograft use include a lack of donor site morbidity, decreased surgical time, and the ability to custom fit the graft based on the pathology being treated.

Fresh osteochondral allografts are composite tissues composed of a viable articular cartilage layer attached to non living subchondral bone, which may be used as structural and functional replacements for articular defects.[1,2] Clinical studies evaluating the outcomes of osteochondral allograft implantation in the management of osteochondral defects within the knee have reported greater than 60% to 80% survival with good to excellent results at 10 years follow-up.[3-9] Recent experience has demonstrated that the success of fresh osteochondral allografts depends on the percentage of viable chondrocytes that remain following implantation.[10,11] This requires an appropriate allograft storage method, transplantation within days of the harvest, and careful attention to implantation technique.

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Osteochondral Allograft Harvest

Procurement protocols for osteochondral allografts are based on guidelines created by the American Association of Tissue Banks under the authority of the Food and Drug Administration. Potential donors between the ages of 15 and 40 years are screened based on medical and social history and available serology testing. Grafts are harvested within 12 hours of the donor's death using standard aseptic technique or in a clean room environment.[10] The joints are removed en bloc, and the tissue is thoroughly pulse lavaged to remove the marrow contents, which serve as the main source of both disease transmission and host immune reaction. Once harvested and cleaned the allograft is transferred to an antibiotic solution for 24 hours at 37° C followed by storage.

Osteochondral Allograft Storage

The primary goal of osteochondral allograft use in orthopae-

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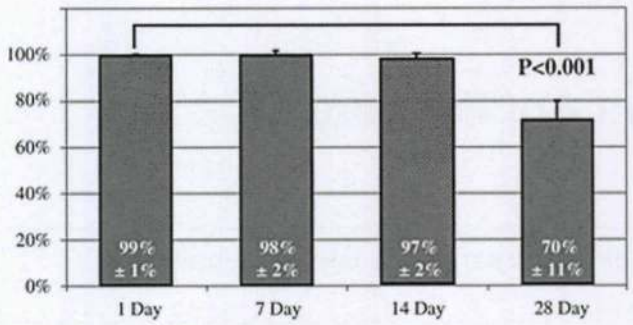

Figure 1 Significant decline in percentage chondrocyte viability after 28 days of storage in physiologic culture medium.[19]

dic surgery is the transplantation of an architecturally sound composite of subchondral bone and articular cartilage with viable chondrocytes capable of maintaining metabolic activity following implantation.[2] Based on storage technique there are three types of osteochondral allografts currently utilized in the management of articular pathology: fresh-frozen, cryopreserved, and fresh. While fresh-frozen osteochondral allografts can be stored indefinitely and have decreased immunogenicity compared to other graft types, this storage technique leads to greater than 95% chondrocyte death. This limits their use to situations that require bulk grafts for reconstruction. Cryopreservation entails adding glycerol or dimethyl sulfoxide to the storage medium followed by a controlled freezing to -70° C. Although longer storage times can be used compared to fresh allografts, chondrocyte viability following cryopreservation is variable with cell survival typically limited to the superficial zone.[12-14] Most osteochondral allografts are implanted fresh due to clinical and experimental evidence demonstrating higher chondrocyte viability, improved maintenance of the cartilage matrix, and better long-term outcomes compared to cryopreserved grafts.[15,16]

Subsequent to harvest and 24 hours of treatment in the antibiotic solution, fresh osteochondral allografts are stored in either lactated ringers solution or a physiologic culture medium at 4° C to maintain chondrocyte viability. Recent laboratory studies evaluating fresh osteochondral allografts show an inverse relationship between graft storage time and chondrocyte viability, function, and ultimately the integrity of the extracellular matrix (Fig. 1).[2,17,18] A significant decline in chondrocyte viability and metabolism was noted after 28 days of storage, with physiologic medium outperforming lactated ringers solution.[19] Based on the findings of these studies most tissue banks have converted to the use of serum-free nutritive culture medium for graft storage. The current recommendations include implantation of fresh osteochondral allografts within 21 days to 28 days of procurement.

Host-Donor Matching

Fresh osteochondral allografts used in the management of articular lesions are not human leukocyte antigen or blood-type matched between the donor and recipient, and patients are not treated with immunosuppressants following implantation.[2] While unmatched osteochondral allografts have been shown to elicit a variable immune reaction in recipients secondary to immunogenic cells in the marrow elements and antigenic proteins present in the subchondral bone, these reactions have not been shown to negatively impact outcomes. The tolerance seen following osteochondral allograft implantation is partly due to the fact that the avascular, aneural, and alymphatic hyaline cartilage is relatively immunoprivileged.[2,10] The dense extracellular matrix in which the chondrocytes are embedded serves as a barrier to host immune surveillance limiting antigen sensitization.

Risk of Disease Transmission

The potential for transmission of a communicable disease is often cited as a disadvantage of the use of fresh allograft tissue. By law, tissue banks are required to carefully screen prospective donors with a detailed medical history, social history, serologic testing, and bacteriologic testing. Based on an observational study, which included 11,391 donors to United States tissue banks between 2000 and 2002, the estimated risk of viremia at the time of donation was 1 in 34,000 for hepatitis B, 1 in 42,000 for hepatitis C, 1 in 55,000 for HIV, and 1 in 128,000 for HTLV.[20] Despite this relatively high prevalence of donor viremia, subsequent to appropriate donor screening and serologic testing, the estimated risk of disease transmission with musculoskeletal allograft tissue remains low. The risk of HIV transmission in screened and tested donors is estimated to be 1 in 1.6 million, with only 1 report of disease transmission from an allogeneic graft, which occurred prior to the screening standards instituted in 1985.[21,22]

Sterilization techniques that would eliminate potential pathogens are unsuitable for human tissue intended for transplant. The dose of irradiation that would be required to eradicate viral DNA is 30 kGy, which would kill all of the chondrocytes and weaken the collagen structure and overall mechanical properties of the allograft.[10,23] Sterilization of the graft with chemical agents has been associated with the development of chronic synovitis and early in-vivo graft failure.[23] As testing methods for HIV, hepatitis, and other potentially transmitted diseases improve the risks associated with fresh osteochondral allograft implantation will decrease. A small but measurable risk remains associated with allograft transplantation.[2]

Osteochondral Allograft Implantation—Surgical Technique

The surgical technique used to implant osteochondral allografts depends on the location, size, and character of the lesion being treated. Once adequate exposure to the symptomatic lesion is obtained, attention is turned to removing the pathologic tissue. This portion can be performed with hand or power instruments, with the goal of obtaining a healthy bed of subchondral bone typically 7 mm to 8 mm deep (Figs.

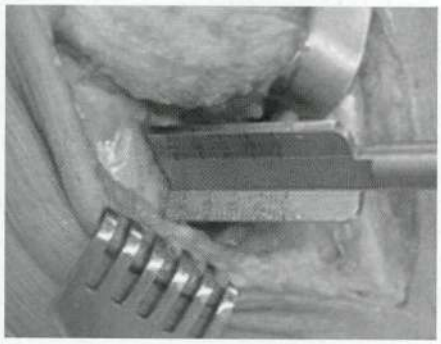

Figure 2 Power reamer allows for removal of pathologic tissue from the medial femoral condyle and preparation of a circular bed of healthy, bleeding subchondral bone.

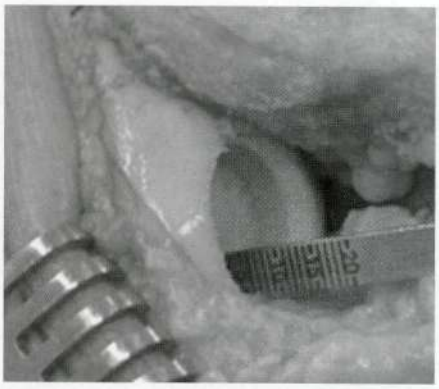

Figure 3 Prepared host medial femoral condyle with circular host site 7 mm to 8 mm in depth.

2 and 3). A circular bed is created for dowel grafting and free-hand shaping is used for shell grafting techniques. Next, dimensions of the prepared bed are measured allowing for fashioning of an appropriately sized graft, while taking into account the shape and radius of curvature of the implantation site (Fig. 4). Osteoarticular allograft transplantation can be performed with commercially available systems such as the allograft Osteoarticular Transplantation System (Arthrex, Naples, FL). Subsequent to trialing, implantation of the graft can be performed using either a press-fit technique or press-fit with screw fixation for augmentation (Fig. 5).

The technique used to impact osteoarticular allografts has been shown to affect cell viability. Recent studies have demonstrated that high impaction loads lead to chondrocyte death, and this emphasizes the importance of avoiding excessive impaction during graft implantation.[24,25] Based on these studies, most investigators recommend a careful sizing of both the recipient site and the donor plug to ensure a relatively atraumatic implantation. The implantation site should be appropriately dilated and the graft press fit with finger pressure when possible.

Experience with Osteochondral Allografts in the Management of Knee Pathology

For more than 20 years, successful outcomes have been reported following the use of osteochondral allografts in

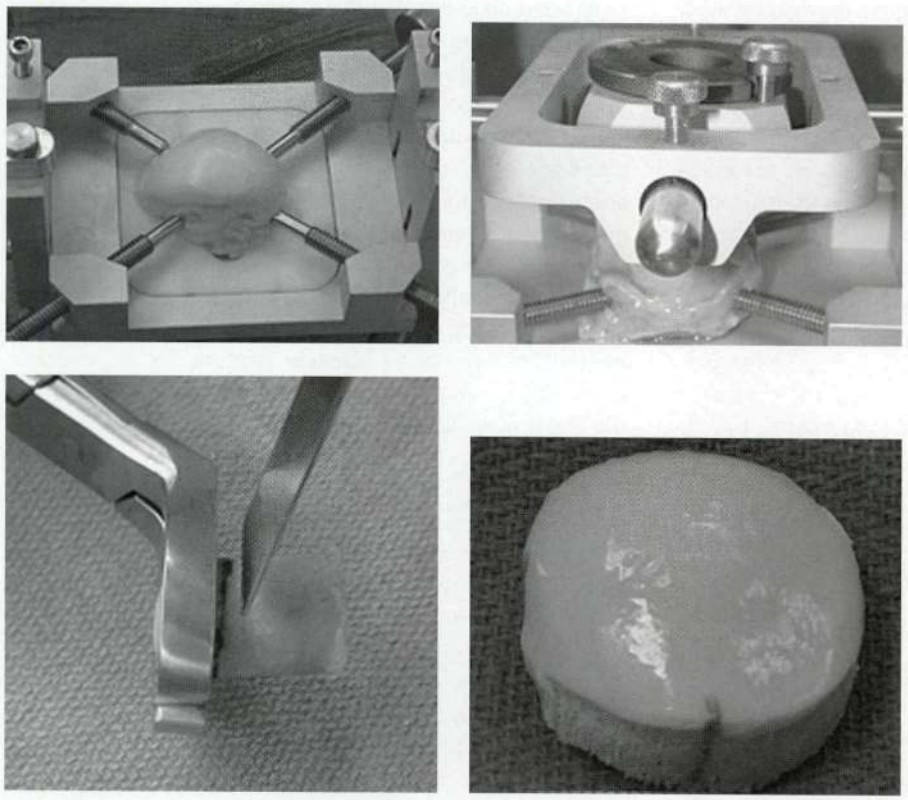

Figure 4 Preparation of fresh osteochondral allograft for implantation.

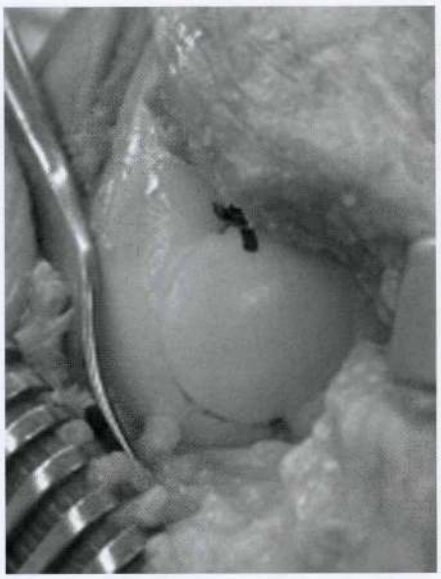

Figure 5 Osteochondral allograft implanted into medial femoral condyle.

the management of osteochondral defects about the knee.[2] Recent follow-up studies have demonstrated 60% to 86% graft survival with good to excellent results at 10 years follow-up (Table 1). In a review of the use of osteochondral allografts in the treatment of post-traumatic defects of the knee, Ghazavi and coworkers[26] reported clinical success in 86% of their 126 cases at a mean follow-up of 7.5 years. Survivorship analysis demonstrated 95% graft survival at 5 years, 71% at 10 years, and 66% at 20 years. Davidson and colleagues[3] similarly reviewed their experience with osteochondral allografts in the management of 67 patients with femoral condylar defects. Davidson and colleagues reported significant improvements in mean International Knee Documentation Committee (IKDC) scores, 27 preoperatively to 79 postoperatively, Lysholm scores, 37 to 78, and SF-36 physical scores, 38 to 51. Ten patients in this cohort underwent second-look arthroscopy with biopsy at a mean of 40 months following the index procedure. At second-look, the mean International Cartilage Repair Society score was 10 (nearly normal), and the mean Outerbridge score of the repaired defect improved from 4.3 preoperatively to 0.6. Biopsy specimens demonstrated no significant difference in chondrocyte viability and density between the grafted tissue and the surrounding normal articular cartilage.

Similar success was reported by Emmerson and associates[4] in their case series of 65 knees in 63 patients with a mean age of 28.6 years treated for osteochondritis dissecans lesions of the femoral condyle. At a mean follow-up of 7.7 years, 47 knees (72%) were rated as good to excellent on the modified D'Aubigne and Postel scale. Subjective knee function in this cohort improved from 3.4 preoperatively to 8.4 on a 10-point scale at the time of final evaluation. Recently, LaPrade and colleagues[8] reviewed their experience in 23 consecutive cases of femoral osteochondral defects managed with refrigerated osteochondral allografts implanted after a mean of 20.3 days of storage. At a mean of 3 years of follow-up, significant improvement in both Cincinnati knee scores was reported, 49.2 preoperatively to 69.0 postoperatively and IKDC scores 52 to 68.5. Postoperative radiographs demonstrated evidence of stable host incorporation of the implanted allograft in 22 of the 23 cases. In a prospective evaluation of osteochondral allograft implantation for full thickness lesions of the femoral condyle, McCulloch and researchers[9] reported significant improvements in mean Lysholm scores, 39 preoperatively to 67 postoperatively, IKDC scores 29 to 58, and SF-12 physical component scores 36 to 40, at a mean of 35 months of follow-up. The study patients reported 84% satisfaction with their clinical outcome believing that their operative knee functioned at 79% of their unaffected contralateral side.

In addition to its use in the management of osteochondral lesions affecting the femoral condyle, osteochondral allografts have also been used for symptomatic defects of the patellofemoral joint. Jamali and colleagues[7] retrospectively reviewed the outcomes of 20 knees in 18 patients with a mean age of 42 years who had undergone a mean of 2.6 prior surgical procedures for patellofemoral lesions. At a mean of 7.5 years of follow-up, the investigators reported good to excellent results in 60% of the study patients with survivorship analysis demonstrating 67% graft survival at 10 years. Despite the relatively lower rate of clinical success,

Table 1 Recent Studies Demonstrating Good to Excellent Outcomes at Up to 10 Years of Follow-Up

Study	Follow-Up (Years)	Outcome
LaPrade 2009	3	IKDC: 52 – 68.5
Emmerson 2007	7.7	72% G/E Results
Davidson 2007	3.5	IKDC: 27 – 79
McCulloch 2007	3	IKDC: 29 – 58; Satisfaction 84%
Gross 2005	10	Survival 85% at 10 Years
Jamali 2005	7.5	Patellofemoral Joint: Merle D'Aubigne-Postel: 11.7 – 16.3
Ghazavi 1997	7.5	85% Success

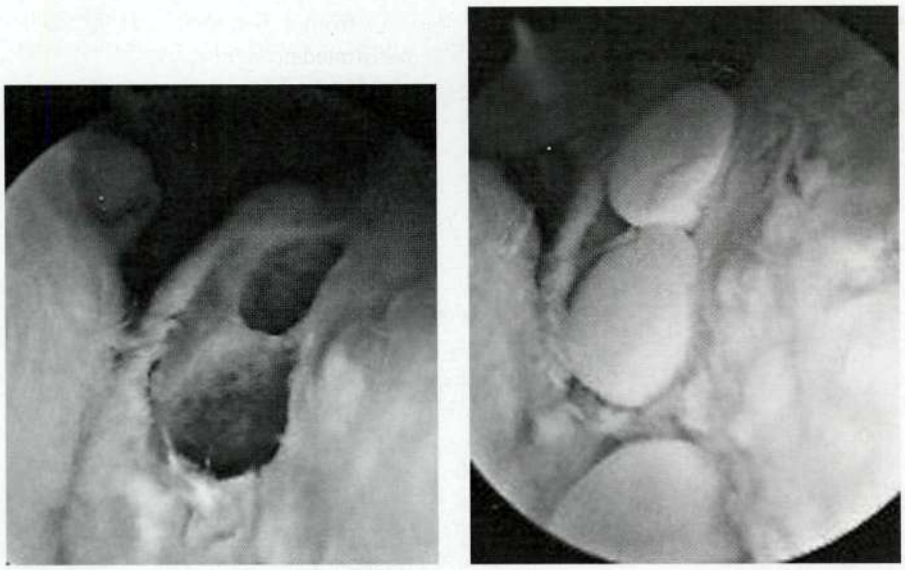

Figure 6 Three osteochondral allograft plugs implanted arthroscopically for the treatment of recurrent instability secondary to an engaging Hill-Sachs lesion in a 16-year-old male patient following Bankart repair.[29] (Reprinted from Chapovsky F, Kelly JD. Osteochondral allograft transplantation for treatment of glenohumeral instability. Arthroscopy. 2005;21:1007, with permission from Elsevier.)

14 of 16 patients interviewed (87.5%) reported pain relief following the procedure, and 87.5% said they would have the operation again if necessary.

The Use of Osteochondral Allografts for Shoulder Pathology

Based on the clinical successes noted following the use of osteochondral allografts in the management of femoral condylar lesions and those of the patellofemoral joint, surgeons have attempted to include their use in the treatment of defects in the glenohumeral joint. Recent reports in the orthopaedic literature have shown promising results of osteochondral allograft implantation for cases of glenohumeral instability including engaging Hill-Sachs lesions and glenoid bone defects.[27-33]

Treatment of Hill-Sachs Lesions

In a recent biomechanical study, Sekiya and associates[27] evaluated the effect varying sizes of Hill-Sachs lesions had on the stability of the shoulder, and the impact treating these lesions with osteochondral allograft implantation had on restoring a stable glenohumeral joint. The investigators found that Hill-Sachs lesions as small as 12.5% of the humeral head had biomechanical consequences influencing shoulder stability. Additionally, the investigators found a significant benefit to osteochondral allograft implantation for defects 37.5% in size or greater, allowing for a restoration of stability in 60° of external rotation, the dislocation point for each of their specimens. Yagashita and Thomas [28] recently reported a case of chronic anterior shoulder dislocation secondary to a large Hill-Sachs lesion, which was successfully treated with a femoral head allograft. At 2 years of follow-up the patient was symptom free with no episodes of recurrent instability. In a similar case report, Chapovsky and Kelly[29] described the use of three osteochondral allograft plugs implanted arthroscopically for the treatment of recurrent instability secondary to an engaging Hill-Sachs lesion in a 16-year-old male patient following Bankart repair (Fig. 6). At one year postoperatively the patient was symptom free and had returned to athletic activity without recurrence.

Gerber and Lambert[30] reported their experience using osteochondral allografts in the treatment of reverse Hill-Sachs lesions for four patients who presented with chronic locked posterior shoulder dislocations. In each treated patient, the humeral head defect was at least 40% of the articular surface. At a mean of 68 months following management with femoral head allografts fashioned to fill the lesions good to excellent results were reported in 3 of the 4 cases. One patient did develop avascular necrosis in the remainder of the humeral head postoperatively, which was considered to be a fair result.

Treatment of Glenoid Bone Defects

As an alternative to the Bristow and Latarjet procedures, osteochondral allografts have been used effectively in the management of glenoid bone loss.[31-33] In a series of nine, epileptic patients who presented with recurrent anterior shoulder instability secondary to major defects of the anterior glenoid rim, Hutchinson and coworkers[31] reported successful outcomes following the use of a bone buttress operating with femoral head osteochondral allografts. Despite a mean loss of 16° of external rotation at their side and 26° in 90° of abduction, no recurrences were reported and all patients were satisfied with their postoperative outcome. Similar success was reported by Weng and colleagues[32] in their series of nine consecutive patients with glenoid bone loss-associated anterior instability. A combination of femoral head osteochondral allograft and an anteroinferior capsular shift resulted in an improvement in mean Rowe scores from 24 preoperatively to 84 postoperatively. At a mean of 4.5 years of follow-up, all of the grafts had radiographic evidence of bony union with the native glenoid. One patient had a repeat dislocation,

and one had a subluxation, both of which occurred following a seizure. Each was managed successfully with closed reduction. In a recent technical note, Provencher and associates[33] reported the use of distal tibial allograft as a means for glenoid reconstruction with successful outcomes in three patients who presented with a mean of 30% glenoid bone loss. Dense weightbearing corticocancellous bone with a thick cartilage surface combined with a curvature that nearly matches the normal glenoid contour as advantages of this technique has been cited.

Osteochondral Allografts for Lesions of the Talus

To avoid the donor-site morbidity associated with autograft harvest, osteochondral lesions of the talus have also been managed with osteochondral allograft techniques. Two small case series exist within the orthopaedic surgery literature describing outcomes following osteochondral allograft implantation into the talus. Gross and colleagues[34] retrospectively reported their experience in nine patients with lesions of the talus exceeding 1 cm in diameter and 5 mm in depth. At a mean follow-up of 11 years, 6 of the 9 grafts remained intact. Three patients in this series required ankle arthrodesis secondary to fragmentation and resorption of the implanted osteochondral allograft. Raikin[35] described a series of six patients with large osteochondral lesions of the talus, five involving the medial talar dome and one involving the lateral talar dome. Following osteochondral allograft implantation, mean AOFAS ankle scores improved from 42 to 86. One patient required ankle arthrodesis for persistent pain, but overall patient satisfaction following the procedure was high. All of the patients reported that they would have the procedure performed on the contralateral ankle if necessary.

Discussion

Indications for the use of osteochondral allografts for orthopaedic surgical applications are increasing with improved surgical techniques and advancing experience. Modern tissue banks have developed harvesting, processing, and storage methods that ensure an adequate, safe supply of grafts. Continued research is necessary to find a technique that maximizes chondrocyte viability and metabolism both during storage and implantation. Recent clinical evidence with medium term follow-up supports the use of fresh osteochondral allografts for articular reconstruction. Techniques are being adapted for use in both the glenohumeral joint and the tibiotalar joint based on the successes reported following the use of osteochondral allografts in the management of femoral condylar lesions. While the current evidence is limited to case reports and small case series, early results of these expanding indications appear promising.

Disclosure Statement

None of the authors have a financial or proprietary interest in the subject matter or materials discussed, including, but not limited to, employment, consultancies, stock ownership, honoraria, and paid expert testimony.

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