Osteochondral Allografts: State of the Art

Christian Lattermann, MD*, Spencer E. Romine, MD

The use of osteochondral allografts continues to gain popularity among orthopedists; however, the concept of replacing bone defects with allograft tissue is not a novel technique. Bolano and Kopta noted that MacEwen was the first to use bone allograft over 120 years ago, followed by Lexer in 1908. A subsequent decline in the early twentieth century was followed by a revival in the 1970s, especially in North America. Today, the use of osteochondral allografts continues to rise throughout the orthopedic world. In 2004, approximately 800,000 bone allografts were used in the United States alone. According to Delloye and colleagues, bone allograft is the most commonly used bone substitute in Europe. With regard to the use of osteochondral allografts for cartilage repair, it has become clear that despite the introduction of several operative procedures that attempt to repair and restore articular cartilage, osteochondral allografting is currently the only option that can potentially restore mature hyaline cartilage in a biologically and structurally appropriate manner. Success can be attributed to advancing technology, reproducible techniques, and an enormous increase in clinical and scientific research.

BASIC SCIENCE

Articular cartilage provides a less than favorable environment for healing. Lack of blood vessels, lymphatics, nerves, and cells capable of a reparative process limits nature’s ability to restore lesions of the articular surface. Buckwalter has described...
mechanisms of injury and subsequent response to injury in detail. Though perhaps a simplistic means summarizing years of research, the basic principle is such that partial-thickness tears (chondral fractures) do not heal and full-thickness tears (osteochondral fractures) heal variably, with a predominance of type I collagen with inferior biomechanical properties. A normal hyaline surface is not reproduced; instead, chondral lesions produce an irregular surface that predisposes the joint as well as soft-tissue structures to further injury.¹¹

Unlike other forms of cartilage repair and restoration, osteochondral allografts take advantage of the inherently poor healing potential of articular cartilage in an attempt to restore a quasi-native joint surface. The goal is to replace what has been lost in a way that is as biologic and anatomic as possible. As articular cartilage is normally avascular, aneural, and alymphatic, newly transplanted chondrocytes are immersed in a familiar environment. Cells are embedded in an acellular matrix protecting them from host immunogenic cells.¹² Metabolic requirements continue to be met through the diffusion of synovial fluid.

Unfortunately, the subchondral component of the graft can be a source of difficulty if allograft tissue is not properly processed. The properties of subchondral bone differ tremendously from its overlying articular surface. Most importantly, transplanted bone is nonviable¹³ and relies on the host for vascular invasion with subsequent osteoclastic resorption of dead bone and replacement with new viable bone (creeping substitution).¹⁴ And along with the invading vessels into the newly transplanted bone come host immunogenic cells.

In essence, osteochondral allografts trade a severely damaged or absent articular surface for an intact one and replace viable with nonviable subchondral bone. The subchondral bone tends to heal, giving structural support to the overlying articular surface. As with osteochondral autografts, consistent healing of the chondral portion of the graft to the adjacent hyaline cartilage layer has not been shown.¹⁰

Although chondrocyte viability within osteochondral allografts has been documented by several studies,¹⁵–¹⁷ the origin (host versus donor) of these cells within grafts could not be definitively confirmed despite several methods of analysis. Jamali and colleagues,¹⁸ using fluorescence in situ hybridization (FISH) and karyotype analysis, recently reported conclusive evidence of donor-cell survival in a fresh osteochondral allograft at 29 years.

ADVANTAGES AND DISADVANTAGES OF OSTEOCHONDRAL ALLOGRAFTS

There are several structural, clinical, and theoretical advantages of osteochondral allografts over other types of articular cartilage restoration (autologous chondrocyte implantation, marrow stimulating techniques, and osteochondral autografts) (Table 1). First, a fully formed mature hyaline cartilage layer with viable chondrocytes capable

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of maintaining the extracellular matrix is transplanted along with a variable-sized sub-
chondral layer of bone.\textsuperscript{15,19} No other method is capable of restoring large defects of
subchondral bone as well as joint contour in a single operative procedure. Several
studies have documented the ability of osteochondral allografts to be an effective
means of replacing focal areas of damaged articular cartilage as well as relieving joint
pain.\textsuperscript{3,20,21} Although the relief of joint pain is not well understood, the current belief is
centered on the replacement of innervated bone with denervated subchondral bone
of the graft.

The clinical and surgical advantages of allografts have been well described: avail-
ability to the surgeon, precise preparation of graft material in any number of sizes,
lack of donor-site morbidity, shorter operative times (one-stage operation) than other
restorative procedures, and lack of clinically significant immunologic reactions.\textsuperscript{22} In
most cases, grafts may be harvested from a younger donor with healthier articular car-
tilage than that of the recipient.

Disadvantages include the potential for disease transmission, immunologic reaction
with subsequent graft rejection, cost, limited availability of allografts, and demanding
surgical technique. Increasing diagnostic technology as well as knowledge of treat-
ment options has allowed the orthopedic surgeon the ability to offer cartilage restor-
ative procedures that were not available in the past. The increasing demand of
osteochondral allografts has, in essence, limited their availability.

**PROCUREMENT AND STORAGE**

The retrieval, processing, and allocation of allografts are highly monitored processes.
The American Association of Tissue Banks (AATB) was founded in 1976 to establish
standards and guidelines for procurement of allografts.\textsuperscript{23} Initially, the use of fresh os-
teochondral allografts was limited to a small number of institutions in North America;
however, in 1998, commercially supplied allografts became available in the United
States. According to the AATB Web site (www.AATB.org), more than 100 accredited
tissue banks are located in the United States today. All forms of bone allograft are pri-
marily obtained from 3 sources: femoral head of a patient undergoing a total hip
arthroplasty (THA), multi-organ donors, and postmortem donors. Allograft from a pa-
tient undergoing a THA is the most convenient because testing can be performed both
pre- and postoperatively. Postmortem donors are most often rejected as retrieval of-
ten takes place in less-than-sterile environments despite sterile technique.\textsuperscript{5}

Osteochondral allografts are stored as fresh, fresh-frozen, or cryopreserved grafts.
Each of these storage options affects chondrocyte viability, immunogenicity, and
length of time to transplantation. Fresh-frozen tissue that is maintained at \(-80^\circ\text{C}\) elim-
inates >95\% of viable chondrocytes, because they are destroyed during the freezing
process.\textsuperscript{24} As chondrocytes are responsible for maintenance of the extracellular ma-
trix, studies\textsuperscript{25} have shown that the matrix in these frozen allografts tends to deteriorate
over time. Deterioration of the matrix is evident by an increase in matrix metalloprotei-
nases (MMPs), as reported by Acosta and colleagues.\textsuperscript{26} Although decreased
chondrocyte viability is not ideal, fresh-frozen allografts do exhibit decreased immu-
nogenicity and, therefore, may be more appropriate for bulk allografting in major os-
seous reconstructions.\textsuperscript{27}

Cryopreservation, on the other hand, is capable of maintaining chondrocyte viability
during this freezing process by adding glycerol and dimethyl sulfoxide (DMSO) to the
tissue. Theoretically, the addition of these chemicals prevents ice formation within
cells and thus destruction of chondrocytes. Multiple studies\textsuperscript{13,19,28–30} have reported
variable results, with chondrocyte survival ranging from 20\% to 70\%. Unfortunately,
cell survival appears to be limited to the surface of the articular cartilage layer. Theories to explain this phenomenon include the inability to uniformly control the freezing rate of the tissue, disruption of cell membranes secondary to ice crystal formation, and inadequate penetration of glycerol or DMSO during the freezing. With the increase in tissue bank screening times and limited osteochondral allograft availability, research regarding cryopreservation will likely increase in the years to follow.

In multiple retrieval studies, fresh allografts have been shown to have the highest rates of chondrocyte viability of the 3 methods of storage and are the most commonly used grafts in the United States. Fresh grafts are placed in lactated Ringer’s solution or tissue culture medium at 4°C or 37°C, where they have historically been thought to be stored for 5 to 7 days before chondrocyte viability begins to decline. Fresh cold-stored osteochondral allografts have been shown to contain viable chondrocytes with maintenance of the extracellular matrix for many years after transplantation. Ranawat and colleagues reported superior histologic and biomechanical properties of cold-stored fresh allograft compared with freeze-thawed specimens. Gross and colleagues recently examined histologic features of 35 fresh osteochondral allograft specimens and found that with a stable osseous graft base, the hyaline cartilage portion of the allograft could survive and function for 25 years or more. Research is ongoing to determine the most biologic means of reversing the metabolic suppression of cold-preserved grafts; gradual rewarming and decreasing nitric oxide at the time of graft implantation may have implications on graft survival.

The length of time of storage before implantation has also been explored recently. Currently, fresh grafts are commercially available to clinicians approximately 14 to 21 days following graft harvest. Studies have shown decreased chondrocyte viability and degradation of biomechanical properties of grafts stored for greater than 14 days. Malinin and colleagues reported time-dependent loss of chondrocytes within cold-stored fresh allografts implanted into adult baboons, especially when stored for longer than 15 to 20 days. Williams and colleagues recently revealed data showing that hypothermically stored fresh grafts implanted after a storage time of 17 to 42 days were effective at 2-year follow up. Grafts were determined to be effective both structurally and functionally in reconstructing symptomatic chondral and osteochondral lesions of the knee. Currently, the goal is to implant fresh osteochondral allografts as soon as possible, within 21 to 28 days of harvest.

**RISK OF DISEASE TRANSMISSION**

As with transplantation of any allogeneic tissue, viral and bacterial disease transmission is possible despite strenuous donor screening, aseptic technique, and testing of tissue. Initial screening occurs long before tissue is retrieved by eliminating potential donors based on a full physical examination, immediate evidence of infection, and a review of the patient’s relevant medical records after consent has been obtained. Aseptic technique is used during and after retrieval of tissues to limit contamination. In addition to testing for human immunodeficiency virus (HIV) types 1 and 2, hepatitis B virus (HBV), hepatitis C virus (HCV), and syphilis, the AATB requires testing for human T-cell lymphotropic virus (HTLV) I and II and uses nucleic acid testing (NAT) for HIV-1 and HCV, which is not yet required by the U.S. Food and Drug Administration (FDA). Polymerase chain reaction (PCR) testing is capable of decreasing the window of vulnerability from 4 to 6 weeks to approximately 10 days in viruses known to have a “window” period, such as HIV and HCV.
Several methods of sterilization have been attempted, including low-dose gamma irradiation, antibiotic soaks, and a variety of inactivating agents (ethylene oxide, ether, and hydrogen peroxide). No perfect sterilization technique is currently available, because methods that completely eradicate viral and bacterial spores also disrupt collagen structure.43 Currently, the most common method to ensure sterile grafts is sterile harvest and processing with low-dose (2.5 Mrad) gamma irradiation to kill surface pathogens.

Although the risks of acquiring disease through transplantation are very small, patients as well as surgeons remain concerned. Buck and colleagues44 estimated the risk of HIV transmission in 1989 to be 1/1.6 million, though this estimate was before the advent of PCR testing. The last reported case of disease transmission from allograft tissue of all types was in 2002 (before NAT/PCR) when 40 patients received tissue from an anti-HCV-negative donor.45 None of the 16 recipients receiving irradiated bone tested positive for HCV after transplantation. The only reported cases of tuberculosis and HBV in tissue recipients occurred more than 50 years ago. Interest arose in 2001 when a male recipient of allograft tissue expired secondary to an infection with *Clostridium*;46 however, the tissue was retrieved by a facility that was not accredited by the AATB, and the donor’s body had initially been refused by the local AATB-accredited tissue bank. According to the AATB in 2006, the majority of bacterial-contaminated transplants that have been reported in the literature have never been confirmed by the Centers for Disease Control and Prevention (CDC). Despite the relatively minuscule risks of disease transmission under today’s standards, both the surgeon and patient should be aware of this possibility, and it must be discussed as a component of the informed-consent process.

**IMMUNOGENICITY**

Another important aspect of informed consent is the risk of immunologic reaction and/or rejection of the graft tissue. Small fragment allografts are not human leukocyte antigen (HLA)- or blood type-matched between the donor and recipient.27 Host immune response to osteochondral allografts is elicited by the major histocompatibility complex (MHC) Class I and II antigens that are present on the surface of osteocytes and chondrocytes. Fortunately, an immune response against chondrocytes is limited secondary to the avascular and alymphatic cartilage matrix surrounding them. The cartilage matrix serves to shield the MHC Class I antigens from recognition by host cells, thereby protecting the chondrocytes from host immune response.12

In contrast to the articular cartilage layer of the graft, the osseous component of the graft expresses MHC cell-surface antigens, which come in contact with host immunogenic cells during vascular invasion and graft incorporation. In order to decrease the risk of this immune response, bone allograft is processed by multiple techniques (pulsatile irrigation, cold storage, and cytotoxic agents) to remove blood and bone marrow cells, thus creating a less immunogenic transplant.42

Although properly processed osteochondral allografts are relatively inert immunologically, showing little or no histologic evidence of an immune-mediated response,14 Sirlin and colleagues47 reported that 11 of 25 individuals generated serum anti-HLA antibodies after transplantation of shell allografts. Compared with antibody-negative patients, patients with anti-HLA antibodies showed an inferior appearance on magnetic resonance imaging (MRI). Statistically significant MRI findings of grafts in antibody-positive patients included greater mean edema, thicker interface, more abnormal marrow, and a higher proportion of surface collapse. The clinical significance
of this finding is unknown, though further research is needed to determine the role of immune behavior in determining the outcome of fresh osteochondral allografts.48

INDICATIONS

Osteochondral allografts are primarily indicated for the treatment of full-thickness articular cartilage defects of 1 cm² or larger.32,49,50 Although these types of defects are most often seen in young patients secondary to a traumatic event, other conditions that are amenable to osteochondral allografting include osteochondritis dissecans (OCD),51,52 avascular necrosis,53 as well as other conditions involving disease or absent underlying subchondral bone. Primary allograft can be considered for large lesions (>2 cm², 6–10 mm deep) less suited for other reparative or restorative procedures.27 The degree of donor-site morbidity and limited availability of donor sites limit the use of autograft in these situations. Allografts have also been shown to be useful for salvage procedures after failure of other methods of cartilage repair and restoration, such as microfracture, autologous chondrocyte implantation, and mosaicplasty.54 Within the knee, osteochondral allografts have been used to treat posttraumatic and degenerative lesions associated with intra-articular tibial plateau fractures,55,56 patellofemoral chondrosis or arthrosis,57 and unicompartmental or multifocal osteoarthritis (Fig. 1).58,59

While the knee is by far the most common anatomic site for osteochondral allografting, other joints have also been treated with variable success.50 Within the ankle, allografts have been used for resurfacing of the tibiotalar joint (bipolar) secondary to post-traumatic arthrosis,61,62 osteonecrosis, and OCD lesions of the talus not amenable to other procedures, as well as reconstruction following excision of tumors of the calcaneus and talus.63

In 2001, Gross and colleagues61 reported the results of osteochondral allografting performed in 9 patients with isolated osteochondral defects of the talar dome. Three of the 9 patients required eventual fusion secondary to resorption and fragmentation of the graft; however, the remaining 6 grafts remained in situ with a mean survival of 11 years, suggesting osteochondral allografts as viable options for focal defects of the talus. Jeng and colleagues64 recently reported a 2-year follow-up of 29 patients

Fig. 1. Osteochondral defect in the knee. Osteochondral defects identified during open or arthroscopic surgery of the knee joint. Note the deep cavitation of the defects extending into and through the subchondral bone plate.
treated with bipolar osteochondral allografts of the tibiotalar joint performed for post-traumatic arthritis. Fourteen of the 29 patients required revision with the use of repeat ankle transplant, prosthetic total ankle arthroplasty, or bone block arthrodesis. Six of the remaining 15 transplants were deemed radiographic failures due to allograft fracture, allograft collapse, or progressive loss of joint space. The authors concluded that due to the extremely high failure rate, bipolar osteochondral allografting should only be considered in patients too young for ankle replacement, with excellent range of motion, low body mass index, normal radiographic alignment, and patients who refuse arthrodesis.

Although indications are less clear and few published data exist, osteochondral grafts have also been used with variable success in both the hip and shoulder joints. Indications include young patients with osteonecrosis of both the femoral head and humeral head\(^{65,66}\) as well as large osteochondral lesions associated with glenohumeral dislocation and instability.\(^{67}\)

**CONTRAINDICATIONS**

Understanding when the use of osteochondral allografts is not appropriate is critical during preoperative assessment. Operative candidates are chosen based on history, physical examination, and a thorough review of imaging studies. All of the following are essential portions of the preoperative assessment: age, activity level, and expectations of the patient; history of inflammatory arthropathies; location, size, and depth of defect; condition of surrounding articular cartilage; meniscal integrity; ligament instability; and limb alignment.\(^{68}\)

Though allografting has been performed with some success in younger patients with multicompartamental arthrosis,\(^{58,59}\) there is no role for osteochondral grafting in patients of appropriate age and activity level with progressive multicompartamental osteoarthritic changes.\(^{27}\) These patients are best treated with primary prosthetic arthroplasty. Soft-tissue (meniscal, ligamentous) instability and malalignment of the limb must be addressed either concomitantly or at a separate procedure to provide the graft with an optimized environment for incorporation and function. Inflammatory disease (rheumatoid arthritis, crystal-induced arthropathy) and severe corticosteroid-induced osteonecrosis should be considered relative contraindications as well.\(^{69}\) As mentioned earlier, all patients should understand the risks, benefits, and alternatives to the surgical procedure, with special interest focused on the potential for disease transmission and graft failure.

**SURGICAL PLANNING**

Although osteochondral allografts have been used in other joints, the majority of procedures and hence the literature have been documented regarding the knee; therefore, the following discussion on surgical technique is limited to the knee joint, specifically the femoral condyle.

Prior to performing any surgical procedure, a thorough preoperative plan with adequate radiographs must be formed. An important aspect of the preoperative plan is a thorough discussion with the patient regarding expectations of the procedure. Young active patients with focal chondral lesions secondary to trauma or OCD can be expected to return to normal activities after sufficient rehabilitation. Conversely, expectations for older individuals, often with chronic lesions, are often to delay the need for prosthetic replacement and reduce pain associated with functional activities of daily living.
As a part of the preoperative plan, many surgeons choose to perform a diagnostic knee arthroscopy before transplantation, verifying the soft-tissue status and overall quality of articular cartilage. Allografts are matched based on anterior-posterior radiographs of the knee, and the medial-lateral dimension of the tibia is measured just distal to the joint surface. After correction for magnification, this measurement is used by the tissue bank to match the donor tibial plateau. Other investigators have used the affected condyle as a parameter for sizing. A match is considered acceptable based on size within \( \pm 2 \text{ mm} \), not taking into account variable anatomy, which may exist secondary to the pathologic or traumatic injury. For instance, the affected condyle in OCD is often larger, wider, and flatter, necessitating a large donor condyle. Before beginning the operative procedure, the surgeon must thoroughly inspect the graft for appropriate sizing and quality of the tissue.

**SURGICAL TECHNIQUE/GRAFT TECHNIQUES**

**Positioning/Access**

The surgical technique for reconstruction of articular cartilage defects with osteochondral allografts has been described in detail by several authors. The patient is positioned supine, a proximal thigh tourniquet is used, and maintenance of 70° to 100° of knee flexion is achieved with the use of a leg or foot holder. Transplantation generally requires an open procedure, typically performed through a midline approach while deviating subcutaneously either medially or laterally to the patellar tendon depending on the location of the lesion. A retinacular incision is then performed from proximal to distal to enter the joint, taking care not to damage the anterior horn of the meniscus or articular surface. Once the joint capsule and synovium have been incised, Z-retractors are placed medially or laterally as well as in the intercondylar notch to protect the cruciate ligaments. The knee is then taken through the range of motion to bring the defect into optimal view.

Once adequate access to the lesion is gained, a probe is used to palpate the size, depth, and quality of the margins of the defect (**Fig. 2**). After sizing is completed, a punch is used to delineate the diameter of the graft needed. A dowel-type drill is used to ream a precise socket down to the level of healthy subchondral bone, indicated by punctate hemorrhage. In focal chondral defects, this depth should be approximately 8 mm; however, in lesions secondary to OCD, the depth may be substantially larger (**Fig. 3**). Lesions involving the tibial plateau or the patella may require a more extensive resection as well. If the depth of the lesion is extensive, morselized autologous bone graft should be used to fill the osseous defect. After the size, shape, and depth of the prepared bed is determined, the graft is ready for insertion.

**Dowel (Press-Fit) Allografts**

Depending on the location and size of the lesion, 2 techniques (dowel, shell) can be used in preparation and implantation of osteochondral allografts. Dowel allograft, the more commonly used technique, involves inserting either a single precisely contoured plug or multiple plugs placed closely together at various angles to match the curvature of the lesion to be resurfaced. A single press-fit plug is optimal, as space between multiple plugs is subject to the formation of fibrocartilage with uneven cobblestoning, which may affect clinical outcome.

Dowel allografts are usually 8 mm thick in focal chondral defects and up to 15 mm thick in OCD lesions. They are primarily recommended for condylar lesions between 15 and 35 mm in diameter. Unlike shell autografts, press-fit grafts generally do not require additional fixation; however, careful insertion of the graft by dilating the recipient...
Site with a slightly oversized tamp must be achieved to prevent excessive impact loading of the articular surface. Borazjani and colleagues\textsuperscript{75} reported that chondrocyte death, particularly in the superficial zone, occurred during impact insertion of dowel grafts and recommended further research regarding insertion techniques.

Technical difficulty with the use of the circular coring system limits the use of the dowel technique in certain locations, such as the posterior femur, tibia, patella, and trochlea. The use of circular plugs may also require extensive removal of normal adjacent cartilage to achieve a stable fit.

\textbf{Shell Allografts}

Shell allografts define the “art” of osteochondral allografting. Using freehand technique, grafts are matched to the outlined defect, minimizing sacrifice of normal articular cartilage. The graft is initially oversized followed by meticulous sculpting to achieve an exact fit. Bioabsorbable pins or low-profile interfragmentary screws are often needed for fixation. The most obvious disadvantage is the technically demanding nature of the procedure, limiting its use by many surgeons. Primary indications for shell allografts include larger lesions with an asymmetric pattern located in regions not amenable to dowel allografts.

\textbf{Technical Considerations}

Whether using the dowel or shell technique, several generalized aspects of the procedure are worthy of special attention. Matching the radius of curvature of the graft to host anatomy is critical to avoid increased contact pressure and restoring joint contour, especially with shell autografts (\textbf{Fig. 4}).\textsuperscript{76} Before insertion, allografts are

\textbf{Fig. 2.} Partially un-contained defect after failed repair of osteochondritis dissecans (OCD). Particularly in a revision situation after previously failed surgery, it is critical to evaluate the location of the defect. In patients with failed OCD lesions, the defect is often partially un-contained, and the shape of the condyle can be significantly altered. The use of a full hemicondyle graft is, therefore, recommended to be able to ideally match the graft to the defect.
subjected to pulsatile lavage to remove blood and bone marrow cells in a final attempt to decrease the risk of a host immune response. The final resting position of the graft relative to the surrounding articular surface has been controversial. Initially, many authors believed that by placing the graft 1 mm proud, the graft would eventually become flush with adjacent tissue after subsidence and resorption occurred in the weeks to follow. Studies exploring contact pressures within grafts have questioned leaving the graft proud by demonstrating that the level of the graft can have a tremendous effect on contact pressures within the graft. Grafts elevated 0.5 to

Fig. 3. Preparation of the graft socket. The defect has to be sized such that the entire defect can be cut out with a circular reamer. The graft socket is prepared deep enough to reach bleeding bone. Ideally, this should be 8 mm deep, but in a failed OCD lesion, it is necessary to reach bleeding subchondral bone. This may require a socket that can be up to 10 or 15 mm deep.

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Fig. 4. Preparation of the allograft. During the preparation of the allograft, it is important to do a precise match with the recipient condyle. Particularly in partially uncontained defects, it is important to match the curvature (black arrows) well to the recipient to avoid recessing the graft.
1.0 mm appeared to have up to a 50% increase in contact pressure. Conversely, grafts that were flush or even slightly recessed restored normal contact pressures (Fig. 5).

**Postoperative Management**

Postoperative management is similar to other cartilage reparative and restorative procedures focusing on weight-bearing protection and regaining joint range of motion. Unless other concomitant procedures (meniscal repair, ligament reconstruction, or osteotomy) are performed at the time of transplantation, early full range of motion is encouraged to prevent adhesions.

Postoperative rehabilitation is divided into 4 phases. During phase I (0–6 weeks), the patient is made non-weight bearing on the affected extremity, and a continuous passive motion (CPM) device is used for 6 to 8 hours per day. Range of motion is initially limited to 0° to 40°, increasing 5° to 10° per day as patient comfort allows. The patient should gain 100° by week 6. A total-range-of-motion (TROM) brace is used, initially locked in extension for the first postoperative week and removed only for CPM and exercises. During weeks 2 to 4, the brace is gradually opened in 20° increments as quadriceps control is gained. Bracing is discontinued when a straight-leg raise can be controlled without an extension lag. Exercises during phase I include passive and active-assisted knee range of motion to tolerance as well as stretching and strengthening of the quadriceps, hamstrings, and gluteus muscles.

During phase II (6–8 weeks), partial weight-bearing (25%) is allowed, and knee flexion to 130° should be achieved. Stretching and strengthening exercises are continued with the addition of a stationary bike to improve range of motion. Phase III (8–12 weeks) allows gradual return to full weight bearing, with progression to full, pain-free, knee range of motion. Gait training and closed-chain exercises (wall sits, shuttle, mini-squats, and toe raise) are performed. Phase IV (12 weeks–6 months) concludes with...
with a full and normalized gait pattern associated with full and pain-free knee range of motion. Return to activities is allowed between 6 to 12 months depending on progression.

Other authors\textsuperscript{27,48} have recommended slightly different postoperative protocols. Key differences include immediate toe-touch weight bearing for 6 to 8 weeks, or longer, depending on the size of the graft, type of fixation, and radiographic evidence of graft incorporation. Closed-chain kinetic chain exercises, such as cycling, are often started at 4 weeks postoperatively. Unrestricted low-demand activities are usually allowed by 3 to 4 months. Braces are often not recommended during rehabilitation, except in the case of patellofemoral grafts, which need early protection by limiting knee flexion to $<45^\circ$ for the first 4 to 6 weeks.

\section*{Results}

Clinical results of fresh osteochondral allografts used in the treatment of focal osteochondral defects of the knee have shown encouraging long-term results.\textsuperscript{32,34,41,51,53,55,56,59,71,73,81} Overall success rates have been reported ranging from 10\% to 95\%, with etiologies that include posttraumatic lesions, osteonecrosis, and OCD. An extensive review of results has been performed recently.\textsuperscript{27,60} Gross and colleagues\textsuperscript{34} found that performing concomitant procedures at the time of osteochondral transplantation had no significant difference with respect to outcome rating or rates of failure. Multiple studies have shown less favorable results with osteochondral allograft use in bipolar reconstruction of the femur and tibia\textsuperscript{32,55,71} as well as the patellofemoral joint.\textsuperscript{57,71} Spak and colleagues\textsuperscript{82} retrospectively reviewed 14 patients younger than 55 years of age treated with fresh osteochondral allografts for patellofemoral arthritis. At an average of 10 years’ follow-up, 8 grafts were in place, 4 for more than 10 years and 2 for more than 5 years. Of the nonsurviving allografts, 3 had survived more than 10 years. Radiographs showed intact allografts with mild or no degenerative changes. Average Knee Society scores also improved, prompting the authors to challenge previous results regarding patellofemoral allografting.

Several studies regarding survivorship of grafts have recently been reported. Gross and colleagues\textsuperscript{36} examined histologic features of 35 fresh osteochondral allograft specimens retrieved at the time of subsequent graft revision, osteotomy, or total knee arthroplasty. Given chondrocyte viability, long-term allograft survival appeared to depend on the stability of host-graft bone interface. In 2007, Jamali and colleagues\textsuperscript{18} and Maury and colleagues\textsuperscript{83} reported chondrocyte stability at 29 and 25 years, respectively.

\section*{COMPlications}

Fortunately, complications such as disease transmission, infection, and immunogenic reaction are rare. Superficial and deep infections must be distinguished on the basis of laboratory markers, physical examination, and joint aspiration. Deep infections necessitate removal of the graft.

Allograft failure may occur both early and late after transplantation. Early failure occurs as a result of chondrocyte death and may be a function of the length and type of storage before transplantation.\textsuperscript{40} Late failures show fracture of the graft, incomplete remodeling of the graft-bone interface, and resorption of the graft tissue by synovial activity at the graft edge.\textsuperscript{36} Graft fragmentation and collapse typically occur in areas of the subchondral bone noted to have limited revascularization. Patients with graft failure often present with new-onset pain or mechanical symptoms.\textsuperscript{27} MRI may be helpful in ruling out other etiologies of postoperative symptoms; however, caution
must be exercised, because normally functioning grafts may also exhibit signal abnormalities. Progression of the disease process or infection may also be the origin of new-onset pain and mechanical symptoms, causing diagnostic confusion. Treatment options for graft failure include observation, bracing, removal of the graft with or without repeat allografting, or conversion to arthroplasty.

SUMMARY

The treatment of osteochondral defects continues to be a difficult problem for both patients and clinicians. As with all treatment options, patients should be made aware of the potential risks and complications associated with the use of osteochondral allografts. Although research and techniques for repair and restoration of articular cartilage continue to develop, osteochondral allografting is currently the only technique capable of restoring mature hyaline cartilage.

REFERENCES


