Allografts in Articular Cartilage Repair

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The use of osteochondral transplants in biologic reconstruction of the knee joint has an extensive clinical history, dating back to Erich Lexer's pioneering work in the early twentieth century[1]. Transplantation of small-fragment fresh allografts evolved into a routine procedure of choice at certain institutions in North America in the 1970s[2-4] and has since undergone a renaissance as a result of renewed clinical interest and scientific investigation. Subsequently, refinements in transplantation protocols, increased availability of fresh donor tissue, as well as physician and patient demand have driven an emerging trend toward biologic resurfacing as an alternative to prosthetic joint replacement and restoration in a select patient population. Although there are several reparative and restorative options for cartilage replacement[5-9], osteochondral allografting remains the only biomimetic technique (emulating normal biology) that restores architecturally appropriate, mature hyaline cartilage in acquired articular cartilage defects.

Currently, fresh osteochondral allografts are utilized to treat a broad spectrum of articular and osteoarticular lesions[10-12], ranging from focal chondral defects[13] to established osteoarthrosis[14]. Allografts also have been successfully utilized in the treatment of disease in the ankle joint[15,16] and, to a lesser extent, in the hip joint[17] and the shoulder[18,19].

Background

The fundamental paradigm of fresh osteochondral allografting is the transplantation of mature orthotopic hyaline cartilage, with viable chondrocytes that survive hypothermic storage[20-22], while maintaining the metabolic activity of the chondrocytes and sustaining the surrounding collagen matrix[2,23-27]. Hyaline cartilage possesses characteristics that make it ideal for transplantation. First, as an avascular tissue, it does not require a blood supply; instead, its metabolic needs are met through diffusion from synovial fluid. Second, it is an aneural structure that does not require innervation to function. Third, articular cartilage is immunoprivileged because the chondrocytes are embedded in the acellular matrix; thus, it is relatively protected from host immune surveillance[28].

The second component of the osteochondral allograft is the osseous portion. Conceptually, this functions as the underlying support structure for the articular cartilage and is the means of attachment and fixation of the graft to the host. The osseous portion of the graft differs from the hyaline portion in that it was originally vascularized tissue and its cells are not thought to survive transplantation[29]. Rather, the osseous structure, like other types of bone graft[30], functions as a scaffold for healing to the host by creeping substitution and can elicit an immune response[31]. Generally, the osseous portion of the graft is limited to a few millimeters; however, depending on the clinical situation, the allograft may contain a more copious amount of bone, as required to restore injured or absent subchondral tissue. According to the aforementioned concepts, it is helpful to consider a fresh osteochondral allograft as a composite graft consisting of a living mature hyaline cartilage portion anchored to a nonliving subchondral bone portion, forming an intact structural and func-

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tional unit to replace a diseased or absent corresponding component in the recipient joint.

Graft Acquisition and Storage

Use of fresh osteochondral allografts is a unique treatment option with inherent issues mostly related to tissue acquisition, storage, and related logistics as well as safety concerns and immunologic ramifications. Understanding the processes of tissue recovery, testing, and storage of the allograft is critically important. Historically, the obstacles presented by these fundamental elements led to the development of fresh-allograft programs only at specialized centers that both had a close association with an experienced and dedicated tissue bank and had invested substantial resources into initiating and incorporating specific protocols for safe and effective transplantation of fresh osteochondral tissue[2,3,32].

Small-fragment osteochondral allografts are utilized while they are fresh to maximize chondrocyte viability; this makes the availability of suitable graft tissue the essential, and often limiting, factor in the transplantation algorithm. The age criterion for donors of fresh grafts is generally between fifteen and forty years. Also, the joint surface must pass a visual inspection for cartilage quality. Strict adherence to tissue-banking standards and quality control of protocols are important, and these criteria increase the likelihood, but do not guarantee, that the tissue will be acceptable for transplantation[33].

Common to all fresh-allograft procedures is the need to match the donor with the recipient. This is done on the basis of size. To size allografts for the knee, an anteroposterior radiograph of the knee is made with a magnification marker and the medial-lateral dimension of the tibia is measured just distal to the joint surface (Fig. 1). This measurement, corrected for magnification, is utilized, and the tissue bank makes a direct measurement of the donor tibial plateau. Alternatively, the affected condyle can be measured[34]. A match is considered acceptable if it is ±2 mm; however, it should be noted that there is substantial variability in anatomy, which is not reflected by size measurements. In particular, in patients with osteochondritis dissecans, the pathologically affected condyle typically is larger, wider, and flatter; therefore, a larger donor condyle generally should be used. It is imperative that the surgeon thoroughly inspect the tissue to be transplanted, optimally before beginning the actual procedure.

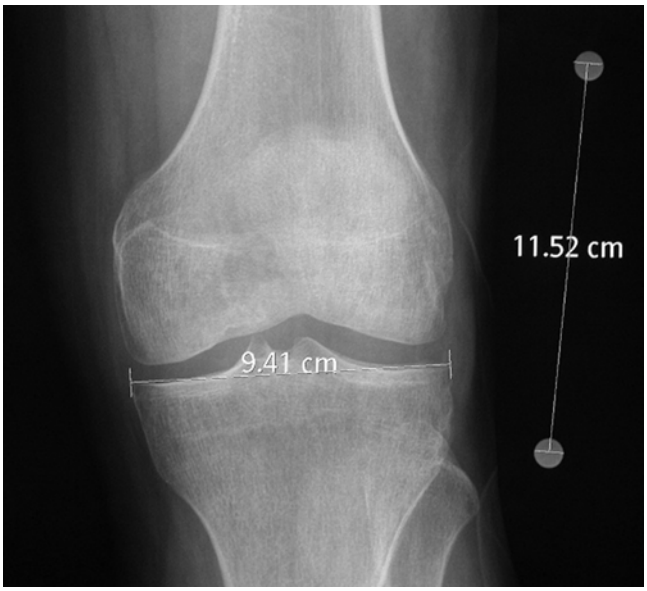

Fig. 1

Anteroposterior radiograph of a left knee, displaying a tibial measurement and a radiographic magnification marker for allograft sizing.

The use of fresh-frozen grafts improves graft availability, reduces immunogenicity, and may be appropriate for bulk allografting in major osseous reconstructions. However, freezing chondrocytes within their extracellular matrix effectively eliminates >95% of viable chondrocytes in the articular cartilage portion of osteochondral grafts[35,36]. Furthermore, clinical experience has indicated that the articular matrix in frozen allografts deteriorates over time, presumably because there are insufficient surviving cells within the matrix to maintain tissue homeostasis[37].

Cryopreservation involves the freezing of whole tissue grafts in a nutritive medium, and cryopreserved grafts have shown variable degrees of residual, albeit drastically reduced, cell viability in different studies; the reasons for this variability are still the subject of debate and ongoing research[38-40].

Conversely, it has been demonstrated, primarily in retrieval studies, that fresh cold-stored osteochondral allografts contain viable chondrocytes and that mechanical properties of the matrix are maintained many years after transplantation[13,15,41]. These experiences have generally supported the use of fresh rather than frozen tissue for small osteochondral allografts employed to reconstruct chondral and osteochondral defects. More recent studies have demonstrated that chondrocyte viability and the structural integrity of the matrix are preserved during hypothermal storage in nutritive culture medium containing amino acids, glucose, and inorganic salts[21,42]. Those studies showed that cell density, viability, and metabolic activity remained essentially unchanged for as many as fourteen days after baseline, before deteriorating significantly ($p < 0.001$[21] and $p < 0.05$[42]) after twenty-eight days while the hyaline matrix remained relatively intact. The clinical consequences of these storage-induced graft changes have yet to be determined.

Safety and Risk of Disease Transmission

The above studies suggested that it is reasonable to store fresh allografts for more than two weeks after graft harvest,

TABLE I Allograft Indications in 365 Knees Treated from 1985 to 2005 at the University of California, San Diego

Indication	Percent of Knees
Complex salvage: trauma, degenerative joint disease	29%
Osteochondritis dissecans	27%
Isolated femoral condylar lesion: degenerative or traumatic	22%
Patellofemoral conditions	14%
Osteonecrosis	8%

which is in contrast to the empirical practice of transplanting tissue within seven days after recovery. The results of the more recent studies have coincided with a trend by tissue banks to hold tissue for fourteen days, to await results of microbiologic testing, prior to releasing it for transplantation. Recovery, processing, and testing of donor tissue are performed according to guidelines established by the American Association of Tissue Banks[33], which include the recording of a detailed donor history as well as serologic and bacteriologic testing[43]. As with transplantation of any allogeneic organ or tissue, there is a risk of transmission of infectious disease despite donor screening and testing[44]. Although advances in serologic testing for human immunovirus, hepatitis, and other pathogens have improved safety, a minute but measurable risk of transmission of serious disease remains. Both the surgeon and the patient should be aware of this risk of bacterial or viral disease transmission, and it must be discussed as part of the informed-consent process. Unfortunately, no published data quantifying this risk are available.

Immunologic Ramifications

The immunologic ramifications of the use of fresh osteochondral allografts are another important consideration, and it should be noted that, in current practice, small-fragment allografts are not HLA (human leukocyte antigen) or blood-type matched between the donor and recipient. While it appears that hyaline cartilage is relatively immunoprivileged[28], it is also evident that fresh unmatched osteochondral allografts elicit a variable immune response[45]. Human allograft retrieval studies have consistently shown that patients generally tolerate the transplant immunologically, with little or no histologic evidence of an immune-mediated pathologic response or frank transplant rejection[26,30]. However, in one study of fresh osteochondral allografts, 50% of individuals generated serum anti-HLA antibodies[46]. The presence of the anti-HLA antibodies correlated with an inferior appearance of the graft-host interface on magnetic resonance imaging studies. While this may suggest that humoral immunity plays a role in the outcome following the use of fresh allografts, the clinical relevance of this phenomenon is unknown[47,48]. The issue of immune behavior may ultimately become clinically relevant, and it is clearly an area where more knowledge is necessary in order to improve outcomes of the use of fresh osteochondral allografts.

Indications

As a result of their osteoarticular nature, fresh allografts are uniquely suited for the treatment of large compound osteochondral lesions. Primary allograft treatment can be considered for large lesions (>2 cm^2) for which the surgeon believes other procedures may be inadequate, for purely chondral defects of a size that presents a relative contraindication to other treatments, and for cases in which bone involvement is greater than 6 to 10 mm deep (Fig. 2-A, Table I). Specific conditions that are most amenable to allografting in clini-

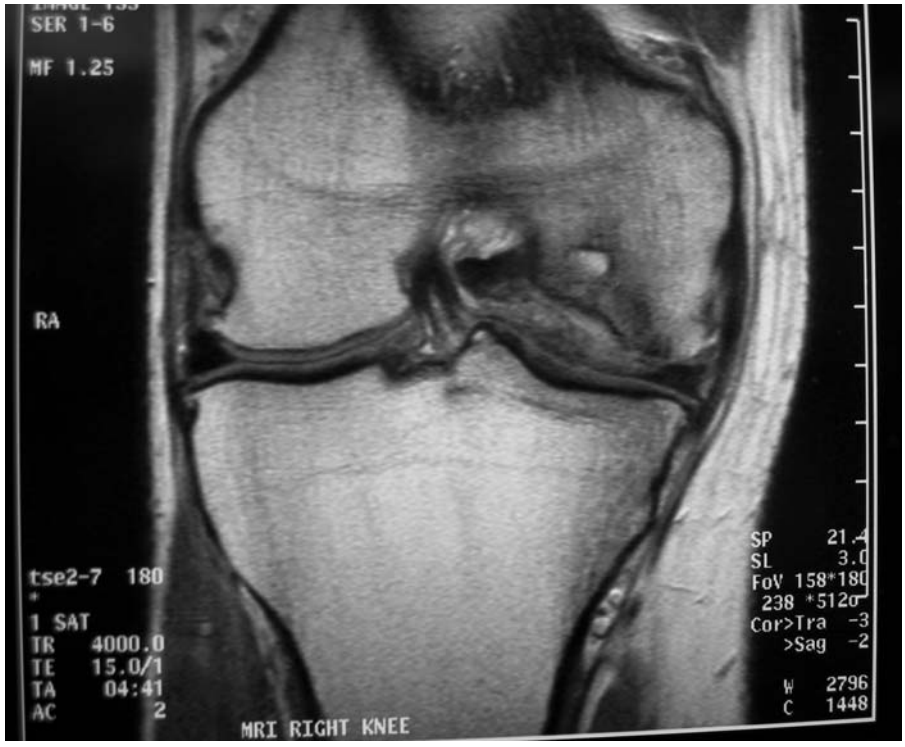

Fig. 2-A

T1-weighted coronal magnetic resonance image documenting an osteochondritis dissecans lesion in the right medial femoral condyle of a thirty-three-year-old woman after prior microfracture and autologous chondrocyte implantation had failed. Note the extent of the subchondral signal abnormality, indicating marked osseous disease.

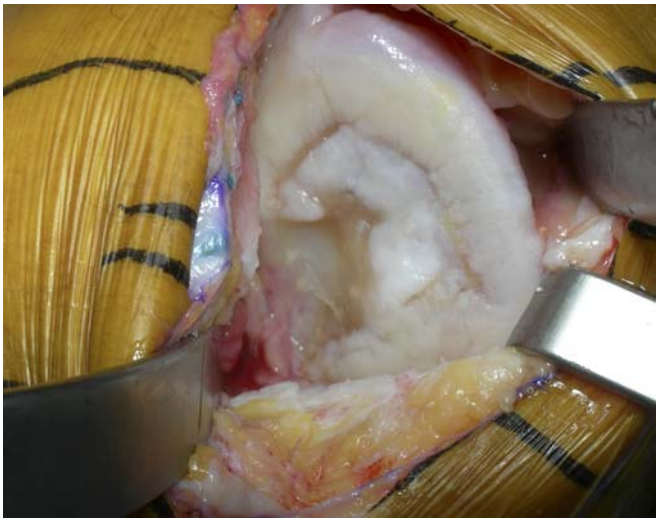

Fig. 2-B

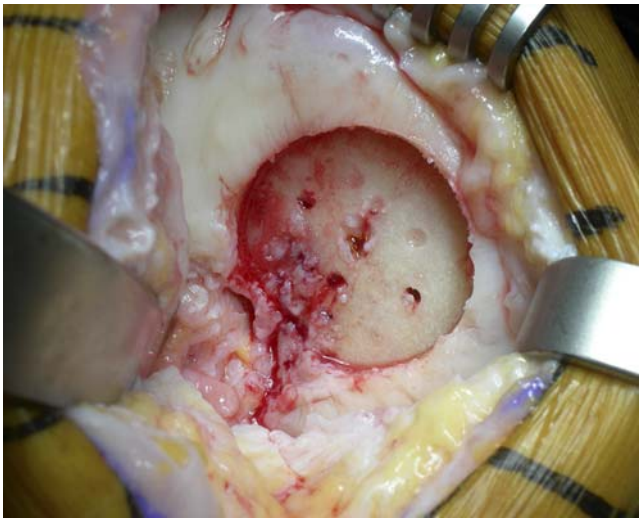

Fig. 2-C

Fig. 2-B Intraoperative appearance of the osteochondritis dissecans lesion of the medial femoral condyle. **Fig. 2-C** Intraoperative photograph after preparation of the graft bed by core reaming of the osteochondral defect and débridement down to bleeding bone.

cal practice include osteochondritis dissecans[49,50], osteonecrosis[49], and posttraumatic defects, such as those occurring after periarticular fractures about the knee[41,51]. Other indications for allografting of the knee include patellofemoral chondrosis or arthrosis[52] and certain cases of unicompartmental or multifocal posttraumatic and degenerative tibiofemoral arthrosis[14,32,53] (Table II). Allografts have also proven valuable for the salvage of knees for which other cartilage resurfacing procedures, such as microfracture, implantation of autologous chondrocytes, and transfer of an osteochondral autologous plug, have failed (Fig. 2-B).

Allografts have also been used successfully in the ankle joint. They are indicated for resurfacing of a tibiotalar joint with posttraumatic arthrosis[15,16], for osteonecrosis of the talus, and for osteochondritis dissecans lesions not amenable to other restorative procedures[54]. The use of fresh allografts for bipolar resurfacing of the tibiotalar joint is unique in the ankle, as bipolar resurfacing with fresh allografts has not been proven to be successful in the knee. This approach also reflects the limited options for younger individuals with end-stage arthrosis of the tibiotalar joint.

In the hip, osteochondral allografts have been utilized in the treatment of osteonecrosis of the femoral head, with mixed results[17]. Current indications include symptomatic lesions with limited involvement of the head that have not responded to other treatments. In the shoulder, allograft reconstruction can be considered for large osteochondral lesions associated with glenohumeral dislocation and instability[18] as well as for osteochondritis dissecans and osteonecrosis of the humeral head[19]. It should be noted that the indications in the hip, shoulder, and conceivably other joints are evolving, although little published data on such applications are currently available.

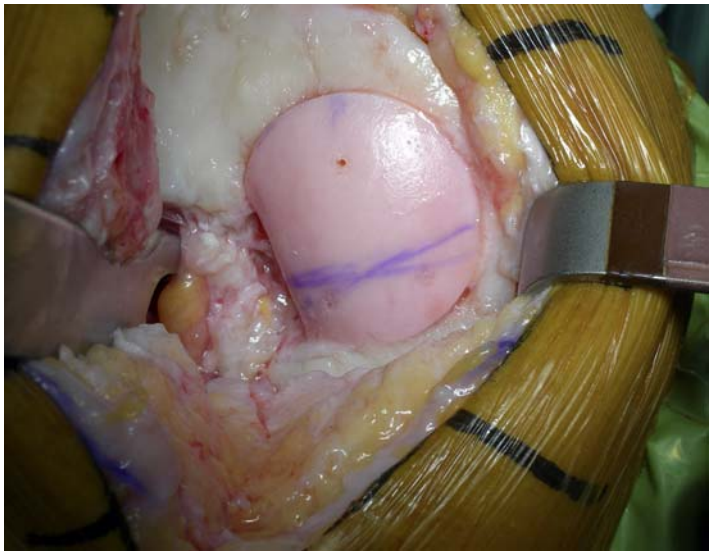

Fig. 2-D

An osteochondral dowel plug in place and secured by several absorbable polydioxanone pins. Note the orthotopic appearance of the graft and its flush fit with the surrounding joint surface.

Contraindications

Allografting in the knee should not be considered an alternative to prosthetic arthroplasty for an individual with symptoms and an acceptable age and activity level for prosthetic replacement. Bipolar and multicompartmental allografting procedures have been

TABLE II Allograft Sites in 365 Knees Treated from 1985 to 2005 at the University of California, San Diego

Site	Percent of Knees
Medial femoral condyle	36%
Lateral femoral condyle	18%
Medial tibial plateau	2%
Lateral tibial plateau	6%
Multifocal	20%
Trochlea	8%
Patella	5%
Bipolar patellofemoral	5%

modestly successful in younger individuals; however, advanced multicompartment arthrosis, even in younger patients, is a relative contraindication to allografting. Other relative contraindications include uncorrected ligamentous instability, meniscal insufficiency, and axial malalignment of the limb. Thus, the biologic and mechanical status of the joint should be assessed preoperatively; all patients should be examined carefully for subtle or obvious instability, and the angular alignment of the limb should be evaluated. Any instability or malalignment should be addressed before allografting is considered or should be treated with a concomitant procedure to optimize the biomechanical environment and achieve a horizontal joint surface. If a realigning osteotomy is to be performed on the same articulating side as the allografting is to be done, staging of the procedure is advised so as not to jeopardize the microvascularity of the recipient bone bed. Inflammatory disease or crystal-induced arthropathy is also considered a relative contraindication to allografting, as is any unexplained synovitis. The use of fresh osteochondral allografts in individuals with altered bone metabolism, such as is seen in association with chronic steroid use, smoking, or even the use of nonsteroidal anti-inflammatory agents, has not been studied extensively. Treatment of steroid-induced aseptic necrosis in the knee and hip has demonstrated mixed results, but this may represent the extent of the disease rather than the effect of steroid usage.

Surgical Technique

Femoral Condyle

The patient is positioned supine, and a proximal thigh tourniquet is applied. A leg or foot-holder is valuable in this procedure, in order to position and maintain the leg in between 70° and 100° of flexion and thus gain access to the lesion. Implantation of a fresh osteochondral allograft generally necessitates an open procedure, including an arthrotomy of variable size (depending on the position and dimension of the lesion). Eversion of the patella is not necessary for most femoral condylar lesions. Usually, diagnostic arthroscopy has been performed shortly before the allograft procedure and is not an imperative step in that procedure; however, if there are any unanswered questions regarding the status of the meniscus or of the other compartments of the knee, diagnostic arthroscopy can be performed prior to the allografting. The fresh graft, which has been placed in chilled saline solution on the back table, is inspected to confirm the adequacy of the size match and the quality of the tissue before the knee joint is opened.

A standard midline incision is made from the center of the patella to the tip of the tibial tubercle. This incision is elevated subcutaneously, either medial or lateral to the patellar tendon, depending on the location of the lesion (medial or lateral). A retinacular incision is then made from the superior aspect of the patella inferiorly. Great care is taken to enter the joint and incise the fat pad without disrupting the anterior horn of the meniscus or damaging the articular surface. Sometimes, when the lesion is posterior or very large, the meniscus must be detached and reflected, and generally this can be done safely, with a small cuff of tissue left adjacent to the anterior attachment of the meniscus for later reattachment and repair.

Once the joint capsule and synovium have been incised and the joint has been entered, retractors are placed medially and laterally. Care is taken to position the retractor within the notch to protect the cruciate ligaments and the articular cartilage. The knee is then flexed and/or extended until the degree of flexion that presents the lesion into the arthrotomy site is achieved. Excessive flexion limits the ability to mobilize the patella. The lesion then is inspected and is palpated with a probe to determine its extent, margins, and maximum size. The two commonly used techniques for the preparation and implantation of osteochondral allografts include the press-fit plug (dowel) technique and the shell graft technique. Each technique has advantages and disadvantages. The press-fit plug technique is similar in principle to autologous osteochondral transfer systems. It is optimal for contained condylar lesions between 15 and 35 mm in diameter. Fixation is generally not required because of the stability achieved with the press-fit. Disadvantages include the fact that many lesions, such as very posterior femoral, tibial, patellar, and trochlear lesions, are not conducive to the use of a circular coring system. In addition, the more ovoid the lesion is in shape, the more normal cartilage that must be sacrificed at the recipient site in order to accommodate a circular donor plug. Shell grafts are technically more difficult to perform and typically require fixation. However, depending on the technique employed, less normal cartilage may need to be sacrificed. Also, certain lesions are more amenable to shell allografts because of their location.

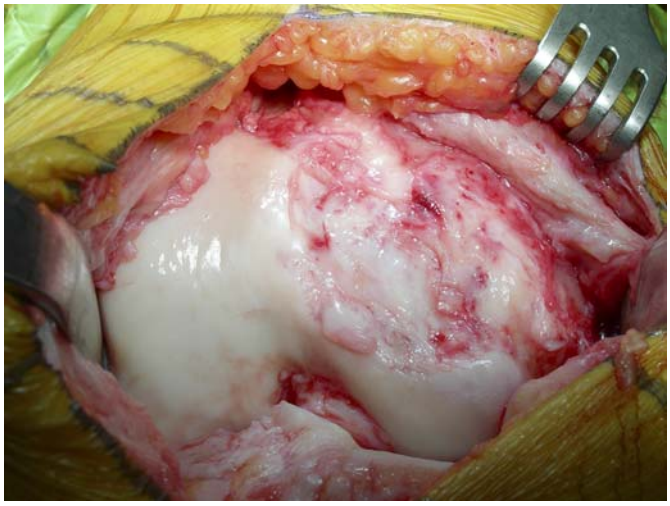

Fig. 3-A

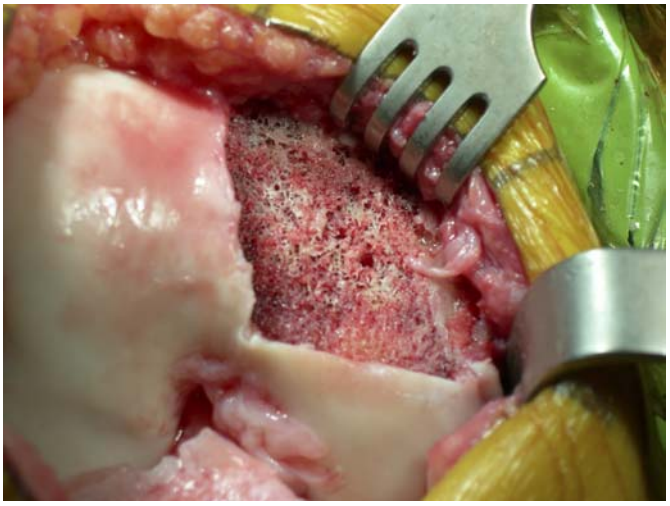

Fig. 3-B

Fig. 3-A Intraoperative appearance of a posttraumatic defect, manifesting marked traumatic osteoarticular loss. **Fig. 3-B** Intraoperative photograph after freehand preparation of the graft bed for a shell allograft.

Dowel Allograft

Several proprietary instrumentation systems are currently available for the preparation and implantation of press-fit dowel allografts up to 35 mm in diameter. Only one of the instrumentation systems will be discussed here; however, most systems are similar.

The symptomatic lesion is identified, and the size of the proposed graft is outlined and templated with use of sizing dowels; it should be kept in mind that overlapping dowels may deliver the best area fit. After a size determination is made, a guidewire is driven into the center of the lesion, perpendicular to the curvature of the articular surface. The remaining articular cartilage is scored, and a core reamer is used to remove that cartilage and at least 3 to 4 mm of subchondral bone (Fig. 2-C). When a patient has a deeper lesion, fibrous and sclerotic bone is removed to a healthy, bleeding osseous base. When a lesion is very deep, coring should not exceed 10 mm in depth, and packed morselized autologous bone graft should be utilized to fill any deeper or more extensive osseous defects. The guidewire then is removed, and circumferential depth measurements of the prepared recipient site are made.

The corresponding anatomic location of the recipient site then is identified on the graft, which is placed into a graft-holder or is held with bone-holding forceps. A saw guide then is placed in the appropriate position, again perpendicular to the articular surface, and an appropriately sized tube saw is used to core out the graft. Before the graft is removed from the condyle, an identifying mark is made to ensure proper orientation. Once the graft has been removed, the depth measurements that were determined from the recipient are transferred to the graft. This graft then is cut with an oscillating saw and is trimmed with a rasp to the appropriate thickness in all four quadrants, and the deep edges of the bone plug can be chamfered with a rongeur and bone rasp. Often, this must be done multiple times, to ensure precise thickness, preferably by refashioning the graft rather than the recipient site and optimally while keeping the graft moist throughout the procedure.

The graft is then irrigated copi-

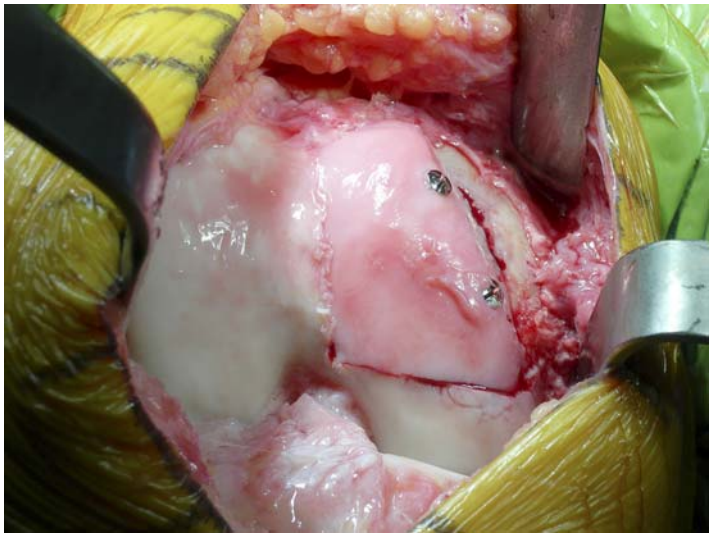

Fig. 3-C

An osteochondral shell graft in place, with additional screw fixation. The relief of the medial trochlear facet has been restored and is secured by compression screws placed outside of the articulating surface of the joint.

ously with high-pressure lavage to remove all marrow elements[55]. The recipient site can be dilated with use of a slightly oversized tamp in order to facilitate the insertion of the graft and prevent excessive impact loading of the articular surface when the graft is applied. At this point, bone graft is applied to any remaining osseous defects. The allograft is then inserted by hand in the appropriate rotation, and it is gently tamped in place until it is flush, again with minimization of mechanical insult to the articular surface of both the native and the graft tissue.

Once the graft is seated, a determination is made regarding whether additional fixation is required. Typically, absorbable polydioxanone pins are utilized, particularly if the graft is large or has an exposed edge within the notch (Fig. 2-D). Often, the graft needs to be trimmed in the notch region to prevent impingement. The knee is then brought through a complete range of motion in order to confirm that it is stable and there is no catching or soft-tissue obstruction. At this point, the wound is irrigated copiously, and, if no more adjunct procedures are planned, routine closure is performed.

Shell Allograft (Fig. 3-A)

The defect is identified by means of the previously described arthrotomy. The circumference of the lesion is marked with a surgical pen. An attempt is made to create a geometric shape that is amenable to hand-crafting of a shell graft; however, sacrifice of normal cartilage should be minimized. A number-15 blade is used to cut around the lesion. Sharp ring curets are used to remove all tissue inside this marked area. With use of both a motorized 4.0-mm burr and sharp curets, the defect is débrided to a depth of 4 to 5 mm (Fig. 3-B). The graft is fashioned in a freehand manner by initially oversizing it slightly and then carefully removing excess bone and cartilage as is found to be necessary through multiple trial fittings. If there is deeper bone loss in the defect, more bone can be left on the graft and cancellous bone graft can be applied to the defect prior to insertion of the shell allograft. The shell allograft is placed flush with the articular surface, and the need for fixation is based on the degree of inherent stability. Bioabsorbable pins are typically used when fixation is required, but compression screws may be utilized as an alternative (Fig. 3-C).

Postoperative Management

Early postoperative management includes the use of continuous passive motion while the patient is in the hospital. Patients generally are allowed a full range of motion unless they had undergone additional reconstructive procedures, such as meniscal repair, anterior cruciate ligament reconstruction, or osteotomy, that would alter the rehabilitation plan. Patients begin early range-of-motion exercises and quadriceps-strengthening and maintain a toe-touch-only weight-bearing status for at least eight weeks, and often twelve weeks, depending on the size of the graft, type of fixation, and ultimately radiographic evidence of incorporation.

At four weeks, patients are allowed to perform closed-chain exercises such as cycling. Progressive weight-bearing as tolerated usually is permitted at three months, and if functional rehabilitation is complete, the patient is allowed to return to recreational and sports activities at approximately six months. Patients are generally cautioned about excessive impact loading of the allograft, particularly in the first year. As with any cartilage replacement procedure, long-term outcomes of osteochondral allografting are directly and inversely related to the time to treatment and the overall burden of disease in the affected joint. It is not unrealistic to expect a young patient with a focal lesion (traumatic or due to osteochondritis dissecans) to go back to normal-impact-loading activities after twelve months and to return to preinjury function, whereas the goals in a salvage situation are usually to delay or even eliminate the need for prosthetic replacement by reducing pain and allowing a return to functional activities of daily living as well as low-impact leisure activities.

Typically, braces are not utilized unless the grafting involves the patellofemoral joint, in which case flexion is limited to <45° for the first four to six weeks, or unless bipolar tibial and femoral grafts are used, in which case an unloader or range-of-motion brace is used to prevent excessive stress on the grafted surfaces.

Complications

The most unique issue regarding possible postoperative complications with fresh allografts relates to transmission of disease from the graft. Infection following the implantation of a fresh osteochondral allograft is rare, but its consequences can be devastating. Generally, all grafts are currently harvested and tested in accordance with American Association of Tissue Banks standards. However, allograft-associated bacterial infections have been reported[56]. Death in the immediate postoperative period has occurred as the result of implantation of a contaminated fresh osteochondral graft. As is the case with most procedures, infection may become apparent in the days to weeks following surgery. Deep infection needs to be distinguished from superficial infection on the basis of the findings of physical examination and joint aspiration. Deep infection involving the allograft should be addressed immediately with removal of the allograft since there is a risk that the fresh tissue is the source of the infection or is a nidus for recurrence. Patients need to be informed of this risk preoperatively and again counseled to look for signs of infection prior to and after discharge from the hospital.

The allograft procedure can fail as a result of nonunion or late fragmentation and graft collapse. Progression of disease (arthritis) may also lead to an inferior clinical outcome. Although healing of the graft-host interface occurs reliably, particularly with smaller grafts, the degree of revascularization appears to be variable. Fragmentation and collapse typically occur in areas of unvascularized allograft bone. Patients with this complication generally present with new-onset pain or mechanical symptoms. Radiographs may show joint space narrowing, cysts, or sclerotic regions. Magnetic resonance imaging can

TABLE III Outcomes of Osteochondral Allografting in the Knee

Author	Site of Lesion	Diagnosis/Indication	No. of Cases	Mean Duration of Follow-up *(yr)*	Successful Outcome
Meyers et al.[3]	Knee	Multiple	31	3.5	77%
Chu et al.[11]	Knee	Multiple	55	6.2	76% good/exc. results
Ghazavi et al.[13]	Knee	Trauma	126	7.5	85% survivorship
Aubin et al.[60]	Femur	Trauma	60	10.0	85% survivorship
Görtz et al.[57]	Femur	Trauma	43	4.5	88% good/exc. results
Garrett[50]	Femur	Osteochondritis dissecans	17	2-9	94% good/exc. results
Emmerson et al.[49]	Femur	Osteochondritis dissecans	65	7.7	72% good/exc. results
Bugbee and Khadivi[59]	Knee	Osteonecrosis	21	5.3	88% good/exc. results
Park et al.[58]	Knee	Osteoarthrosis	34	3.0	76% good/exc. results
Jamali et al.[14]	Patellofemoral	Multiple	29	4.5	52% good/exc. results

help to rule out contributory concomitant joint disease in the differential diagnosis of postoperative symptoms. In the event of mechanical allograft failure, magnetic resonance images often show areas of graft collapse. However, care must be taken in the interpretation of these images, as even normal well-functioning grafts demonstrate signal abnormalities. Depending on the status of the knee joint, the treatment options include observation, removal of the fragmented portion of the graft, repeat allografting, or conversion to an arthroplasty.

Results

Emmerson et al. reported on a series of sixty-six knees in sixty-four patients in whom osteochondritis dissecans of the femoral condyle had been treated with fresh osteochondral allograft[49] (Table III, Fig. 4). All patients were evaluated both preoperatively and postoperatively with a modified Merle d'Aubigné and Postel scale, which measures function, range of motion, and absence of pain, allotting 1 to 6 points to each, for a maximum of 18 points. There were forty-five male and nineteen female patients with a mean age of 28.6 years (range, fifteen to fifty-four years). Forty-one lesions involved the medial femoral condyle, and twenty-five involved the lateral femoral condyle. All lesions were high-grade osteochondritis dissecans, and all had been treated previously with surgery. The mean allograft size was 7.5 cm^2. The mean duration of follow-up was 7.7 years (range, two to twenty-two years). One knee was lost to follow-up. Of the remaining sixty-five knees, forty-seven (72%) were rated good/excellent, with a score of ≥15 points on the 18-point

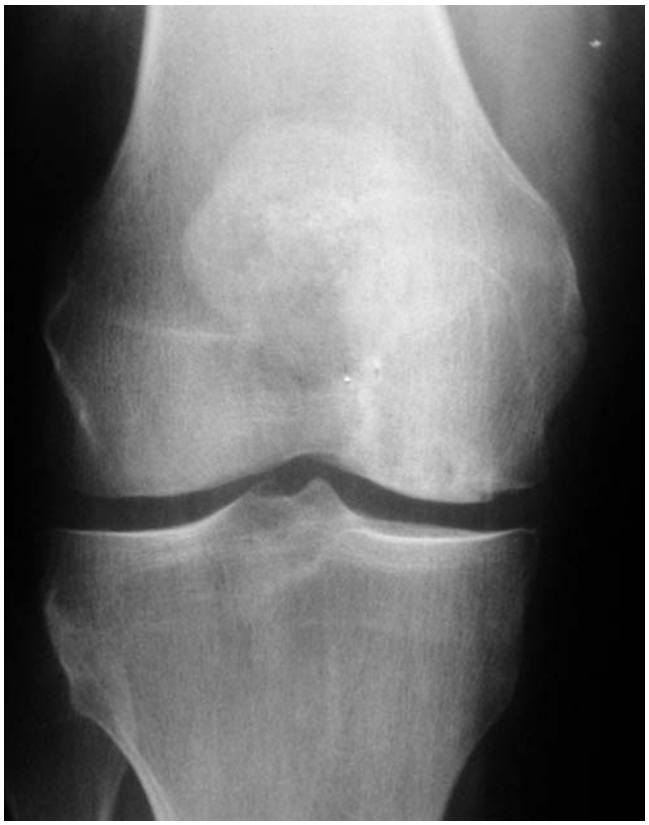

Fig. 4

Anteroposterior radiograph of a right knee, made ten years after placement of a shell allograft in the medial femoral condyle. The joint space has been maintained, without radiographic evidence of frank joint degeneration.

scale; seven (11%) were rated fair; and one (2%) was rated poor. The mean clinical score improved from 13.0 points preoperatively to 16.3 points postoperatively ($p < 0.01$). Ten patients underwent a reoperation, with a mean time to the reoperation of fifty-six months. Fifty-nine of the sixty-four patients completed questionnaires. The mean subjective score for knee function improved from 3.4 to 8.4 points on a 10-point scale ($p < 0.01$).

Garrett reported his experience with the use of fresh osteochondral allografts as both press-fit plugs and large shell grafts in the treatment of osteochondritis dissecans[50]. All patients had undergone previous surgery[50]. Sixteen of the seventeen patients reported relief of symptoms at two to nine years postoperatively; the only failure was a particularly large graft that fragmented.

Between 1997 and 2004, forty-three patients with an isolated cartilage lesion of the femoral condyle were treated with a fresh osteochondral allograft at our institution[57]. The study population included twenty-three male patients and twenty female patients with a mean age of thirty-five years. Twenty-nine patients had involvement of the medial femoral condyle; thirteen, the lateral femoral condyle; and one, both condyles. All patients had undergone prior surgery. The mean allograft area was 5.88 cm^2. Thirty-eight (88%) of the forty-three allograft procedures were considered to be successful (a score of ≥15 points on the 18-point modified Merle d'Aubigné and Postel scale) at a mean of 4.5 years postoperatively.

Park et al. reported the results of osteochondral allografting in thirty-four patients with a clinically established and radiographically confirmed diagnosis of advanced knee arthrosis[58]. Of these grafts, nineteen were unipolar, ten were bipolar, and five included multiple surfaces. The mean graft area was 10.5 cm^2. At the time of follow-up, at a mean of three years, twenty-eight procedures were considered to be successes, with significant objective and subjective improvement ($p < 0.01$).

In a study on the use of allografts for the salvage of twenty-one knees (seventeen patients) with established severe osteonecrosis, fifteen patients were satisfied with the result of the treatment and fourteen felt that the overall condition of the knee was improved[59]. Furthermore, none of the knees had required conversion to total knee arthroplasty at a mean of 5.3 years following this challenging salvage procedure.

Chu et al. reported on fifty-five consecutive knees treated with osteochondral allografting in patients with diagnoses such as traumatic chondral injury, osteonecrosis, osteochondritis dissecans, and patellofemoral disease[11]. The mean age of this group was 35.6 years, and the duration of follow-up averaged seventy-five months (range, eleven to 147 months). Of the fifty-five knees, forty-three had a unipolar replacement and twelve had a bipolar resurfacing. On an 18-point scale, forty-two (76%) of these fifty-five knees were rated as good to excellent and three were rated as fair. It is important to note that thirty-six of the forty-three knees that had undergone unipolar femoral grafting had a good to excellent result and only six of the twelve knees treated with bipolar grafting had a good or excellent result.

McDermott et al. reported on 100 patients in whom a fresh osteochondral graft had been implanted within twenty-four hours after harvest[12]. Thirty-eight of fifty patients with a unifocal traumatic defect of the tibial plateau or femoral condyle were considered to have a successful result at an average of 3.8 years postoperatively. Patients with osteoarthritis and osteonecrosis fared much worse. Ghazavi et al. reported on 126 knees in 123 patients who had been followed for an average of 7.5 years[13]. Eighty-five percent of the procedures were rated as successful while the remainder had failed. Factors related to failure included an age of more than fifty years, bipolar defects, malalignment, and a Workers' Compensation claim. Aubin et al.[60] later reported the long-term results for sixty patients in whom a fresh femoral graft had been implanted for the treatment of a posttraumatic lesion. Survivorship analysis showed the survival of fifty-one grafts at ten years and forty-four at fifteen years. Forty-one of the patients had undergone a simultaneous realignment osteotomy, and ten had had a concomitant meniscal transplantation. Radiographic analysis revealed moderate to severe arthritis in thirty-one of the knees at the time of the latest follow-up.

Overview

Fresh osteochondral allografts have a role in the treatment of a wide spectrum of articular pathological conditions, particularly those that include both an osseous and a chondral component. Many clinical and basic scientific studies have supported the theoretical foundation and efficacy of the use of small-fragment allografts, although more scientific validation of empirical clinical practice is still needed.

The operative procedure for the treatment of femoral condylar lesions is straightforward but demands precision to achieve reproducible results and to minimize early graft failures related to surgical technique. As with other cartilage-restoration methods, the indications for the use of fresh osteochondral allografts are being expanded to include the primary treatment of focal femoral condylar lesions, use in joints with an advanced burden of disease, as well as use in other joints.

With respect to fresh grafts, tissue-banking standards and techniques are still evolving with regard to enhancing graft quality and prolonging storage intervals, which will allow more surgeons and their patients to gain access to the procedure. Further understanding of the immunologic behavior of fresh allografts is clearly needed. Modulating the healing response by donor-recipient matching, use of bioactive growth factors, or other adjunct therapies may further improve short and long-term outcomes of procedures involving the use of fresh osteochondral allografts.

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