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Osteochondral allograft

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Abstract Over the past decade, osteochondral allograft transplantation has soared in popularity. Advances in storage techniques have demonstrated improved chondrocyte viability at longer intervals and allowed for potential of increased graft availability. Recent studies have stratified outcomes according to location and etiology of the chondral or osteochondral defect. Unipolar lesions generally have favorable outcomes with promising 10-year survival rates. Though those undergoing osteochondral allograft transplantation often require reoperation, patient satisfaction remains high.

Keywords Osteochondral allograft · Articular cartilage restoration

Background

Articular cartilage lesions involving the knee are common among young, active patients. Chondral lesions are identified in up to 60 to 66 % of those undergoing arthroscopic procedures [1–4]. Furthermore, 5 to 20 % of these lesions are "high-grade" [1–4] with 11 % considered to be "focal" and suitable for a cartilage repair/restoration procedure [1]. Among the reparable lesions, 55 % (or 6 % overall) have defects greater than 2 cm^2 [1].

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Due to the advent of procedures such as autologous chondrocyte implantation and improvements in osteochondral autograft and allograft transplantations, surgical treatment of articular cartilage lesions has become increasingly popular. From the period 2004 through 2011, the number of cartilage restoration procedures increased at an average of 5 % annually in the USA [5]. Osteochondral allograft transplantation has seen the greatest increases in utilization from 660 cases in 2005 to 1619 transplants in 2011 [5].

The growth in osteochondral allograft use can be directly linked to standardization in graft storage. In 1998, the American Association of Tissue Banks collaborated with the US Food and Drug Administration to create standards for refrigeration, storage mediums, and amount of time tissues could be stored before exceeding a threshold of chondrocyte death [6]. These regulations provided the impetus for fresh osteochondral allografts to become commercially available from tissue banks and thus accelerated the more widespread use of these tissues [6].

Due to its versatility, it is not surprising that osteochondral allografts have soared in popularity. While generally indicated for lesions greater than 2 cm^2, osteochondral allografts can be used to treat lesions of all sizes, locations, and contours. Unlike other restoration procedures like autologous cartilage implantation, osteochondral allografts are performed in a single stage and can be used to remedy osteochondral or purely articular surface defects. While outcomes are generally more favorable in monopolar lesions [7•], osteochondral allograft transplantation has been successfully described in the treatment of bipolar lesions [8•]. Given its important position in the landscape of cartilage restoration, the purpose of this review is to report (a) current standards and recent advances in graft storage and implantation; (b) outcome data stratified by location, etiology, and adjuvant surgeries performed; and (c) common complications.

Preparation and storage

The loss of chondrocytes in the articular surface's superficial zone is considered the earliest and most important indicator of cartilage deterioration [9]. Presence of viable chondrocytes is considered important to maintain tissue composition, structure, and function of the implanted graft [10–12]. Therefore, in order to maximize chances of long-term survival of the allograft, storage conditions are manipulated to limit chondrocyte death.

Storage temperature

The accepted standards for osteochondral allograft refrigeration have been established at either −80 °C for "frozen" grafts or 4 °C for "fresh" grafts. Currently, the favored method of osteochondral allograft preparation is fresh technique in which is harvested within 24 h of donor demise and preserved hypothermically at 4 °C. Studies have demonstrated improved cartilage stiffness, increased cartilage cellularity and matrix content, and decreased surface degeneration of fresh versus frozen osteochondral allografts 6 months after implantation [9].

Fresh allografts have the advantage of more consistent chondrocyte viability but have a limited shelf life and limited availability. Williams and associates demonstrated 98.2 % chondrocyte viability up to 8 days following harvest, but with a significant decline after 15 days [13]. By 45 days post-harvest, the usual expiration period for fresh allografts, less than 66 % of chondrocytes are viable [13]. Recently, Laprade and associates reported a slightly less optimistic prognosis for chondrocyte stored at 4 °C: chondrocyte viability decreased dramatically after 14 days, with a threshold of 70 % reached after 28 days [14].

An alternative to fresh grafts, frozen osteochondral allografts have a prolonged maximal storage time and therefore broader graft availability. Under freezing conditions, however, the viability of chondrocytes fluctuates considerably based on protocol, medium, and chance. Cryoprotectants, such as ethylene glycol, dimethyl sulfoxide, or glycerol, are often used in the freezing process to minimize chondrocyte death from frozen water in their extracellular matrix [6]. Of these, dimethyl sulfoxide appears to be the most effective and can facilitate recovery of approximately 15 % of the chondrocyte viability [15]. However, these chemicals may not be distributed equally across the depth of the graft and may cause unequal freezing patterns deep into the graft [15, 16].

Storage of osteochondral allografts at a physiological temperature of 37 °C has been proposed as a means to preserve chondrocyte viability [6, 17]. Using a canine model that used osteochondral allograft stored in a serum-free media, Garrity et al. demonstrated greater than 70 % chondrocyte viability for at least 56 days after harvest [6]. This value represented a twofold increase over accepted fresh techniques. While graft quality measurements, such as glycosaminoglycans and collagen, were maintained, elastic and dynamic moduli were not different from fresh controls stored at 4 °C [6]. Pallante et al. presented equally encouraging results of chondrocyte viability with grafts stored at 37 °C: chondrocyte viability of osteochondral allografts when stored at 37 °C for 28 days measured 80 % at the surface, 65 % in the superficial zone, and 70 % in the middle zone compared to 100, 85, and 95 % chondrocyte viability for time-zero controls, respectively [17]. In the same study, osteochondral allografts preserved for 28 days at 4 °C had surface, superficial zone, and middle zone chondrocyte viabilities of 45, 20, and 35 %, respectively [17].

Storage media

Historically, Ringer's lactate served as the storage medium for osteochondral allograft. While maintaining nearly 100 % chondrocyte viability in the initial period following harvest, allografts stored in lactated Ringer's solution experience marked declines in chondrocyte viability after the first 48 h [18]. The impracticality of transplantation within 48 h combined with the 2-week testing period required by tissue banks to ensure the safety of the graft prompted the search for a medium that allows prolonged storage of the graft.

The two most common current mediums are serum-free media consisting of glucose, salts, and amino acids, and fetal bovine serum containing nutrients and growth factors. Fetal bovine serum media offer the advantage of improved chondrocyte viability. Pennock et al. reported 67 % chondrocyte viability in osteochondral allografts stored in fetal bovine serum medium for 28 days compared to 27.3 % viability in serum-free media over the same time period [19]. Along with providing stimulus for growth and avoiding apoptosis, fetal bovine serum improves glycosaminoglycan content and histologic appearance at 4 °C over 60 days compared to just serum-free media [6]. Despite the improved chondrocyte viability when stored in a fetal bovine medium, there is concern with fetal bovine serum medium due to the variability in solutions and the potential infection risks [19]. Therefore, chemically defined supplements to serum-free media are commonly employed to allow consistent and safe results.

Storage time

In 1993, the US Food and Drug Administration established a Current Good Tissue Practice protocol to minimize the risk of disease transmission of allograft tissue. In addition to stringent screening of donors, osteochondral allografts must be harvested within 24 h of donor death to limit potential for *Clostridium* contamination, stored at 4 °C, and aseptically handled at all times from procurement to implantation [19, 20]. While chondrocyte viability decreases with time starting at graft

procurement, current screening requires a minimum of 14 days to perform the following serologic and microbiologic tests: HIV type 1 and 2 antibody, total antibody to hepatitis B core antigen, hepatitis B surface antigen, HTLV-1/HTLV-2 antibody, hepatitis C antibody, syphilis assay, and HCV and HIV1 with nucleic acid amplification tests [21].

After negative serologic and microbiologic test results, osteochondral allografts should be implanted as rapidly as possible to attenuate chondrocyte viability reductions. However, a study using a goat model demonstrated that, at 1 year following implantation, the chondrocyte viability, histology, equilibrium aggregate modulus, proteoglycan content, or hypotonic swelling of the implanted fresh osteochondral allograft did not differ significantly based on pre-implantation storage time between 1 and 42 days [22]. The current average time from procurement to implantation of an osteochondral allograft is 24 days and ranges from 15 to 43 days [17].

Adjunctive therapy

Recently, in an attempt to enhance chondrocyte viability, investigators have sought to modulate factors that contribute to cell apoptosis. Robertson and associates identified a series of genes up-regulated in prolonged allograft storage [23]. One of these cytokines, tumor necrosis factor-α, is a potent pro-apoptotic cytokine that has a known inhibitor, etanercept. When administered at a daily dose of 10 μg/mL, etanercept has demonstrated significantly improved surface layer chondrocyte viability of osteochondral allografts in a goat model [24]. Despite its efficacy in animal models, etanercept has not been routinely incorporated into clinical practice.

Surgical considerations

Two surgical options, shell and dowel techniques, have been developed to implant osteochondral allografts. Shell techniques involve creation of free-hand osteochondral grafts of various shapes and sizes to match recipient defects. Dowel allografts are prepared by cylindrically coring out the defect and inserting a matched cylindrical dowel into the recipient site using a commercially available series of cutting guides. Due to reproducibility and ease of specimen and defect preparation, dowel techniques have become more popular for common defects such as those involving the central weight-bearing portions of the femoral condyles, trochlea, and patella.

The decision to use a shell or dowel technique depends largely on the appearance and location of the defect. Once the chondral lesion has been accessed using a medial or lateral mini-parapatellar arthrotomy, the borders of the defect are defined using a curette, and the size and geometry of the defect are assessed. Commercially available sizing plugs are placed over the defect to fully incorporate the defect. Dowel techniques are limited by requirements for perpendicular access to the center of the defect and a "well-shouldered" lesion to seat the plug. Therefore, a dowel technique can be used if (a) the defect can be completely surrounded by the plug(s) and maintain a well-shouldered cartilage border, and (b) the plug can be placed perpendicular to the articular surface. In regions such as the posterior femoral condyles, tibia, and edges of the condyles, shell grafts are often required.

While the defect is prepared free-hand when using the shell technique, the dowel technique requires the use of cannulated dowel reamers. The goal of recipient-site preparation is the creation of a perfectly cylindrical void. To begin, a guide wire is inserted perpendicular to the tangent of the articular surface. The reamer is passed over the guide wire and advanced to a healthy, bleeding base of bone, usually measuring a depth of 6 to 12 mm referenced from the normal articular surface. In cases where multiple osteochondral plugs are required to fill the cartilage lesion, a bridge of 1 to 3 mm is left between recipient sites. Attempts should be made to avoid convergence of tunnels when multiple dowels are needed. Recipient sites that converge into each other risk inability to fully seat each graft and/or inadequate press-fit fixation.

Allograft preparation can commence only after the recipient site dimensions have been determined. Using a surgical marker, hash marks are made on the adjacent articular cartilage at the 12-, 3-, 6-, and 9-o'clock positions of defect border. The depth of the defect is measured at each of these four sites and recorded. These measurements serve as a guide to assist in the creation of a dowel allograft plug.

The contour of the allograft articular cartilage must replicate the contour of the surface to be recreated. A medial condyle defect can be restored equally effectively using a medial or lateral hemicondyle allograft [25••]. With the allograft hemicondyle secured in a commercially available holder, a cylindrical dowel is created using a donor reamer passed perpendicular to the tangent of the articular surface. Using the measured depths of the recipient site, the graft is marked at four quadrants of the allograft dowel. These markings serve a guide to cut the graft and ensure correct length of the graft dowel. The osseous portion of the graft is copiously irrigated to minimize allogeneic cells that may contribute to graft-host reaction.

The dowel allograft is positioned with the hash marks aligned and gently tapped into place. Regardless of technique, precise contour matching and gentle handling of the articular surface are important elements contributing to the ultimate success of the procedure. Often times, especially when an osteochondral dowel is used, one of the quadrants of the graft does not match the contour of the recipient surface layer [25••]. This "uneven" edge is usually turned toward the less articulating region such as the border of the notch. Multiple studies have demonstrated that contact pressures on the graft

are maximal when the surface of the allograft is left proud when compared to the recipient articular cartilage surface layer [26, 27].

Most allografts are prepared slightly larger than the corresponding defect to facilitate secure press-fit graft fixation without need for additional instrumentation. However, caution must be taken to avoid excessive impaction force during graft implantation. Pylawka and associates demonstrated that graft impaction during implantation has pressure-related deleterious effects on chondrocyte viability [28]. Fixation should be considered in cases in which (a) dowel allografts are undersized compared to the defect, (b) multiple dowel allografts converge and render one or both of the allografts unstable, and (c) shell allografts are inherently unstable.

Outcomes

Based on location

Femoral condyle

While osteochondral allograft procedures have been described for most regions of the knee, the femoral condyles are the most extensively studied. Table 1 presents results from several published series exclusively devoted to osteochondral allograft transplantation to treat defects of the femoral condyles.

Levy and associates presented the largest retrospective series of patients having undergone osteochondral allograft transplantation to the femoral condyles [29••]. One hundred and twenty-two patients were followed for at least 10 years and outcomes measured using Merle d'Aubigné-Postel, IKDC, and KS-F questionnaires. When failure was defined as removal of the allograft or conversion to arthroplasty, 82 % of the fresh osteochondral grafts survived at 10 years [29••]. The only statistically significant factors which predicted failure were ages greater than 30 years and a history of two or more previous knee surgeries prior to the allograft transplantation [29••]. There was a trend toward higher failure rates in medial versus lateral condylar lesions, but this did not reach statistical significance (p=0.099) [29••].

Tibial plateau

Unlike lesions involving the femoral condyles which tend to be secondary to osteochondritis dissecans or degenerative etiology and are amenable to dowel techniques, chondral damage to the tibial plateau is usually post-traumatic and often must be reconciled with shell-type osteochondral allografts. Only three series are available that report outcomes following treatment of tibial chondral lesions using unipolar osteochondral allografts [35•, 36, 37]. Outcomes of those studies with minimum of a 2-year follow-up are presented in Table 2. Most studies that describe osteochondral allograft for tibial plateau chondral defects include concomitant realignment procedures, meniscal transplants, and/or bipolar osteochondral allografts [35•, 36, 37]. Overall, osteochondral allografts to treat chondral lesions of the tibial plateau provide

Table 1 Studies of osteochondral allograft to treat femoral condyle articular cartilage lesions

Author	Year	No. of subjects	Follow-up	Graft type	Outcome
Levy et al. [29••]	2013	129	13.5 years	Fresh	- 82 % graft survival at 10 years - 66 % graft survival at 20 years - 24 % failed at mean 7.2 years - Merle d'Aubugne-Postel score increased from 12.1 to 16 - IKDC function score increased from 3.4 to 7.2
Laprade et al. [14]	2009	23	3 years	Fresh	- 100 % graft survival - IKDC subjective score improved from 52 to 68.5
Davidson et al. [30]	2007	10	40 months	Fresh	- IKDC subjective score improved from 27 to 79 - Tegner activity level increased from 4.3 to 5.3
Emmerson et al. [31]	2007	65	7.7 years	Fresh	- 85 % graft survival - Merle d'Aubugne-Postel score improved from 13.0 to 16.4 - 86 % satisfaction with results
Aubin et al. [32]	2001	60	10 years	Fresh	- 85 % graft survival at 10 years - 74 % graft survival at 15 years - Mean Hospital for Special Surgery Score 83 points at 10 years
Garrett et al. [33]	1994	17	2–9 years	Fresh	- 94 % graft survival
Marco et al. [34]	1993	15	3.2 years	Fresh, frozen	- 86.6 % graft survival

Table 2 Studies of osteochondral allograft to treat tibial plateau articular cartilage lesions

Author	Year	No. of subjects	Follow-up	Graft type	Outcome
Drexler et al. [35•]	2015	27	13.3 years	Fresh	- 81 % graft survival - 88.9 % (±4.6 %) predicted graft survival at 10 years - 23.8 % (±11.1 %) predicted graft survival at 20 years - Knee Society subjective score improved from 55 to 84 - Knee Society functional score improved from 51 to 71
Shasha et al. [36]	2003	65	12 years	Fresh	- 68 % graft survival - 80 % predicted graft survival at 10 years using Kaplan Meier analysis - 46 % predicted graft survival at 20 years using Kaplan Meier analysis - Hospital for Special Surgery scores improved to 85

significant functional improvement for 10 years; however, less than 50 % are expected to survive 20 years [35•, 36].

Patellofemoral

Table 3 reports outcomes of selected series of osteochondral allografts used to treat chondral lesions affecting the patellofemoral joint. Generally, outcomes following osteochondral allografts used to treat chondral injury of the patellofemoral joint are not as successful as outcomes seen to treat similar lesions in the femoral condyles [40]. Most studies report 10-year graft survival rates around 70 %, which is lower than other anatomic regions [38••, 39, 40]. Many of the patients described in these series had lesions of both the patella and trochlea, which were addressed with bipolar grafts [39, 40]. In addition, the less successful outcomes may be due to complex interplay of forces and the geometry of the articular surfaces or the tendency of those undergoing osteochondral allografts in the patellofemoral joint to have more pre-existing degenerative changes throughout the knee joint [40]. Most authors advocate realignment and/or unloading procedures before or at the time of osteochondral allograft procedure to enhance outcomes [39–41].

Bipolar grafts

One of the most consistent themes among studies assessing outcomes following osteochondral allograft is that bipolar transplantation has much higher revision and failure rates than unipolar transplants [7•]. A variety of factors, such as increased immunogenic response [42], resorption of larger grafts [43], mechanical overload of grafts [44], and worsened pre-operative arthritis in other compartments, likely contribute to the increased failure rate with bipolar grafts.

A recent study reported results of knee bipolar osteochondral allografts exclusively [8•]. Similar to other

Table 3 Studies of osteochondral allograft to treat patellofemoral articular cartilage lesions

Author	Year	No. of subjects	Follow-up	Graft type	Outcome
Gracitelli et al. [38••]	2015	27	9.7 years	Fresh	- 78 % graft survival at 5 and 10 years - 55.8 % graft survival at 15 years - 89 % satisfaction with results
Torga Spak et al. [39]	2006	14	10 years	Fresh	- 71.4 % graft survival at 10 years - Knee Society subjective score improved from 46 to 82 - Knee Society functional score improved from 30 to 75 - Lysholm scores improved from 27 to 80
Jamali et al. [40]	2005	20	7.8 years	Fresh	- 75 % graft survival - 67 % (±25 %) predicted graft survival at 10 years using Kaplan Meier analysis - 88 % satisfaction with results - Merle d'Aubugne-Postel score increased from 11.7 to 16.3

studies that contained bipolar osteochondral allograft transplants, graft survivorship diminished to 64.1 and 39 % at 5- and 10-year follow-up intervals, respectively [8•]. These values are decreased compared to reported survival rates of unipolar transplants. Not all those with bipolar osteochondral allografts did poorly: in the surviving grafts, 96 % of patients had improved function, 92 % noted reduced pain, and 88 % were extremely satisfied or satisfied with the procedure [8•]. The use of osteochondral allografts to remedy bipolar lesions and arthritis remains controversial [7•, 8•].

Effects of adjuvant procedures

Osteotomy

Mechanical overload of osteochondral allograft during the healing phase is thought to be a contributor to graft failure [44]. To minimize the forces on the graft, combined realignment osteotomy have been suggested to correct underlying malalignment at or before time of osteochondral allograft transplantation [45]. Few studies are available to determine if the theoretical benefits of realignment manifest into improved clinical outcome. Despite lack of control groups, two recent studies have documented favorable outcomes following combined osteochondral allograft transplantation combined with lateral distal femur osteotomy to correct genu valgum [35•, 46•]. The outcomes following these combined procedures tend to deteriorate from 71 to 24 % survival at 15 and 20 years post-operatively, respectively [35•].

Meniscal transplantation

Many with osteochondral defects have co-existing meniscal pathology. Because of poor outcomes, articular cartilage damage was historically a contraindication to meniscal transplant [47•]. However, several studies have reported acceptable results following combined meniscal transplantation and cartilage restoration [48••, 49]. Most series exploring outcomes following combined meniscal transplant and cartilage restoration include a myriad of techniques, including osteochondral autografts and allografts, microfracture, and autologous cartilage implantation [49]. Although these combined procedures ultimately improve symptoms in majority of cases, 50 % require additional surgery. In 85 %, revision surgery was secondary to meniscal pathology [49].

Getgood and associates reported on the only series to present outcome data containing only those undergoing osteochondral allografts with meniscal transplants [48••]. In this series, 48 patients were followed for an average of 6.8 years (range, 1.7 to 17.1 years) [48••]. Despite 50 % having undergone bipolar osteochondral allograft transplants, only eleven patients (22.9 %) had graft failures requiring graft removal or revision [48••]. The mean time to failure was 3.2 years and the 10-year survival was 68 % for osteochondral allografts [48••]. Fifty-four percent of patients did have a subsequent knee arthroscopy [48••].

Revision osteochondral allografts

When osteochondral allografts fail, there remain two options, revision osteochondral allograft or conversion to a prosthetic arthroplasty. A correctable mode of allograft failure such as malalignment, lack of progression of cartilage disease in adjacent regions, acute traumatic injury causing failure, desire to avoid prosthetic arthroplasty, and/or clinical variables such as younger age, high-demand activity level, and body-mass index less than 35 [29••] may favor using a biologic approach and osteochondral allograft. Unfortunately, there is a paucity of data on the survivorship and clinical improvement of revision osteochondral allografts to guide surgeons and patients.

Horton and associates reported the mean time frame of a revision from time of primary allograft was 35 months (range, 6–145 months) [50••]. When comparing revision allografts to primary allografts, it has been shown that revision allografts have a higher reoperation and failure and only a 61 % survivorship [50••]. However, when comparing clinical outcomes (pain, function, satisfaction) of primary versus revision allografts, these appeared to be comparable [50••]. These results may be slightly skewed in that the patient opting for a revision allograft versus conversion to arthroplasty were motivated patients who were trying to avoid arthroplasty and typically had good outcomes initially with the primary allograft [50••]. More research is needed to assess long-term results of revision allografts. At a mean 10-year follow-up, there was a 39 % rate of failure and a 67 % rate of reoperation; however, those patients with surviving grafts reported good and excellent outcomes [50••].

Etiology

Osteonecrosis

While arthroplasty is typically successful in treating osteonecrosis [51], it may not be the best option for the young (younger than 50 years) and active population due to concerns regarding implant durability [52]. Osteochondral allografts have been found to be an alternative to arthroplasty. Compared to other types of cartilage restoration such as autologous chondrocyte implantation (ACI), osteochondral allografts have the theoretical advantage of addressing the osseous and chondral components concomitantly by replacing the juxaarticular necrotic lesions with a structural graft [52]. Opponents to osteochondral allograft for treatment of osteonecrosis cite two limitations: (a) potential impaired healing of the underlying bone, (b) lesions often involve multiple condyles [51].

For maximal benefit of osteochondral allografts, steroid use must be discontinued or the underlying disease causing the osteonecrosis must be resolved or in remission. When these conditions are not met, Bayne and associates found that all those in their study had poor revascularization of the allograft and suffered late collapse despite initial success between 6 and 18 months [53]. In particular, Gortz et al. theorized that steroid use interferes with the revascularization of the osseous portion of the allograft and thus contributes to eventual collapse [52].

If steroid use is avoided and the underlying disease process is not active, favorable outcomes can be expected when osteochondral allografts are used to treat osteonecrotic lesions. Gortz et al. [52] reported that 96 % avoid arthroplasty at an early age; only 18 % required additional surgery and 4 % had allograft failure [52]. Stable fixation, removal and supplemental grafting of deep necrotic lesions, and protected weight-bearing are important concepts to facilitate graft incorporation in this potentially unfavorable environment [52]. While osteochondral allografts have shown promise in treating osteonecrosis, a recent review paper found that, when compared to other causes of osteochondral lesions, osteonecrotic lesions had less favorable outcomes [54•].

Osteochondritis dissecans

Though other types of cartilage restoration procedures, such as microfracture, osteochondral autograft transfer, and autologous chondrocyte implantation, have been described as options for treating osteochondritis dissecans (OCD) defects [31], osteochondral allografts have become the favored treatment of choice [29••, 31]. Unlike the other options, osteochondral allografts have the unique potential to reconstruct large defects of the subchondral bone.

Emmerson et al. [31] presented the largest series of OCD lesions treated exclusively with osteochondral allografts. In this retrospective study with a mean age of 28.6 years (range, 15 to 54 years), 72 % of subjects reported good to excellent outcomes at a mean of 7.7 years post-operatively [31]. Graft survival was 91 % at 5 years and 75 % at both 10 and 15 years post-operatively [31]. Radiographs also demonstrated 72 % incorporated and 79 % intact at 3.3 years post-primary transplant [31]. When assessing patient satisfaction and clinical outcomes, knee function improved from a mean of 3.4 to 8.4 on a 10-point scale [31].

Osteoarthritis

Because of worse outcomes with bipolar lesions in older patients (age greater than 50 years), osteochondral allografts are typically contraindicated for advanced osteoarthritis [29••, 31]. Giannini et al. reported six of seven patients that had osteochondral allograft transplantation for osteoarthritis underwent conversion to total knee arthroplasty within 2 years [7•].

Overall, the results, defined as a lack of progression to arthroplasty and/or repeat osteochondral transplantations and improved postoperative knee scores, have been promising at up to 10 years [29••, 32, 35•, 36, 38••, 39]. Patient satisfaction has also been uniformly high, even in medium- and long-term follow-up [31, 38••, 40].

Unfortunately, the studies reporting outcomes following osteochondral allograft procedures are hindered by significant limitations. First, few studies report follow-up beyond 10 years and most lack stratification of the patients' diagnosis and indication for osteochondral allograft. Second, nearly all studies of osteochondral allograft procedures have been level IV or V evidence. To date, no large randomized, controlled studies have been published comparing osteochondral allografts to other methods of cartilage restoration. Third, there is no uniformity in scoring systems used to report outcomes. Furthermore, the Merle d'Aubigné-Postel knee scoring system used by many of the investigations involving osteochondral allografts has yet to be scientifically validated.

Return to athletic activity

There is limited data documenting return to athletics following osteochondral allograft transplantation. Krych et al. reported on a series of 43 athletes with an average age of 32.9 years (range, 18–49) [55]. At an average of 2.5-year follow-up, 79 % of athletes fully returned to pre-injury activity levels, while another 9 % returned to sports but with limitations [55]. Athletes returned to sports at an average of 9.6 months post-operatively [55]. Age greater than 25 years and preoperative duration of symptoms greater 12 months predicted a lower likelihood to return to athletics [55].

Complications

Failure of the osteochondral allografts has been linked to age at time of primary allograft, number of previous surgeries, size of defects, and bicondylar involvement. Patients who were 30 years or older at the time of surgery suffer graft failure 3.5 times more often than younger patients [29••]. Similarly, those who underwent two or more previous surgeries in the operative knee were 2.8 times more likely to have failure of the allograft [29••]. A major benefit of osteochondral allografting is that failure does not preclude other reconstructive procedures, such as a second graft procedure or arthroplasty [48••].

One of the most common causes of graft failure is lack of incorporation. Potential signs of failed incorporation include sclerosis, narrowing or obliteration of the joint space, and the

formation of osteophytes [56]. While not a sign of poor graft incorporation, subchondral cyst formation is another sign of graft failure.

Immunogenic causes of complications are considered rare. In histopathologic analysis of failed osteoarticular allografts, there has been no overt evidence of transplant rejection [54•, 57]. Theoretically, the thick matrix polysaccharides of the hyaline cartilage prevent exposure of the graft chondrocytes to the tissue and fluids of the host [41]. To further limit potential immunogenicity, allografts are copiously lavaged to remove residual bone marrow elements [29••]. Articular cartilage and subchondral bone are thought to be immune-privileged, and no anti-immunogenic drugs are required [58]. Instead of donor matching based on ABO blood type, donors and recipients are matched based on anatomical dimensions using radiographs [29••].

Disease transmission remains a potential complication associated with osteochondral allografts. However, with modern screening practices, including a minimum 14-day waiting period to allow for serologic and microbiologic testing, the risk of catastrophic disease transmission has been minimized.

Conclusions

Osteochondral allograft transplantation has become an increasingly popular method to reconcile chondral and osteochondral defects. Standardization of storage techniques has improved graft availability and allowed for improved chondrocyte viability for up to 40 days. Recent studies have explored options that have shown promise in improving graft viability by exposing the graft to various chemical agents and altering storage temperatures or by exposing the host to immunomodulating agents. Though outcomes vary significantly based upon defect location, etiology, and concomitant maladies (malalignment, meniscal deficiency), osteochondral allograft transplantation produces the best outcomes when the defect is isolated, caused by a traumatic etiology, and occurs in a patient younger than 30 years.

Compliance with ethics guidelines

Conflict of interest Dr. Torrie, Dr. Kesler, and Dr. Elkin have not received (or agreed to receive) from a commercial entity something of value (exceeding the equivalent of US$500) related in any way to this manuscript.

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•• Of major importance

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