Return to Play Among Elite Basketball Players After Osteochondral Allograft Transplantation of Full-Thickness Cartilage Lesions

George C. Balazs,*† MD, Dean Wang,† MD, Alissa J. Burge,‡ MD, Alec L. Sinatro,† BA, Alexandra C. Wong,† BS, and Riley J. Williams III,† MD

Investigation performed at Hospital for Special Surgery, New York, New York, USA

Background: Osteochondral allograft transplantation (OCA) is a recognized option for full-thickness articular cartilage defects of the knee, especially in the setting of large lesions or those involving the subchondral bone. Previous heterogenous studies of athletes have shown a 75% to 79% rate of return to play after the procedure.

Purpose: To define return-to-play rates in a cohort of elite collegiate and professional basketball players following osteochondral allograft of the knee.

Study Design: Case series; Level of evidence, 4.

Methods: Prospectively collected data from an institutional cartilage repair registry were retrospectively reviewed. Patients were eligible for inclusion if they were collegiate or professional basketball players at the time of surgery. Patient demographics, lesion size and location, and surgical details were collected. Postoperative magnetic resonance imaging scans were scored with the OCAMRISS system. Time to return to play and pre- versus postoperative player performance were determined with publicly available internet resources.

Results: Eleven athletes (4 professional, 7 collegiate) with a total of 14 treated lesions (1 to the medial femoral condyle, 6 to the lateral femoral condyle, 5 to the trochlea, and 2 to the patella) were eligible for study inclusion. Mean lesion size was 509 mm^2. All patients underwent OCA through an arthrotomy, with fresh grafts. The overall rate of return to play at the same level of competition was 80%. Median time to return to play was 14 months (range, 6-26 months). Among players with available statistics, there was no significant reduction in any performance category.

Conclusion: OCA in elite basketball players results in an 80% return to previous level of competition, which is consistent with previous reports of athletes playing other sports. Osteochondral allografting is a reasonable option to consider for full-thickness cartilage lesions of the knee, even for elite jumping athletes.

Keywords: osteochondral allograft transplantation; knee; return to sport basketball

*Address correspondence to George C. Balazs, MD, Sports Medicine and Shoulder Service, Hospital for Special Surgery, 535 E 70th Street, New York, NY 10021, USA (email: gcbalazs@gmail.com).

†Sports Medicine and Shoulder Service, Hospital for Special Surgery, New York, New York, USA.

‡Department of Radiology, Hospital for Special Surgery, New York, New York, USA.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution.

Ethical approval for this study was obtained from the Hospital for Special Surgery.

Injury to the articular cartilage of the knee may result in persistent pain, swelling, and activity limitation among young active individuals,[29] and it may increase the likelihood of developing earlier osteoarthritis over time.[9] Multiple treatment modalities have shown efficacy in reducing symptoms, including microfracture, various autologous cartilage transplantation procedures, and autograft or allograft osteochondral transplantation. With the exception of microfracture, all techniques have demonstrated similar outcomes in the setting of small, constrained chondral lesions,[11] however only osteochondral allograft transplantation (OCA) has been consistently shown to be appropriate for large lesions or lesions where disease extends into the subchondral or metaphyseal bone.[12]

The benefits of OCA in the treatment of young patients are increasingly recognized. The number of OCA procedures performed in the United States nearly tripled between 2005 and 2011,[28] even as the total number of cartilage procedures remained relatively stable.[31] Even when performed among higher-demand adolescent and young adult athletes, the majority of patients will experience an excellent clinical result.[14,37] Among athletes, reported rates of return to play are between 75% and 79%.[22,26,33] In all cases, however, series addressing return to play contain a mixture of high school, collegiate, and professional athletes in a variety of sports. The stresses placed on an osteochondral allograft presumably differ markedly between sports that require frequent jumping and pivoting and those that do not. Estimates of articular cartilage injuries vary considerably depending on the sport, with approximately one-third of distance runners having a chondral lesion[40] in contrast to the 61% of players at the National Football League Combine[40] and 81% of National Collegiate Athletic Association (NCAA) basketball players[35] demonstrating magnetic resonance imaging (MRI) evidence of the same.

Basketball places a very high demand on articular knee cartilage because of the need for constant pivoting and jumping,[21] and cartilage injuries are ubiquitous among high-level basketball players. MRI studies of asymptomatic collegiate and professional basketball players found incidence of chondral injuries in 81% and 50%, respectively.[35,41] Prior studies of microfracture among high-level basketball players have shown generally disappointing results.[5,17,32] Thus, OCA potentially represents a superior solution in this subpopulation, since it provides inherent bony support as the extracellular matrix surrounding transplanted chondrocytes integrates with the surrounding articular surface. The question remains whether the transplanted bone is capable of absorbing the repetitive loads required of a jumping athlete without collapse and/or fragmentation. While prior series have reported on the results of osteochondral allografting in basketball players, these are typically contained in larger series of "athletes," making the precise results of these high-risk individuals difficult to discern.

This study reports the results of OCA for large chondral defects of the knee among collegiate and professional basketball players. Rates of return to play are reported, as are rates of failure and reoperation. We hypothesized that OCA in this unique population would have substantially higher complications and lower rates of return to play when compared with prior series.

METHODS

Since 1999, the senior author (R.J.W.) has maintained a prospective registry tracking patients undergoing articular cartilage restoration procedures. This registry was approved by our institutional review board, and all patients enrolled signed informed consent forms agreeing for their data to be utilized for research purposes. Enrolled patients were evaluated preoperatively and were observed for up to 10 years postoperatively.

Patient Identification and Data Collection

We performed a search of the registry for all patients undergoing fresh OCA for an articular cartilage lesion of the knee who indicated that they played basketball. Electronic medical records and publicly available data sources were then screened to determine the patient's level of play: NCAA Division I, II, or III; National Basketball Association (NBA) G League; or NBA. Patients were included if they competed in at least 10 basketball games at the collegiate or professional level and had at least 1 year of clinical follow-up. All patients were included in analysis of demographic details, complication rate, and failure rate. To be included in analysis of return-to-play rates and postoperative player statistics, patients had to be eligible to return to their previous levels of play (eg, not graduating from college before the start of the next season).

Following identification of the study cohort, medical records were searched for demographic/clinical and injury details, surgical records for procedure details and concomitant intra-articular pathology, and our institutional radiology picture archiving and communication system (PACS) for pre- and postoperative imaging findings. Follow-up MRI scans were obtained with a previously published protocol[20] and scored by a board-certified radiologist with subspecialty training in musculoskeletal radiology using the Osteochondral Allograft MRI Scoring System (OCAMRISS) developed by Chang et al.[8] Additionally, publicly available websites were searched to determine patients' time to return to play and individual productivity statistics, including minutes played, points, rebounds, steals, assists, and blocks per game.

For purposes of this study, time to return to play was defined as the time from surgery to the first preseason or regular season game in which an athlete participated following surgery. Failure was defined as any reoperation requiring removal of the allograft or conversion to arthroplasty. Lesion size was determined by the surgeon's intraoperative measurements.

Surgical Indications and Technique

All surgical procedures were performed by the senior author. The indications for osteochondral allografting in this population were based on the clinical judgment of the senior author, depending on the nature and size of the symptomatic chondral lesion. In general, patients were eligible for osteochondral allografting if the lesion was full thickness and >2 cm^2 in size and had proved refractory to nonoperative measures, such as periods of rest, rehabilitation, and intra-articular injections (platelet-rich plasma, hyaluronic acid, etc).

Following examination under anesthesia, initial diagnostic arthroscopy of the knee was performed to assess the chondral lesion, as well as the other articular surfaces, menisci, and ligaments. Following arthroscopy, OCA was performed with the dowel technique as described by Williams et al.[44] Lesions of the condyles or trochlea were exposed with a small medial or lateral parapatellar

arthrotomy as appropriate. Patellar lesions were exposed with a longer medial parapatellar arthroscopy and eversion of the patellar surface. Lesions were then sized and reamed to a bed of normal bone. A sized and contoured graft was next taken from a hemicondyle allograft, or an appropriately sized fresh allograft dowel was obtained. Fresh cold-stored osteochondral allografts were obtained from commercial sources. Donor tissue was screened and processed according to standards of the American Association of Tissue Banks.[25] Grafts were transplanted between 16 and 30 days after harvest, depending on serologic testing and patient availability.

Lesion depth was carefully measured at 4 points around the lesion, marked, and matched on the donor tissue. For select patients, depending on surgeon preference, grafts were soaked in bone marrow aspirate concentrate obtained percutaneously from the ipsilateral iliac crest for 15 minutes before implantation. Grafts were then impacted into place to achieve press-fit fixation. No supplemental fixation was required for any graft in this series.

Postoperatively, patients were limited to touchdown or nonweightbearing for a minimum of 1 to 2 weeks, with progressively increasing weightbearing thereafter. Range of motion was permitted and encouraged immediately without restriction. Unsupported weightbearing without a brace was permitted once patients demonstrated normal gait. All patients participated in a supervised physical therapy program, with the duration dependent on the restoration of normal gait, return of quadriceps function, and performance of sport-specific skills. All patients were restricted from running and pivoting until 6 months postoperatively; otherwise, no temporal restrictions were placed on patients' progression through rehabilitation. Postoperative rehabilitation did not change according to the size, location, or depth of the osteochondral lesions. Formal quantitative movement assessments were performed at 6 months and 1 year postoperatively to identify any residual strength or motion deficits.

The return to higher-level activities and athletics was initiated on an individual patient basis in coordination with team training staff and typically depended on a return of lower extremity strength and mobility. Return to unrestricted play was a multifactorial decision that considered the patient's progress in rehabilitation, the results of movement assessments, any residual symptoms, coaching/player/training staff assessments of performance, and objective clinical evaluation.

Statistical Analysis

Demographic and injury details are reported descriptively. Pre- and postoperative player statistics were compared only in cases where the athlete returned to the same level of play in which she or he competed before surgery. Given the relatively small size of the cohort, demographic and injury factors predicting return to play could not be calculated. Differences in pre- and postoperative player statistics were analyzed with nonparametric testing (Wilcoxon matched-pairs test).

TABLE 1
Demographic Summary of Included Patients[a]

	Mean (Range) or n (%)
Age, y	22.8 (19-29)
Sex	
Male	9 (82)
Female	2 (18)
Height, inches [cm]	76.9 (67-82) [195 (170-208)]
Weight, lb [kg]	211 (121-255) [95.7 (54.9-115.7)]
Body mass index	24.8 (18.9-28.5)
Position	
Center	1 (10)
Guard	5 (45)
Forward	5 (45)
Level of play	
NBA	4 (36)
NCAA	7 (64)

[a]NBA, National Basketball Association; NCAA, National Collegiate Athletic Association.

RESULTS

A total of 11 patients with 14 treated chondral lesions were identified. Nine patients had single lesions treated, and 2 patients had multiple lesions addressed simultaneously: 1 patient with lesions of the lateral femoral condyle and trochlea and 1 patient with lesions of the medial trochlea, lateral trochlea, and patella. Mean patient age was 22.8 years, and 82% of patients were male. Table 1 summarizes the demographic data for the cohort.

Clinical/Injury Details

Treated lesions were large, with a mean size of 509 mm^2. All lesions were >4 cm^2, except for 1 lesion (100 mm^2) in a patient undergoing treatment of 2 lesions simultaneously, where the second lesion was 625 mm^2. In this patient, the decision was made to proceed with allografting rather than autografting, given the ready availability of allograft and a desire to limit further trauma to the knee.

Lesions of the lateral femoral condyle were most prevalent (43%), followed by trochlear lesions (36%). Seven patients (64%) had undergone at least 1 prior knee procedure, most of which were arthroscopic chondroplasties and/or partial meniscectomies. The majority of patients (73%) did not have any procedures concurrent with the OCA, with the remainder undergoing partial lateral meniscectomy at the time of arthroscopy. Table 2 summarizes additional injury details.

Preoperatively, all patients achieved full extension as compared with the contralateral knee, and all had a normal arc of motion (mean, 141°; range, 140°-145°). Two patients had a preoperative effusion (all graded as trace or 1+). Postoperatively, all patients achieved full extension and a functional arc of motion (mean, 138°; range, 135°-145°) at the time that they returned to sport-specific training. Three patients had a residual effusion when they returned to sport-specific training (graded as trace or 1+).

TABLE 2
Surgical Details and Complications of Treated Lesions

	Mean (Range) or n (%)
Lesion size, mm^2	509 (100-625)
Previous knee surgical procedures	1 (0-2)
Previous knee cartilage surgical procedures	0.7 (0-2)
Lesion location (n = 14)	
Medial femoral condyle	1 (7)
Lateral femoral condyle	6 (43)
Trochlea	5 (36)
Patella	2 (14)
Concurrent knee procedures (n = 11)	
Partial lateral meniscectomy	3 (27)
None	8 (73)
Complications (n = 6)	
Persistent synovitis	2 (32)
Postoperative hematoma	1 (17)
Stiffness requiring manipulation	1 (17)
Graft failure	1 (17)
Septic joint	1 (17)
Reoperations (n = 7)	
Arthroscopic debridement	2 (29)
Manipulation under anesthesia	1 (14)
Irrigation and debridement	3 (43)
Revision	1 (14)

TABLE 3
Return to Play and Player Productivity Following
Osteochondral Allograft Transplantation

	Preoperative	Postoperative
Previous level of play, n		
Returned		8
Did not return		2
Ineligible to return		1
Median (range)		
Seasons played	2 (1-7)	1.5 (1-2)
Games played	63 (28-433)	24 (9-62)
Mean (range) per game		
Minutes	23.8 (9.1-33.4)	15.1 (5.1-24.7)
Points	9.9 (2.5-20)	5.3 (2.2-10.3)
Rebounds	3.9 (1.6-7.2)	2.2 (1.3-3.4)
Assists	2.2 (0.3-5.3)	1.2 (0.1-3.1)
Steals	1.0 (0.1-2.0)	0.5 (0-0.9)
Blocks	0.4 (0.1-0.8)	0.1 (0-0.5)

Return to Play

The overall return to play rate was 80%. Of the 10 players eligible to return to their previous levels of play, 8 did so at a median of 14 months postoperatively (range, 6-26 months). One collegiate athlete underwent surgery after her senior season and was ineligible to return.

Three of the 4 NBA athletes (75%) returned to play at a median 20 months after surgery (range, 10-26 months). The remaining NBA athlete was cleared to return to play but remained an unsigned free agent.

Of the 6 collegiate athletes eligible to return to play, 5 (83%) did so at a median 8 months after surgery.

Player Productivity

Among the 8 players returning to play at the same level, 6 had publicly available pre- and postoperative productivity statistics available. The 2 players without available productivity numbers were Division III NCAA players.

There was a general trend toward decreasing productivity in all domains following return from surgery. However, these differences did not reach statistical significance on Wilcoxon matched-pairs testing. Table 3 summarizes pre- and postoperative player productivity.

Complications and Reoperations

The overall complication rate in this cohort was 36%, and the major complication rate was 18%. There were 6 complications among 4 patients, with 2 patients experiencing 2 complications each. Four complications were considered minor: 2 cases of synovitis requiring arthroscopic debridement, 1 case of stiffness requiring manipulation under anesthesia, and 1 case of postoperative hematoma requiring surgical evacuation.

There were 2 major complications. One patient experienced graft failure with delamination of the osteochondral allograft. He underwent revision to a freeze-dried osteochondral allograft (ChondroFix; Arthrex). He was able to return to play 26 months after the index procedure. A second patient experienced septic arthritis following arthroscopic debridement for persistent synovitis. Following multiple irrigation and debridement procedures, he was able to return to play 20 months after index surgery.

Among the 4 patients experiencing a complication, 3 returned to play, while the fourth was ineligible to return to play, as she underwent surgery following her senior season.

Imaging Follow-up

Ten patients underwent follow-up MRI at a mean 10.7 months after surgery. Among the 8 patients who returned to play, 3 had MRI performed after they had already returned to sport (mean, 3 months after to return to sport), while 5 had MRI performed after to their return (mean, 6 months before return to sport).

Thirteen grafts were assessed in 10 patients on follow-up MRI. The mean postoperative OCAMRISS score was 9.5 (range, 5-17; SD, 3.5). Three grafts (23%) showed complete osseous integration, while the remainder had a residual discernable cleft present, indicating lack of complete osseous healing. Three grafts (23%) showed complete graft integration with the surrounding native cartilage, while the remainder had evidence of incomplete incorporation. Of the 13 grafts, 11 (85%) had continued evidence of subchondral marrow edema, and 10 (77%) had no evidence of cystic change at the graft-host bony interface.

No correlation was identified between OCAMRISS score and failure or ability to return to play.

DISCUSSION

The most important finding of this study is that return-to-play rates among collegiate and professional basketball players after OCA of the knee equal or exceed previous rates among lower-level and nonjumping athletes. The overall return-to-play rate at the same level of competition was 80%. However, complications and reoperations were not infrequent.

OCA as a treatment for chondral injuries is growing in popularity.[28] This technique is particularly suited for large or unconstrained lesions where autologous chondrocyte implantation (ACI) and other related procedures are not indicated. Additionally, the osseous component of the allograft allows replacement of diseased subchondral bone, providing restoration of the articular contour and potentially reducing pain generated from edematous bone. It also avoids the potential of donor site morbidity seen with autograft harvest. The procedure does have drawbacks, including the high cost of allograft, a limited period in which it may be implanted, and the theoretical risk of disease transmission.[12] Historical concerns about laterality matching have recently been shown to be unfounded, which may increase the number of available grafts in the future.[42] OCA has shown excellent clinical results throughout the knee in a variety of patient populations.[2,6,10,37,43]

For young athletic patients seeking a return to high-level sporting activity, OCA has proved highly successful. In a meta-analysis by Campbell et al,[4] the return-to-play rate of OCA was exceeded only by that of osteochondral autograft transplantation. Reported return-to-play rates of OCA appear superior to those of ACI and related procedures. The previous gold standard in the treatment of chondral lesions—microfracture—was shown to be inferior to osteochondral autografting[15,16,39] and, likely, ACI procedures[38]; it resulted in reduced performance among professional basketball players[5,32]; and it has a substantial drop-off in clinical benefits beyond the short term.[13]

While these results are promising, questions remain about the appropriateness of osteochondral allografting in elite jumping athletes. Kinematic analysis of the knee joint has demonstrated that the highest peak loads across the articular cartilage occur during landing from a jump with the knee in the fully extended position.[23,36] This force is substantially higher than in the flexed position, during which controlled eccentric flexion distributes some of the applied load, protecting the articular cartilage and intra-articular structures. The femoral cartilage absorbs the highest load and is therefore at highest risk for chondral injury during landing with the knee extended. In contrast, substantially increased contact pressures are seen in the patellofemoral joint with jump takeoff, during which forceful contraction of the extensor mechanism may produce forces well in excess of that needed to fissure or lacerate articular cartilage.[18] Among elite basketball players, who perform a mean of 19 maximal-force jumps per game,[21] this places substantial and repetitive force on the hyaline cartilage of the knee joint, predisposing it to chondral injuries. Imaging studies of asymptomatic basketball players have shown that the majority have evidence of chondral injury,

ranging from signal abnormalities on MRI to frank full-thickness lesions.[35,41] Repetitive, maximal force jumping also theoretically increases the risk of graft collapse and clinical failure, since allografts may not fully incorporate until 12 months after surgery.[27]

Prior reports of return to play following OCA provide only limited support for its use in elite basketball players. McCarthy et al[26] recently reported a same-level return-to-play rate of 54% among high school and collegiate athletes identified as participating at a high level. When adjusted for patients ineligible to return to play because of graduation, the overall rate was 77%. However, only 4 of their 13 patients participated in jumping sports (1 patient each played basketball, volleyball, and cheerleading). The majority played football and soccer, including 1 equestrian. Additionally, no specification was given on how or why the 9 high school athletes were categorized as "unequivocally high level."

Nielsen et al[33] found an overall return-to-play rate after OCA of 75.2% among patients self-identifying as participating in sports or recreational activities. Sports included canoeing, kayaking, bicycling, and other athletic activities that do not place high demands on the knee. No results were presented for different levels of participation or individual sports, nor did the authors report time to return to sport. Krych et al[22] reported an 88% return-to-play rate (79% at previous level) among self-identified athletes. As with Nielsen et al,[33] there was apparently no independent corroboration of athletic participation. The majority of these athletes (74%) participated at the recreational level, and no separate results were provided for return-to-play rates among different levels of play. The authors did find that patients who failed to return to play were less likely to engage in regular participation preoperatively, as measured by the Cincinnati sports activity scale. This factor may account for the discrepancy between their time to return to play (9.6 months) and ours (20 months).

This series reaffirms these prior results for elite jumping athletes, demonstrating an overall 80% return-to-play rate at preinjury levels of competition following OCA of the knee among collegiate and professional basketball players. This rate is comparable with that of previous studies, despite our unequivocally higher-demand cohort. Our overall complication rate of 36% and major complication rate of 18% are also in line with larger published series.

The first major limitations of this study are its relatively small number of patients and its retrospective nature. This is likely unavoidable, given the relatively small number of truly elite athletes playing collegiate and professional basketball. Furthermore, while we identified only 11 elite basketball players for this series, it compares favorably with the 1 previous series of elite athletes undergoing OCA, which identified 13 athletes from a range of jumping and nonjumping sports.[33] To confirm our results, we recommend a collaborative series that is based on NBA athletes who have undergone OCA and that utilizes existing NBA player-profile and injury-tracking databases.

A second limitation is that we lacked patient-reported outcome measures (PROs) for our study cohort. While our registry is intended to track PROs, this subset of patients

was generally unwilling or unable to participate in follow-up assessments of PROs. Thus, while we can conclude that most patients were able to return to preinjury levels of play, we cannot assess the degree to which they continued to experience symptoms in their knees. However, we believe that the ability to return to play and player performance measures are major considerations for elite athletes contemplating this procedure. These are the most common questions that we receive when proposing osteochondral allografting to appropriately indicated patients. This methodology proved useful in a number of recent studies of elite athletes for various conditions.[1,3,7,19,24,34] We believe that the data presented here will be of interest to team physicians caring for collegiate and professional basketball players.

A third limitation is that given our small cohort size, we were unable to analyze factors predicting successful return to play or player performance. While unfortunate, this scenario is relatively common in studies of elite athletes, where overall cohort sizes tend to be small. Previous studies of cartilage repair in elite athletes suffered from similar methodologic weaknesses.[5,17,30]

In spite of these limitations, we believe that this series should provide support for the use of OCA as a means to return elite basketball players to the court following full-thickness chondral injuries.

REFERENCES

1. Arundale AJH, Silvers-Granelli HJ, Snyder-Mackler L. Career length and injury incidence after anterior cruciate ligament reconstruction in Major League Soccer players. *Orthop J Sports Med*. 2018;6(1):2325967117750825.
2. Assenmacher AT, Pareek A, Reardon PJ, Macalena JA, Stuart MJ, Krych AJ. Long-term outcomes after osteochondral allograft: a systematic review at long-term follow-up of 12.3 years. *Arthroscopy*. 2016;32(10):2160-2168.
3. Begly JP, Guss MS, Wolfson TS, Mahure SA, Rokito AS, Jazrawi LM. Performance outcomes after medial ulnar collateral ligament reconstruction in Major League Baseball positional players. *J Shoulder Elbow Surg*. 2018;27(2):282-290.
4. Campbell AB, Pineda M, Harris JD, Flanigan DC. Return to sport after articular cartilage repair in athletes' knees: a systematic review. *Arthroscopy*. 2016;32(4):651-668.
5. Cerynik DL, Lewullis GE, Joves BC, Palmer MP, Tom JA. Outcomes of microfracture in professional basketball players. *Knee Surg Sports Traumatol Arthrosc*. 2009;17(9):1135-1139.
6. Chahal J, Gross AE, Gross C, et al. Outcomes of osteochondral allograft transplantation in the knee. *Arthroscopy*. 2013;29(3):575-588.
7. Chalmers PN, Erickson BJ, Verma NN, D'Angelo J, Romeo AA. Incidence and return to play after biceps tenodesis in professional baseball players. *Arthroscopy*. 2018;34(3):747-751.
8. Chang EY, Pallante-Kichura AL, Bae WC, et al. Development of a comprehensive osteochondral allograft MRI scoring system (OCAMRISS) with histopathologic, micro-computed tomography, and biomechanical validation. *Cartilage*. 2014;5(1):16-27.
9. Davies-Tuck ML, Wluka AE, Wang Y, et al. The natural history of cartilage defects in people with knee osteoarthritis. *Osteoarthritis Cartilage*. 2008;16(3):337-342.
10. Degen RM, Coleman NW, Tetreault D, et al. Outcomes of patellofemoral osteochondral lesions treated with structural grafts in patients older than 40 years. *Cartilage*. 2017;8(3):255-262.
11. Devitt BM, Bell SW, Webster KE, Feller JA, Whitehead TS. Surgical treatments of cartilage defects of the knee: systematic review of randomised controlled trials. *Knee*. 2017;24(3):508-517.
12. Familiari F, Cinque ME, Chahla J, et al. Clinical outcomes and failure rates of osteochondral allograft transplantation in the knee: a systematic review [published online October 17, 2017]. *Am J Sports Med*. doi:10.1177/0363546517732531
13. Gobbi A, Nunag P, Malinowski K. Treatment of full thickness chondral lesions of the knee with microfracture in a group of athletes. *Knee Surg Sports Traumatol Arthrosc*. 2005;13(3):213-221.
14. Gortz S, De Young AJ, Bugbee WD. Fresh osteochondral allografting for steroid-associated osteonecrosis of the femoral condyles. *Clin Orthop Relat Res*. 2010;468(5):1269-1278.
15. Gudas R, Gudaite A, Pocius A, et al. Ten-year follow-up of a prospective, randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint of athletes. *Am J Sports Med*. 2012;40(11):2499-2508.
16. Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. *Arthroscopy*. 2005;21(9):1066-1075.
17. Harris JD, Walton DM, Erickson BJ, et al. Return to sport and performance after microfracture in the knees of National Basketball Association players. *Orthop J Sports Med*. 2013;1(6):2325967113512759.
18. Haut RC. Contact pressures in the patellofemoral joint during impact loading on the human flexed knee. *J Orthop Res*. 1989;7(2):272-280.
19. Jack RA 2nd, Sochacki KR, Navarro SM, McCulloch PC, Lintner DM, Harris JD. Performance and return to sport after clavicle open reduction and internal fixation in National Football League players. *Orthop J Sports Med*. 2017;5(8):2325967117720677.
20. Johnson CC, Johnson DJ, Garcia GH, et al. High short-term failure rate associated with decellularized osteochondral allograft for treatment of knee cartilage lesions. *Arthroscopy*. 2017;33(12):2219-2227.
21. Klusemann MJ, Pyne DB, Hopkins WG, Drinkwater EJ. Activity profiles and demands of seasonal and tournament basketball competition. *Int J Sports Physiol Perform*. 2013;8(6):623-629.
22. Krych AJ, Robertson CM, Williams RJ 3rd; Cartilage Study Group. Return to athletic activity after osteochondral allograft transplantation in the knee. *Am J Sports Med*. 2012;40(5):1053-1059.
23. Makinejad MD, Abu Osman NA, Abu Bakar Wan Abas W, Bayat M. Preliminary analysis of knee stress in full extension landing. *Clinics (Sao Paulo)*. 2013;68(9):1180-1188.
24. Marshall NE, Jildeh TR, Okoroha KR, et al. Performance, return to play, and career longevity after ulnar collateral ligament reconstruction in professional catchers. *Arthroscopy*. 2018;34(6):1809-1815.
25. McAllister DR, Joyce MJ, Mann BJ, Vangsness CT Jr. Allograft update: the current status of tissue regulation, procurement, processing, and sterilization. *Am J Sports Med*. 2007;35(12):2148-2158.
26. McCarthy MA, Meyer MA, Weber AE, et al. Can competitive athletes return to high-level play after osteochondral allograft transplantation of the knee? *Arthroscopy*. 2017;33(9):1712-1717.
27. McCarty EC, Fader RR, Mitchell JJ, Glenn RE Jr, Potter HG, Spindler KP. Fresh osteochondral allograft versus autograft: twelve-month results in isolated canine knee defects. *Am J Sports Med*. 2016;44(9):2354-2365.
28. McCormick F, Harris JD, Abrams GD, et al. Trends in the surgical treatment of articular cartilage lesions in the United States: an analysis of a large private-payer database over a period of 8 years. *Arthroscopy*. 2014;30(2):222-226.
29. Messner K, Maletius W. The long-term prognosis for severe damage to weight-bearing cartilage in the knee: a 14-year clinical and radiographic follow-up in 28 young athletes. *Acta Orthop Scand*. 1996;67(2):165-168.
30. Minhas SV, Kester BS, Larkin KE, Hsu WK. The effect of an orthopaedic surgical procedure in the National Basketball Association. *Am J Sports Med*. 2016;44(4):1056-1061.

31. Montgomery SR, Foster BD, Ngo SS, et al. Trends in the surgical treatment of articular cartilage defects of the knee in the United States. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(9):2070-2075.
32. Namdari S, Baldwin K, Anakwenze O, Park MJ, Huffman GR, Sennett BJ. Results and performance after microfracture in National Basketball Association athletes. *Am J Sports Med*. 2009;37(5):943-948.
33. Nielsen ES, McCauley JC, Pulido PA, Bugbee WD. Return to sport and recreational activity after osteochondral allograft transplantation in the knee. *Am J Sports Med*. 2017;45(7):1608-1614.
34. Nwachukwu BU, Bedi A, Premkumar A, Draovitch P, Kelly BT. Characteristics and outcomes of arthroscopic femoroacetabular impingement surgery in the National Football League. *Am J Sports Med*. 2018;46(1):144-148.
35. Pappas GP, Vogelsong MA, Staroswiecki E, Gold GE, Safran MR. Magnetic resonance imaging of asymptomatic knees in collegiate basketball players: the effect of one season of play. *Clin J Sport Med*. 2016;26(6):483-489.
36. Podraza JT, White SC. Effect of knee flexion angle on ground reaction forces, knee moments and muscle co-contraction during an impact-like deceleration landing: implications for the non-contact mechanism of ACL injury. *Knee*. 2010;17(4):291-295.
37. Sadr KN, Pulido PA, McCauley JC, Bugbee WD. Osteochondral allograft transplantation in patients with osteochondritis dissecans of the knee. *Am J Sports Med*. 2016;44(11):2870-2875.
38. Saris D, Price A, Widuchowski W, et al. Matrix-applied characterized autologous cultured chondrocytes versus microfracture: two-year follow-up of a prospective randomized trial. *Am J Sports Med*. 2014;42(6):1384-1394.
39. Solheim E, Hegna J, Strand T, Harlem T, Inderhaug E. Randomized study of long-term (15-17 years) outcome after microfracture versus mosaicplasty in knee articular cartilage defects. *Am J Sports Med*. 2018;46(4):826-831.
40. Stahl R, Luke A, Ma CB, et al. Prevalence of pathologic findings in asymptomatic knees of marathon runners before and after a competition in comparison with physically active subjects—a 3.0 T magnetic resonance imaging study. *Skeletal Radiol*. 2008;37(7):627-638.
41. Walczak BE, McCulloch PC, Kang RW, Zelazny A, Tedeschi F, Cole BJ. Abnormal findings on knee magnetic resonance imaging in asymptomatic NBA players. *J Knee Surg*. 2008;21(1):27-33.
42. Wang D, Jones KJ, Eliasberg CD, Pais MD, Rodeo SA, Williams RJ 3rd. Condyle-specific matching does not improve midterm clinical outcomes of osteochondral allograft transplantation in the knee. *J Bone Joint Surg Am*. 2017;99(19):1614-1620.
43. Wang D, Kalia V, Eliasberg CD, et al. Osteochondral allograft transplantation of the knee in patients aged 40 years and older. *Am J Sports Med*. 2018;46(3):581-589.
44. Williams RJ 3rd, Ranawat AS, Potter HG, Carter T, Warren RF. Fresh stored allografts for the treatment of osteochondral defects of the knee. *J Bone Joint Surg Am*. 2007;89(4):718-726.