Washington University School of Medicine
Digital Commons@Becker

Open Access Publications

2017

Accelerated return to sport after osteochondral autograft plug transfer

Brian C. Werner
University of Virginia

Chris T. Cosgrove
Washington University School of Medicine in St. Louis

C. Jan Gilmore
Presbyterian Rust Medical Center

Matthew L. Lyons
GroupHealth Orthopaedic Surgery

Mark D. Miller
University of Virginia

See next page for additional authors

Follow this and additional works at: https://digitalcommons.wustl.edu/open_access_pubs
Please let us know how this document benefits you.

Recommended Citation

Werner, Brian C.; Cosgrove, Chris T.; Gilmore, C. Jan; Lyons, Matthew L.; Miller, Mark D.; Brockmeier, Stephen F.; and Diduch, David R., "Accelerated return to sport after osteochondral autograft plug transfer." Orthopaedic journal of sports medicine. 5, 4. 2325967117702418. (2017).
https://digitalcommons.wustl.edu/open_access_pubs/5862

This Open Access Publication is brought to you for free and open access by Digital Commons@Becker. It has been accepted for inclusion in Open Access Publications by an authorized administrator of Digital Commons@Becker. For more information, please contact vanam@wustl.edu.

Authors

Brian C. Werner, Chris T. Cosgrove, C. Jan Gilmore, Matthew L. Lyons, Mark D. Miller, Stephen F. Brockmeier, and David R. Diduch

This open access publication is available at Digital Commons@Becker: https://digitalcommons.wustl.edu/open_access_pubs/5862

Accelerated Return to Sport After Osteochondral Autograft Plug Transfer

Brian C. Werner,*† MD, Chris T. Cosgrove,‡ MD, C. Jan Gilmore,§ MD, Matthew L. Lyons,‖ MD, Mark D. Miller,† MD, Stephen F. Brockmeier,† MD, and David R. Diduch,† MD

Investigation performed at the Department of Orthopaedic Surgery, University of Virginia Health System, Charlottesville, Virginia, USA

Background: Previous studies have reported varying return-to-sport protocols after knee cartilage restoration procedures.

Purpose: To (1) evaluate the time for return to sport in athletes with an isolated chondral injury who underwent an accelerated return-to-sport protocol after osteochondral autograft plug transfer (OAT) and (2) evaluate clinical outcomes to assess for any consequences from the accelerated return to sport.

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

Methods: An institutional cohort of 152 OAT procedures was reviewed, of which 20 competitive athletes met inclusion and exclusion criteria. All patients underwent a physician-directed accelerated rehabilitation program after their procedure. Return to sport was determined for all athletes. Clinical outcomes were assessed using International Knee Documentation Committee (IKDC) and Tegner scores as well as assessment of level of participation on return to sport.

Results: Return-to-sport data were available for all 20 athletes; 13 of 20 athletes (65%) were available for clinical evaluation at a mean 4.4-year follow-up. The mean time for return to sport for all 20 athletes was 82.9 ± 25 days (range, 38-134 days). All athletes were able to return to sport at their previous level and reported that they were satisfied or very satisfied with their surgical outcome and ability to return to sport. The mean postoperative IKDC score was 84.5 ± 9.5. The mean Tegner score prior to injury was 8.9 ± 1.7; it was 7.7 ± 1.9 at final follow-up.

Conclusion: Competitive athletes with traumatic chondral defects treated with OAT managed using this protocol had reduced time to preinjury activity levels compared with what is currently reported, with excellent clinical outcomes and no serious long-term sequelae.

Keywords: osteochondral autograft plug transfer; accelerated rehabilitation; return to sport; knee chondral injury

Injuries to knee articular cartilage have significant clinical consequences due to a limited capacity for healing.[6,7,30] An increasing frequency of chondral injuries has been noted in populations of both highly competitive and recreational athletes, especially in athletes participating in pivoting sports such as soccer, basketball, and football.[3,11,31,38,40] Articular cartilage injury also frequently occurs in association with other knee injuries, and up to 50% of athletes undergoing an anterior cruciate ligament reconstruction have a concomitant cartilage defect.[13,40,46] Left untreated, an articular cartilage injury in the setting of anterior cruciate ligament deficiency portends significantly inferior outcome scores.[48]

Regardless of etiology or chronicity, knee articular cartilage injuries can be particularly devastating to athletes, limiting their continued participation in sports as well as predisposing them to marked lifestyle changes and future joint degeneration.[13-15,36,39,40,47,49] Athletes in pivoting sports are reported to have a 4.4- to 12-fold increased risk for knee osteoarthritis due to the increased repetitive mechanical stresses encountered during sport.[12,15,36,47] A proper restoration of the articular surface has long-term implications in preventing the negative outcomes associated with the inability to maintain an active lifestyle after the end of an athlete's career.[47]

*Address correspondence to Brian C. Werner, MD, Department of Orthopaedic Surgery, University of Virginia Health System, 400 Ray C. Hunt Drive, Suite 330, Charlottesville, VA 22908, USA (email: bcw4x@virginia.edu).

†Department of Orthopaedic Surgery, University of Virginia Health System, Charlottesville, Virginia, USA.

‡Department of Orthopaedic Surgery, Washington University, St Louis, Missouri, USA.

§Presbyterian Rust Medical Center, Rio Rancho, New Mexico, USA.

‖GroupHealth Orthopaedic Surgery, Seattle, Washington, 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 University of Virginia IRB-HSR.

The Orthopaedic Journal of Sports Medicine, 5(4), 2325967117702418
DOI: 10.1177/2325967117702418
© The Author(s) 2017

This open-access article is published and distributed under the Creative Commons Attribution - NonCommercial - No Derivatives License (http://creativecommons.org/licenses/by-nc-nd/3.0/), which permits the noncommercial use, distribution, and reproduction of the article in any medium, provided the original author and source are credited. You may not alter, transform, or build upon this article without the permission of the Author(s). For reprints and permission queries, please visit SAGE's website at http://www.sagepub.com/journalsPermissions.nav.

Pivoting athletes with articular cartilage injuries present a significant clinical challenge, as any restorative procedure must withstand the repetitive, forceful nature of the knee movements demanded by their sport.[30,51] Osteochondral autograft plug transfer (OAT) utilizes a healthy osteochondral plug from a low-weightbearing cartilage surface and transplants it to the defective site.[22-24] This technique establishes a new hyaline cartilage surface, as opposed to traditional techniques such as microfracture, which yield a fibrocartilage repair.[1,2,4,16,22,24,27] Because of the potential for harvest site morbidity, OAT is typically limited to focal femoral defects with an area less than 2 to 3 cm^2.[8] Previous studies have demonstrated improved outcomes in young athletes using OAT compared with microfracture and superior clinical and histological results compared with autologous chondrocyte transplantation,[18,26] although a recent study demonstrated comparable cost-effectiveness between OAT and microfracture.[41] In a recent systematic review of 20 studies including 1363 patients, OAT had the highest return-to-sport rates for athletes (91%) as well as the highest durability of preinjury level of performance (96%). The mean time to return to sport in this review was 8 months after microfracture, 7 months after OAT, and 18 months after autologous chondrocyte transplantation.[43] Similar results were reported in a second systematic review, which identified 11 studies including 658 patients, in which athletes who underwent OAT had a 93% return-to-sport rate at a mean 6.5 months, better than microfracture (59%, 17 months) and autologous chondrocyte transplantation (78%, 25 months).[25] However, although there are some benefits with regard to return to sports, there is little evidence of superior clinical results with OAT compared with other cartilage restoration techniques, including microfracture.[9,34]

The purpose of this study was to (1) evaluate the time for return to sport in athletes with an isolated chondral injury who underwent an accelerated return-to-sport protocol after OAT and (2) evaluate clinical outcomes to assess for any consequences from the accelerated return to sport. The null hypothesis was that athletes with isolated knee chondral injury who underwent an accelerated return-to-sport protocol after OAT would be able to return to sport more quickly and return to their preinjury level of sport.

METHODS

Patients

After institutional review board approval was obtained, an institutional cohort of 152 OAT procedures performed from 2005 to 2012 at a single institution were retrospectively reviewed. Inclusion criteria were the following: (1) an articular cartilage defect or osteochondral defect of the medial or lateral femoral condyle confirmed on magnetic resonance imaging, (2) isolated knee OAT procedure, and (3) participation in competitive athletics at an International Cartilage Repair Society level I or II equivalent.[5] Exclusion criteria were the following: (1) concomitant osteoarthritis; (2) concomitant ligamentous, meniscus repair, or surgical procedure other than OAT on the operative knee; and (3) cartilage defect in a location other than the medial or lateral femoral condyle, such as the trochlea or patella.

TABLE 1
Patient Cohort[a]

Demographics	
Age, y, mean ± SD	21.1 ± 7.6
BMI, kg/m^2, mean ± SD	25.0 ± 3.0
Male sex, n (%)	14 (70)
Sports, n (%)	
Soccer	5 (25)
Football	4 (20)
Basketball	4 (20)
Lacrosse	3 (15)
Baseball	1 (5)
Softball	1 (5)
Swimming	1 (5)
Distance running	1 (5)
Surgical details	
Lesion size, cm^2, mean (range)	1.34 (0.15-2.8)
Lesion location	
MFC, n (%)	8 (40)
LFC, n (%)	12 (60)
No. of plugs, mean (range)	2 (1-4)
Plug diameter, cm, mean (range)	0.7 (0.4-1.0)

[a]BMI, body mass index; LFC, lateral femoral condyle; MFC, medial femoral condyle.

The final cohort consisted of 20 consecutive competitive athletes (Table 1). The mean age was 21.1 ± 7.6, and the mean body mass index was 25.0 ± 3.0 kg/m^2. Fourteen (70%) patients were male. Ten patients (50%) were collegiate or professional athletes, 7 patients (35%) were varsity high school athletes, and the remaining 3 patients were regional or national competitive athletes who had graduated college. Athletes participated in soccer (n = 5), football (n = 4), basketball (n = 4), lacrosse (n = 3), baseball (n = 1), softball (n = 1), swimming (n = 1), and distance running (n = 1). The mean lesion size was 1.34 cm^2 (range, 0.15-2.8 cm^2). On average, 2 plugs (range, 1-4 plugs) were used. The mean plug diameter was 0.7 cm (range, 0.4-1.0 cm). Eight lesions were located on the medial femoral condyle, while the remaining 12 were located on the lateral femoral condyle. There was a mix of etiologies, including acute traumatic, remote traumatic, and more insidious.

OAT Procedure

All procedures were performed by 1 of 3 fellowship-trained orthopaedic surgeons. Diagnostic arthroscopy was completed to evaluate and measure the articular cartilage defect as well as evaluate for any concomitant knee pathology. The lesion was then debrided to a healthy cartilage rim. Donor osteochondral plugs were harvested from a lower weightbearing cartilage surface of the affected knee, typically the superolateral trochlear ridge, using a small arthrotomy of approximately 2.5 cm. The harvested plug(s) were then transplanted arthroscopically into the cartilage defect to create a congruent surface with the existing

healthy cartilage. Care was taken to assure perpendicular placement of the OAT plug. Additional operative procedures that did not specifically meet exclusion critera were performed in 30% of patients, including partial lateral or medial meniscectomy (25%) and platelet-rich plasma injection into the patellar tendon (5%).

Accelerated Postoperative Rehabilitation Protocol

A physician-directed accelerated rehabilitation protocol was followed for each patient postoperatively. Patients were allowed to be up to 50% weightbearing immediately postoperatively. Postoperative visits within the first month emphasized regaining full range of motion. After 4 weeks, patients progressed to full weightbearing as tolerated and as dictated by their clinical progress with physical therapy. Patients with 1 or 2 plugs advanced more quickly, with transition to full weightbearing at 2 weeks postoperatively, pending normalization of quad control, gait, and diminished effusion. At the final standard scheduled clinical visit, between 6 and 10 weeks postoperatively, patients were permitted to progress to full athletic activities as tolerated. Those patients with 1 to 2 plugs (n = 14) were permitted to return as early as 6 weeks if they demonstrated sufficient functional abilities for their respective sport without effusion or increased pain.

Return to Sport

Return to sport was determined by a retrospective review of the patient's visit documentation and a review of athletic training and team participation logs. We defined the date of return as the date that patients resumed full and unrestricted athletic activities, including practices during off-season and competitive play when in-season.

Clinical Outcomes

Clinical outcomes were assessed using the International Knee Documentation Committee (IKDC) subjective knee score[20,28,29] and the Tegner activity scale.[19] These were obtained by in-person interview, phone questionnaire, or mailed survey.

RESULTS

Return to Sport

All (100%) of the patients were able to successfully return to sport postoperatively at a mean of 82.9 days (range, 39-134 days). Three patients were outliers with a mean return to sport of 120 days. Two of these athletes were collegiate soccer players who had surgery in the off-season and had no scheduled practice or games when released to sport. The patient with the longest return to sport (134 days) was late for their clearance appointment but had normal function and was pain free at 2-month follow-up. All (100%) patients reported that they were satisfied or very satisfied with their surgical outcome and ability to return to sport. The reported mean pain score during the ensuing athletic season was 4.4 ± 1.5 (out of 10). Fifty percent had mild or no knee swelling or stiffness, and 50% reported "moderate" swelling or stiffness. A total of 75% of respondents noted that during the ensuing athletic season, they were able to perform "strenuous to very strenuous activities without significant swelling." All (100%) patients were able to perform most or all of the physical demands of their sport without significant instability.

TABLE 2
Summary of Results[a]

Clinical outcome measures	
Successful return to sport, n (%)	20 (100)
Time to return to sport, days, mean (range)	82.9 (39-134)
Pain score during subsequent season, mean ± SD	4.4 ± 1.5
IKDC score, mean ± SD	84.5 ± 9.5
Tegner score, mean ± SD	7.7 ± 1.9
Symptoms, n (%)	
Mild/no swelling or stiffness	10 (50)
Moderate swelling or stiffness	10 (50)
Pain at the time of return to sport	5 (25)
Knee effusion after return to sport	5 (25)
Required joint aspiration or injection after return	5 (25)

[a]IKDC, International Knee Documentation Committee.

Clinical Outcomes

Clinical outcome scores were obtained in 13 of 20 athletes (65%) at a mean follow-up of 4.4 ± 1.7 years (Table 2). The mean postoperative IKDC score was 84.5 ± 9.5. The mean Tegner score prior to injury was 8.9 ± 1.7, and 7.7 ± 1.9 at final postoperative follow-up. Five athletes (25%) reported pain at the time of return to sport or later during clinical follow-up visits. These same 5 athletes (25%) reported having a knee effusion at the time of return or later during clinical follow-up visits, and all 5 of these athletes (25%) required joint aspiration and/or injection postoperatively. No athletes required reoperation, and no persistent mechanical symptoms were noted.

DISCUSSION

In the present study, the efficacy and safety of an accelerated return-to-sport protocol after OAT for isolated knee chondral injury was evaluated. Athletes in the present study were able to return to sport in less than 3 months on average after this procedure, with the longest return to sport being 4.5 months, although a quarter of patients had persistent pain and effusions that required aspiration or injection. This accelerated time for return to sports participation is unique when compared with studies reporting return to sport for athletes undergoing knee cartilage restoration. Several prior studies have evaluated return to sport after microfracture.[4,16,33,42-44,50] Blevins et al[4] reported a mean return to sport of 9.3 months for both highly competitive and recreational athletes after

microfracture. A recent retrospective study noted a return to regular activities between 6 and 8 months after microfracture.[35] These outcomes were summarized in a recent systematic review of 1363 patients in which the mean time for return to sports participation after microfracture was 8 ± 1 months postoperatively.[43] Other articular cartilage repair techniques are reported to have slightly longer times before an athlete can expect to return to unrestricted activities. Krych et al[35] reported a mean of 9.6 months until return to sport after osteochondral allograft transplantation. Average return to sport after autologous chondrocyte implantation is significantly longer, averaging 18 ± 4 months.[35,42]

A potential advantage of OAT is that athletes may return to sports participation at a quicker rate due to the direct incorporation of autologous bone with an already intact, healthy hyaline cartilage articular surface.[22,23] The impetus for allowing early return to activities after OAT is based on the improved and more rapid integration of the transplanted cartilage and bone. Experimental studies in dogs[21] and horses[10] have demonstrated that at 4 weeks, there is osseous integration of the bony portion of the graft, although a gap remains between the donor cartilage and the recipient site. At 8 weeks, fibrocartilage formed between the hyaline cartilage plugs.[21] With bony integration demonstrated in animal models as early as 4 weeks postoperative, it is reasonable to consider earlier return to sport. Conversely, microfracture relies on the influx of marrow products to form a fibrin clot, which is slowly remodeled into fibrocartilage. This results in a less durable construct initially and over time and requires prolonged protection prior to initiating activities.[8,37,42,45]

Reported time for return to sport after OAT is more rapid than what is cited for the other articular cartilage repair techniques.[17,18,42] A recent systematic review reported a mean time of 7 ± 2 months for return to sport after OAT.[42] Athletes in a prospective randomized trial returned to full athletic participation at a mean of 6.5 months after OAT.[17] Additional literature report a mean return to sport ranging from 6 to 9 months after OAT.[18,32] All competitive athletes in the present study were able to successfully return to sport postoperatively at a mean of 2.8 months (83 days)—more than 50% faster than any previous study of athletes undergoing OAT.

In our study, 100% of patients were able to successfully return to their prior sport, although a quarter of patients reported persistent pain and effusions, requiring aspiration and/or injections. In a systemic review, the overall return to sports participation averaged 73% ± 5% for all cartilage repair techniques.[42] Of those, OAT procedures yielded the highest rate of return at 91% ± 2%, which is consistent with the data in our study. In that same review, 70% ± 3% of athletes returned to their preinjury level after OAT.[42]

This retrospective study has several limitations. First, the small number of patients within the athlete cohort offers room for various biases. Second, the retrospective nature of the study may be a source of recall bias. Additionally, no preoperative scores were collected, so it is not possible to quantify the amount of improvement patients experienced. Neither were routine postoperative radiographs performed, nor were mechanical axis radiographic views obtained, which limits our ability to ascertain whether malalignment contributed to outcomes. Many of the players likely had a variety of different nonoperative treatments or interventions prior to presenting to the surgeon, particularly those who were in season; however, these data were not routinely documented in the medical record. We also could only assess return to sport and not truly measure return to prior level of performance. Finally, the study lacks a control or comparison group, such as a nonoperative group, microfracture group, or other cartilage restoration group, requiring comparisons with historical published data.

CONCLUSION

The present study demonstrates the feasibility of an accelerated return-to-sport protocol after an OAT procedure. Athletes with isolated traumatic knee chondral defects treated with OAT managed using this protocol had substantially reduced time to preinjury activity levels compared with what is currently reported, although a quarter of players had persistent pain and effusions requiring aspiration and/or injection after return to sport.

REFERENCES

1. Aglietti P, Ciardullo A, Giron F, Ponteggia F. Results of arthroscopic excision of the fragment in the treatment of osteochondritis dissecans of the knee. *Arthroscopy*. 2001;17:741-746.
2. Anderson AF, Richards DB, Pagnani MJ, Hovis WD. Antegrade drilling for osteochondritis dissecans of the knee. *Arthroscopy*. 1997;13:319-324.
3. Arendt E, Dick R. Knee injury patterns among men and women in collegiate basketball and soccer. NCAA data and review of literature. *Am J Sports Med*. 1995;23:694-701.
4. Blevins FT, Steadman JR, Rodrigo JJ, Silliman J. Treatment of articular cartilage defects in athletes: an analysis of functional outcome and lesion appearance. *Orthopedics*. 1998;21:761-767.
5. Brittberg M, Winalski CS. Evaluation of cartilage injuries and repair. *J Bone Joint Surg Am*. 2003;85-A(suppl 2):58-69.
6. Buckwalter JA. Evaluating methods of restoring cartilaginous articular surfaces. *Clin Orthop Relat Res*. 1999;367(suppl):S224-S238.
7. Buckwalter JA, Mankin HJ. Articular cartilage: degeneration and osteoarthritis, repair, regeneration, and transplantation. *Instr Course Lect*. 1998;47:487-504.
8. Camp CL, Stuart MJ, Krych AJ. Current concepts of articular cartilage restoration techniques in the knee. *Sports Health*. 2014;6:265-273.
9. Chalmers PN, Vigneswaran H, Harris JD, Cole BJ. Activity-related outcomes of articular cartilage surgery: a systematic review. *Cartilage*. 2013;4:193-203.
10. Convery FR, Akeson WH, Keown GH. The repair of large osteochondral defects. An experimental study in horses. *Clin Orthop Relat Res*. 1972;82:253-262.
11. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31,516 knee arthroscopies. *Arthroscopy*. 1997;13:456-460.
12. Drawer S, Fuller CW. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *Br J Sports Med*. 2001;35:402-408.
13. Drongowski RA, Coran AG, Wojtys EM. Predictive value of meniscal and chondral injuries in conservatively treated anterior cruciate ligament injuries. *Arthroscopy*. 1994;10:97-102.

14. Engstrom B, Forssblad M, Johansson C, Törnkvist H. Does a major knee injury definitely sideline an elite soccer player? *Am J Sports Med*. 1990;18:101-105.
15. Felson DT, Lawrence RC, Dieppe PA, et al. Osteoarthritis: new insights. Part 1: the disease and its risk factors. *Ann Intern Med*. 2000;133:635-646.
16. 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;13:213-221.
17. 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;21:1066-1075.
18. Gudas R, Stankevicius E, Monastyreckiene E, Pranys D, Kalesinskas RJ. Osteochondral autologous transplantation versus microfracture for the treatment of articular cartilage defects in the knee joint in athletes. *Knee Surg Sports Traumatol Arthrosc*. 2006;14:834-842.
19. Hambly K. The use of the Tegner Activity Scale for articular cartilage repair of the knee: a systematic review. *Knee Surg Sports Traumatol Arthrosc*. 2011;19:604-614.
20. Hambly K, Griva K. IKDC or KOOS? Which measures symptoms and disabilities most important to postoperative articular cartilage repair patients? *Am J Sports Med*. 2008;36:1695-1704.
21. Hangody L, Kish G, Karpati Z. Autogenous osteochondral graft technique for replacing knee cartilage defects in dogs. *Orthop Int*. 1997; 19:175-181.
22. Hangody L, Fules P. Autologous osteochondral mosaicplasty for the treatment of full-thickness defects of weight-bearing joints: ten years of experimental and clinical experience. *J Bone Joint Surg Am*. 2003; 85-A(suppl 2):25-32.
23. Hangody L, Kish G, Kárpáti Z, Szerb I, Udvarhelyi I. Arthroscopic autogenous osteochondral mosaicplasty for the treatment of femoral condylar articular defects. A preliminary report. *Knee Surg Sports Traumatol Arthrosc*. 1997;5:262-267.
24. Hangody L, Rathonyi GK, Duska Z, Vásárhelyi G, Füles P, Módis L. Autologous osteochondral mosaicplasty. Surgical technique. *J Bone Joint Surg Am*. 2004;86-A(suppl 1):65-72.
25. Harris JD, Brophy RH, Siston RA, Flanigan DC. Treatment of chondral defects in the athlete's knee. *Arthroscopy*. 2010;26:841-852.
26. Horas U, Pelinkovic D, Herr G, Aigner T, Schnettler R. Autologous chondrocyte implantation and osteochondral cylinder transplantation in cartilage repair of the knee joint. A prospective, comparative trial. *J Bone Joint Surg Am*. 2003;85-A:185-192.
27. Hunziker EB. Articular cartilage repair: basic science and clinical progress. A review of the current status and prospects. *Osteoarthritis Cartilage*. 2002;10:432-463.
28. Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the International Knee Documentation Committee subjective knee form. *Am J Sports Med*. 2001;29:600-613.
29. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form. *Am J Sports Med*. 2006;34:1567-1573.
30. Jackson DW, Lalor PA, Aberman HM, Simon TM. Spontaneous repair of full-thickness defects of articular cartilage in a goat model. A preliminary study. *J Bone Joint Surg Am*. 2001;83-A:53-64.
31. Jones SJ, Lyons RA, Sibert J, Evans R, Palmer SR. Changes in sports injuries to children between 1983 and 1998: comparison of case series. *J Public Health Med*. 2001;23:268-271.
32. Kish G, Modis L, Hangody L. Osteochondral mosaicplasty for the treatment of focal chondral and osteochondral lesions of the knee and talus in the athlete. Rationale, indications, techniques, and results. *Clin Sports Med*. 1999;18:45-66.
33. Krych AJ, Harnly HW, Rodeo SA, Williams RJ 3rd. Activity levels are higher after osteochondral autograft transfer mosaicplasty than after microfracture for articular cartilage defects of the knee: a retrospective comparative study. *J Bone Joint Surg Am*. 2012;94:971-978.
34. Krych AJ, Pareek A, King AH, Johnson NR, Stuart MJ, Williams RJ 3rd. Return to sport after the surgical management of articular cartilage lesions in the knee: a meta-analysis [published online August 18, 2016]. *Knee Surg Sports Traumatol Arthrosc*. doi:10.1007/s00167-016-4262-3.
35. 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;40:1053-1059.
36. Kujala UM, Kettunen J, Paananen H, et al. Knee osteoarthritis in former runners, soccer players, weight lifters, and shooters. *Arthritis Rheum*. 1995;38:539-546.
37. LaPrade RF, Bursch LS, Olson EJ, Havlas V, Carlson CS. Histologic and immunohistochemical characteristics of failed articular cartilage resurfacing procedures for osteochondritis of the knee: a case series. *Am J Sports Med*. 2008;36:360-368.
38. Levy AS, Lohnes J, Sculley S, LeCroy M, Garrett W. Chondral delamination of the knee in soccer players. *Am J Sports Med*. 1996;24: 634-639.
39. Mandelbaum BR, Browne JE, Fu F, et al. Articular cartilage lesions of the knee. *Am J Sports Med*. 1998;26:853-861.
40. 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: 165-168.
41. Miller DJ, Smith MV, Matava MJ, Wright RW, Brophy RH. Microfracture and osteochondral autograft transplantation are cost-effective treatments for articular cartilage lesions of the distal femur. *Am J Sports Med*. 2015;43:2175-2181.
42. Mithoefer K, Hambly K, Della Villa S, Silvers H, Mandelbaum BR. Return to sports participation after articular cartilage repair in the knee: scientific evidence. *Am J Sports Med*. 2009;37(suppl 1): 167S-176S.
43. Mithoefer K, McAdams T, Williams RJ, Kreuz PC, Mandelbaum BR. Clinical efficacy of the microfracture technique for articular cartilage repair in the knee: an evidence-based systematic analysis. *Am J Sports Med*. 2009;37:2053-2063.
44. Mithoefer K, Williams RJ 3rd, Warren RF, Wickiewicz TL, Marx RG. High-impact athletics after knee articular cartilage repair: a prospective evaluation of the microfracture technique. *Am J Sports Med*. 2006;34:1413-1418.
45. Nehrer S, Spector M, Minas T. Histologic analysis of tissue after failed cartilage repair procedures. *Clin Orthop Relat Res*. 1999;365: 149-162.
46. Piasecki DP, Spindler KP, Warren TA, Andrish JT, Parker RD. Intraarticular injuries associated with anterior cruciate ligament tear: findings at ligament reconstruction in high school and recreational athletes. An analysis of sex-based differences. *Am J Sports Med*. 2003;31: 601-605.
47. Roos H. Are there long-term sequelae from soccer? *Clin Sports Med*. 1998;17:819-831.
48. Shelbourne KD, Jari S, Gray T. Outcome of untreated traumatic articular cartilage defects of the knee: a natural history study. *J Bone Joint Surg Am*. 2003;85-A(suppl 2):8-16.
49. Smith AD, Tao SS. Knee injuries in young athletes. *Clin Sports Med*. 1995;14:629-650.
50. Steadman JR, Miller BS, Karas SG, Schlegel TF, Briggs KK, Hawkins RJ. The microfracture technique in the treatment of full-thickness chondral lesions of the knee in National Football League players. *J Knee Surg*. 2003;16:83-86.
51. Vrahas MS, Mithoefer K, Joseph D. The long-term effects of articular impaction. *Clin Orthop Relat Res*. 2004;423:40-43.