Clinical Outcomes after Revision of Autologous Chondrocyte Implantation to Osteochondral Allograft Transplantation for Large Chondral Defects: A Comparative Matched-Group Analysis

Gergo Merkely^{1,2}, Takahiro Ogura^{1,3}, Jakob Ackermann¹ , Alexandre Barbieri Mestriner^{1,4}, and Andreas H. Gomoll^{1,5}

CARTILAGE
2021, Vol. 12(2) 155–161
© The Author(s) 2019
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1947603519833136
journals.sagepub.com/home/CAR

Abstract

Objective. Osteochondral allograft transplantation (OCA) is a well-established procedure for patients with symptomatic cartilage defects in the knee. Revision to OCA after prior failed cartilage repair has shown similar clinical outcomes as primary OCA; however, most of the failed procedures were arthroscopic procedures for smaller defects. There is no literature investigating the clinical outcomes after OCA for prior failed autologous chondrocyte implantation (ACI) for the treatment of large chondral defects of the knee. The purpose of this study was therefore to determine clinical outcomes of patients undergoing revision to OCA after prior failed ACI as compared with a matched cohort of patients undergoing OCA as a primary cartilage repair procedure (primary OCA). **Design.** In this review of prospectively collected data, we analyzed data from 26 patients with at least 2 years follow-up. Thirteen patients who underwent revision to OCA after prior failed ACI by a single surgeon were compared with a matched group of patients who underwent primary OCA. The patients were matched per age, gender, body mass index, and defect size. Patient-reported outcomes, reoperations, and survival rates were compared between groups. **Results.** There were no significant differences in patient-reported clinical outcome scores between the groups at final follow-up. Moreover, there was no significant difference in reoperation rates and survival rates between the groups. **Conclusion.** The present study demonstrates that revision to OCA is a viable treatment option with favorable functional outcomes and similar reoperation and survival rate as primary OCA even for revision of large chondral defects previously treated with ACI.

Keywords

osteochondral allograft transplantation, autologous chondrocyte implantation, knee joint preservation, clinical outcomes, cartilage repair

Introduction

Cartilage damage can lead to persistent symptoms including swelling, pain, loss of function, and may ultimately progress to symptomatic degeneration of the joint.¹ Articular cartilage has limited inherent capacity for spontaneous healing after injury; thus, symptomatic, full-thickness articular cartilage defects are difficult to manage especially in the young, high-demand patient population.² To delay or avoid a prosthetic arthroplasty, multiple treatment options are available to restore the injured cartilage depending on patient and lesion characteristics including drilling, abrasion arthroplasty, microfracture, osteochondral autograft transplantation (OAT), osteochondral allograft transplantation (OCA), and autologous chondrocyte implantation (ACI).^{2,3} Although choosing the proper cartilage restoration procedure is influenced by numerous factors, either marrow

stimulation technique or OAT are preferred procedures for small chondral lesions.³⁻⁵ In contrast, large full-thickness

¹Cartilage Repair Center, Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA

²Department of Traumatology, Semmelweis University, Budapest, Hungary

³Sports Medicine Center, Funabashi Orthopaedic Hospital, Funabashi, Chiba, Japan

⁴Universidade Federal de São Paulo, São Paulo, Brazil

⁵Hospital for Special Surgery, New York, New York, USA

Investigation performed at the Cartilage Repair Center, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts, USA.

Corresponding Author:

Gergo Merkely, Cartilage Repair Center, Brigham and Women's Hospital, Harvard Medical Center, 850 Boylston St # 112, Chestnut Hill, MA 02467, USA.
Email: gmerkely@bwh.harvard.edu

chondral and osteochondral defects are frequently treated with ACI and OCA resulting in high patient satisfaction rates and significantly improved functional outcomes.^{3,6-11} Despite low failure rates over a long-term follow-up, especially young patients are at risk for revision surgery.^{3,5-11} In this situation, choosing the appropriate subsequent surgical intervention is challenging and not clearly determined. Surgeons may either perform a repeat cartilage restoration procedure or total knee arthroplasty.¹²⁻¹⁶

OCA is a well-established single-step procedure with the ability to restore bone stock and transplant viable chondrocytes within mature hyaline cartilage.^{15,17,18} Outcomes after OCA for the revision of prior failed non-OCA cartilage repair for smaller defects are similar to primary OCA, while outcomes of revision of a prior failed OCA are worse.^{10,14-16,18-20} Outcomes of OCA after prior failed ACI remain unclear. Since OCA and ACI are indicated for the same defect size, determining the clinical outcomes of revision to OCA after prior failed ACI is necessary to better define an overall treatment algorithm.

The purpose of this study was to assess the clinical outcomes of patients undergoing revision to OCA after prior failed ACI as compared with a matched cohort of patients undergoing OCA as a primary cartilage repair procedure (primary OCA). We hypothesized that revision to OCA would provide comparable clinical outcomes to those after primary OCA.

Methods

Patient Cohort

Our institutional review board approved this study (2018P000693/PHS), and written informed consent was obtained from all patients at the time they were entered into the database. In this review of prospectively collected data, 112 patients underwent OCA transplantation between September 2012 and February 2016. All procedures were performed by a single surgeon. Of the identified patients, 15 underwent OCA after failed prior ACI procedure. Two patients were lost during the follow-up period. Thus, 13 patients with a minimum of 2 years follow-up were included in this study.

The indications for treatment of cartilage defects with OCA were one or more full-thickness chondral or osteochondral defects of the knee with symptoms matching the defect location. Surgery was indicated in patients who were resistant to nonoperative therapies. Patients were evaluated through a physical examination, radiography, magnetic resonance imaging (MRI), and arthroscopic surgery before treatment with OCA was considered. Contraindications to treatment included inflammatory joint disease, unresolved or recent septic arthritis, metabolic or crystal disorders, or deficient soft tissue coverage. Tibiofemoral malalignment $>3^\circ$ from the neutral mechanical axis into the involved

Table 1. Patients' Demographics Comparison between Case and Matched Control Groups.

	Revision to OCA after Prior ACI	Primary OCA	P
Number of patients	13	13	
Failure, n (%)	3 (23.1)	1 (7.7)	0.593
Age (years), mean (SD)	36.2 (9.1)	36.2 (8.5)	0.758
BMI (kg/m ²), mean (SD)	27.1 (4.3)	26.6 (3.2)	0.644
Female sex, n (%)	8 (61.5)	8 (61.5)	
Defect size (cm ²), mean (SD)	6.1 (2.9)	5 (2.5)	0.826
Defect location, n			
Medial femoral condyle	11	6	0.097
Lateral femoral condyle	1	4	0.322
Patella	4	4	
Trochlea	1	3	0.593
Medial tibial plateau	0	0	
Lateral tibial plateau	0	0	
HTO (%)	1 (7.7)	2 (15.4)	0.500
TTO (%)	4 (30.7)	0	0.096
Follow-up (years), mean (SD)	3.5 (1.7)	2.7 (0.9)	0.287

OCA = osteochondral allograft transplantation; ACI = autologous chondrocyte implantation; SD = standard deviation; BMI = body mass index; HTO = high tibial osteotomy; TTO = tibial tubercle osteotomy.

compartment was corrected with concomitant osteotomy. Patellofemoral maltracking was addressed with anteromedialization tibia tubercle osteotomy (TTO)²¹ to centralize patellar tracking, and proximal soft tissue balancing (lateral release/lengthening, vastus medialis obliquus advancement, MPFL reconstruction) as necessary to centralize the extensor mechanism.

A case-control study was conducted with a group of 13 patients who underwent primary OCA. These patients were matched individually according to age, gender, body mass index (BMI) and defect size. Patient demographics are summarized in **Table 1**. The closest existing match was used for age, BMI, and defect size, but a deviation of 5 years for age, 4.0 kg/m² for BMI, and 10 mm for defect size was accepted. The groups were matched by an independent reviewer who was blinded to the clinical outcomes of each patient. ACI failure was defined as failure of the graft of more than 25% as judged on postoperative MRI or second-look arthroscopy, repeat cartilage repair, additional surgical MST (marrow stimulation technique) treatment violating the subchondral bone of the treated defect, or prosthetic replacement. The number and type of subsequent surgeries after the OCA transplantation were assessed. The survival rate was assessed using the Kaplan-Meier method, with failure after OCA as outcome endpoint. Patients were evaluated utilizing the Knee injury and Osteoarthritis Outcome Score (KOOS) Pain, KOOS Symptom, KOOS ADL, KOOS Sport/Rec, KOOS QOL, Lysholm, and IKDC.

Surgical Procedure

OCA was performed as described in detail previously.^{22,23} Briefly, after induction of anesthesia, concomitant procedures were performed before OCA if necessary. Mini-parapatellar arthrotomy was performed to visualize the cartilage defect. Any degenerated cartilage as well as fibrous tissue was debrided. The defect was then sized with a sizing guide and an identical sized reamer was used to ream to a depth of approximately 6 to 8 mm using constant cold irrigation. The donor condyle was prepared using the same sizing guide. After harvesting the allograft plug, it was trimmed to the previously measured depths using a sagittal saw. The allograft was then pulse lavaged to remove any remaining marrow elements to decrease immunogenicity. Finally, the graft was placed into the recipient site with manual pressure only, until it was flush circumferentially.

Postoperative Rehabilitation

Postoperative rehabilitation was also described previously. Briefly, protected weight-bearing with knee brace was applied for 4 to 6 weeks, followed by progression to full weight-bearing as tolerated. During this period, patients were permitted to begin unrestricted range of motion exercises, quadriceps sets, straight-leg raises, and patellar mobilization. A stationary bicycle was permitted at 4 weeks. Open chain exercises were not permitted in this first phase. Strengthening was added at the 6-week point and was increased over the next 2 to 3 months. Patients progressed to sport-specific activities by 4 to 6 months after surgery for isolated OCA and by 8 to 12 months for those undergoing concomitant procedures.¹⁰

Statistical Analysis

SPSS (version 21.0; IBM Corp) was used to perform statistical analyses. Demographic results are reported as mean and standard deviation. Descriptive statistics were performed with chi-square or Fisher exact testing, and Mann-Whitney *U* testing. Survivorship of OCA was calculated utilizing the Kaplan-Meier method. The log rank test was performed to compare survivorship of primary and revision to OCA. Among patients' intact graft at final follow-up, the Wilcoxon signed-rank test was used to compare differences in functional scores (obtained from KOOS, Lysholm, and IKDC) between the 2 time points (preoperatively and final follow-up). Mann-Whitney *U* tests were used to compare the improvement in scores between OCA after failed ACI and primary OCA. All statistical tests were 2-tailed. A *P* value of 0.05 was used to determine statistical significance.

Table 2. Type and Frequency of Previous Surgeries before ACI in the Revision to OCA Group.

Procedure	Number of Procedure	Percentage
Chondroplasty	2	16.8
Partial medial meniscectomy	3	25
MPFL reconstruction	1	8.3
ACL reconstruction	2	16.8
Internal fixation for OCD fragment	3	25
Microfracture	2	16.8
Number of previous surgeries		
One surgery	6	50
Two surgeries	1	8.3
Three surgeries	1	8.3
Four or more surgeries	4	33.3

ACI = autologous chondrocyte implantation; OCA = osteochondral allograft transplantation; MPFL = medial patellofemoral ligament; ACL = anterior cruciate ligament; OCD = osteochondritis dissecans.

Results

Baseline demographics showed no significant differences between groups (**Table 1**). In the revision to OCA group, 12 patients (92.3%) underwent at least one prior procedure before ACI (excluding the cartilage biopsy) (**Table 2**). The time to failure after ACI averaged 3.3 ± 1.7 years. Mean follow-up period was 3.2 ± 1.5 years (revision to OCA: 3.5 ± 1.7 ; primary OCA: 2.7 ± 0.9). The reason for failure after ACI was defined based on the intraoperative findings: 7 patients failed through delamination, 5 patients due to biological failure to form adequate cartilaginous repair tissue, and 1 patient due to progression of disease.

Preoperative KOOS Pain was significantly lower in the revision to OCA group (48.5 ± 15.6) than in the primary OCA group (61.6 ± 14.4) ($P = 0.042$). Postoperative functional scores showed no significant difference between both groups (**Fig. 2**).

All patients in both groups demonstrated significant improvement in all functional scores after failed ACI revision to OCA ($P < 0.05$) (**Fig. 3**).

Among patients who underwent revision to OCA, 5 patients (38.4%) had reoperations, including chondroplasty, lysis of adhesions, and removal of painful hardware, compared with 3 patients (23.1%) in the primary OCA group (**Table 3**). In all these cases, the OCA graft was intact. There was no significant difference in either reoperation rate ($P = 0.673$) or mean time to reoperation between the groups (revision to OCA: 1.8 ± 1.9 years; primary OCA: 0.7 ± 0.4 years; $P = 0.157$). No difference was seen regarding failure rates between both groups with 3 patients (23.1%) in the revision to OCA group and 1 patient (7.7%) in the primary OCA group ($P = 0.593$) (**Table 3**). OCA graft survival rate

Table 3. Reoperations Performed During the Follow-up Period.

	Revision to OCA after Prior ACI	Primary OCA	P
Reoperation with intact OCA graft			
Lysis of adhesions, n (%)	1 (7.7)	1 (7.7)	
Chondroplasty, n (%)	1 (7.7)	1 (7.7)	
Hardware removal, n (%)	1 (7.7)	1 (7.7)	
Hardware removal and chondroplasty, n (%)	2 (15.4)	0	
Total, n (%)	5 (38.5)	3 (23.1)	0.673
Reoperation due to failure			
MST, n (%)	0	1 (7.7)	
OAT, n (%)	1 (7.7)	0	
OCA, n (%)	1 (7.7)	0	
TKA, n (%)	1 (7.7)	0	
Total, n (%)	3 (23.1)	1 (7.7)	0.593

OCA = osteochondral allograft; ACI = autologous chondrocyte implantation; MST = marrow stimulation technique; OAT = osteochondral autograft transplantation; TKA = total knee arthroplasty.

was 86.7% at 5 years (95% confidence interval = 49.4-95.7) among patients who underwent revision to OCA compared with 91.4% at 5 years (95% confidence interval = 56.6-98.9) among patients who underwent primary OCA. Survivorship distributions were not statistically different between both groups ($P = 0.515$) (**Fig. 1**).

Discussion

The key finding of the present study is that patients undergoing revision to OCA after failed ACI present with similar clinical outcomes compared with those who underwent primary OCA at mid-term follow-up. There were no significant differences in reoperation rates and graft survival rates between both groups. These results suggest that OCA is a viable treatment option in patients with prior failed ACI, resulting in favorable outcomes.

The interest in understanding the influence of a previous cartilage surgery on a subsequent revision cartilage restoration has increased over recent years. Many of our patients are young, increasing the likelihood of subsequent procedures over their life time. Mapping out a reasonable treatment course with consideration for potential revision procedures therefore appears advisable. Several studies reported good to excellent clinical outcomes after either primary OCA or OCA as a salvage procedure for failed prior cartilage restoration (Suppl. Table S1).^{10,14,16,19,20,24} However, to the best of our knowledge, this is the first study comparing clinical outcomes in patients undergoing revision to OCA after prior failed ACI or primary OCA. Gracitelli *et al.*²⁰ conducted a matched case-control study and compared patients who

underwent OCA as a primary cartilage restoration (group 1, 46 knees) with patients who underwent OCA after failed previous MST procedure (group 2, 46 knees). A significant difference was found only for reoperation rates between both groups (group 1 = 24% vs. group 2 = 44%), while survivorship was similar between groups (group 1 = 87.4%; group 2 = 86% at 10 years). Both groups showed significantly improved outcomes with no significant differences between the groups, which was consistent with our results. In contrast to their study, our study did not find a significant difference in the reoperation rate between the groups. Frank *et al.*¹⁰ also reported similar survival distribution after OCA (180 patients) between patients with and without a history of previous MST. In another study, Gracitelli *et al.*¹⁴ analyzed a population of 164 knees treated with OCA transplantation after previous failed cartilage repair with a minimum follow-up of 2 years. Of the 164 knees, 145 underwent a previous MST procedure (88.4%), 3 underwent OAT (1.8%), 5 had previous OAT and MST procedure (3%), 5 knees underwent prior ACI with MST (3%), 1 underwent ACI and MST and synthetic plugs transplantation (0.6%), and 1 had periosteal implantation (0.6%). Sixty-eight knees (41.5%) had reoperations after OCA transplantation and 31 (19%) were considered a failure. Survivorship of the OCA transplantation was 87.8% at 5 years and 82% at 10 years. In their study, most of the patients underwent previous MST alone or in conjunction with other cartilage restoration techniques (overall 95%); therefore, the effects of cartilage restoration techniques beside MST were not clearly identified.

Prior studies also investigated the outcome of revision OCA for prior failed OCA.^{15,16} Horton *et al.*¹⁶ reported data of 33 knees that underwent revision OCA transplantation after failed primary OCA with at least 2 years follow-up. In their study, revision OCA demonstrated inferior clinical outcomes compared to primary OCA with higher reoperation rate (22 patients [67%]) and failure rate (13 patients [39%]).¹⁹ Both reoperation and failure rates were higher than reported for primary allografts.^{19,20} In contrast, the present study shows that survival and reoperation rates were similar in patients undergoing primary or revision to OCA after prior ACI.

As postoperative outcomes, reoperation and failure rates are similar to primary OCA, revision to OCA provides a reliable treatment option after failed ACI.¹² ACI, as surface procedure, requires intact subchondral bone for the successful treatment of focal chondral lesions.²⁵ However, OCA technique removes the damaged, abnormal subchondral bone to a depth necessary to achieve normal subchondral bone and substitutes it by the donor bone, which makes the OCA technique resistant to subchondral bone abnormalities.^{14,26,27} This may explain the favorable clinical outcomes of OCA after failed ACI and marrow stimulation. Several studies showed that ACI provides excellent survivorship in younger patients over a long-term follow-up.^{6,8} Nevertheless,

Figure 1. Kaplan-Meier survival curves. Survival rate after either primary osteochondral allograft transplantation (Primary OCA [osteochondral allograft]) or revision to osteochondral allograft transplantation after prior failed autologous chondrocyte implantation (Revision to OCA). The endpoint was defined as the failure of the graft.

Figure 2. Pre- and postoperative patient-reported outcome measures between patients undergoing revision to OCA (osteochondral allograft) after failed ACI (autologous chondrocyte implantation) and primary OCA. Asterisk demonstrates significance ($P < 0.05$).

in case of failure, patients are still young, such as in our study in which the mean age when the patient underwent revision to OCA after a prior failed ACI was 36.23 years. Given that young patients demonstrate increased risk of failure, less improvement, and higher dissatisfaction after total knee arthroplasty,²⁸⁻³⁰ performing another cartilage restoration instead of arthroplasty might be more desirable for this young population.

Our study is not without limitations. First, the relatively small sample size. Revision to OCA after prior failed ACI is

a unique and rare procedure, performed in only 15 cases between September 2012 and February 2016. Second, the rather short follow-up period, which is a logical consequence of the rare nature of the procedure.

Conclusion

Revision of prior failed ACI with OCA is a viable treatment option with similar clinical outcomes, reoperation, and survivorship rates as primary OCA.

Figure 3. Improvement of patient-reported outcome measures from pre- to postoperative in patients undergoing revision to OCA (osteochondral allograft) after failed ACI (autologous chondrocyte implantation) and primary OCA. Asterisk demonstrates significance ($P < 0.05$).

Acknowledgments and Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

Our institutional review board approved this study (2018P000693/PHS).

Informed Consent

written informed consent was obtained from all patients at the time they were entered into the database.

ORCID iD

Jakob Ackermann <https://orcid.org/0000-0002-4063-5815>

Supplemental Material

Supplementary material for this article is available online.

References

- Batty L, Dance S, Bajaj S, Cole BJ. Autologous chondrocyte implantation: an overview of technique and outcomes. *ANZ J Surg.* 2011;81(1-2):18-25.
- Rosenberger RE, Gomoll AH, Bryant T, Minas T. Repair of large chondral defects of the knee with autologous chondrocyte implantation in patients 45 years or older. *Am J Sports Med.* 2008;36(12):2336-44.
- Farr J, Cole B, Dhawan A, Kercher J, Sherman S. Clinical cartilage restoration: evolution and overview. *Clin Orthop Relat Res.* 2011;469(10):2696-705.
- Asik M, Ciftci F, Sen C, Erdil M, Atalar A. The microfracture technique for the treatment of full-thickness articular cartilage lesions of the knee: midterm results. *Arthroscopy.* 2008;24(11):1214-20.
- Hangody L, Dobos J, Balo E, Panics G, Hangody LR, Berkes I. Clinical experiences with autologous osteochondral mosaicplasty in an athletic population: a 17-year prospective multicenter study. *Am J Sports Med.* 2010;38(6):1125-33.
- Minas T, Von Keudell A, Bryant T, Gomoll AH. The John Insall Award: a minimum 10-year outcome study of autologous chondrocyte implantation. *Clin Orthop Relat Res.* 2014;472(1):41-51.
- Nawaz SZ, Bentley G, Briggs TW, Carrington RW, Skinner JA, Gallagher KR, *et al.* Autologous chondrocyte implantation in the knee: mid-term to long-term results. *J Bone Joint Surg Am.* 2014;96(10):824-30.
- Ogura T, Bryant T, Minas T. Long-term outcomes of autologous chondrocyte implantation in adolescent patients. *Am J Sports Med.* 2017;45(5):1066-74.
- Ogura T, Mosier BA, Bryant T, Minas T. A 20-year follow-up after first-generation autologous chondrocyte implantation. *Am J Sports Med.* 2017;45(12):2751-61.
- Frank RM, Lee S, Levy D, Poland S, Smith M, Scalise N, *et al.* Osteochondral allograft transplantation of the knee: analysis of failures at 5 years. *Am J Sports Med.* 2017;45(4):864-74.
- Gomoll AH, Farr J, Gillogly SD, Kercher JS, Minas T. Surgical management of articular cartilage defects of the knee. *Instr Course Lect.* 2011;60:461-83.
- Rosa D, Di Donato SL, Balato G, D'Addona A, Smeraglia F, Corraa G, *et al.* How to manage a failed cartilage repair: a systematic literature review. *Joints.* 2017;5(2):93-106.
- Minas T, Gomoll AH, Rosenberger R, Royce RO, Bryant T. Increased failure rate of autologous chondrocyte implantation after previous treatment with marrow stimulation techniques. *Am J Sports Med.* 2009;37(5):902-8.
- Gracitelli GC, Meric G, Pulido PA, McCauley JC, Bugbee WD. Osteochondral allograft transplantation for knee lesions after failure of cartilage repair surgery. *Cartilage.* 2015;6(2):98-105.
- Murphy RT, Pennock AT, Bugbee WD. Osteochondral allograft transplantation of the knee in the pediatric and adolescent population. *Am J Sports Med.* 2014;42(3):635-40.

16. Horton MT, Pulido PA, McCauley JC, Bugbee WD. Revision osteochondral allograft transplantations: do they work? *Am J Sports Med.* 2013;41(11):2507-11.
17. Gross AE, Shasha N, Aubin P. Long-term follow-up of the use of fresh osteochondral allografts for posttraumatic knee defects. *Clin Orthop Relat Res.* 2005(435):79-87.
18. Bugbee W, Cavallo M, Giannini S. Osteochondral allograft transplantation in the knee. *J Knee Surg.* 2012;25(2):109-16.
19. Briggs DT, Sadr KN, Pulido PA, Bugbee WD. The use of osteochondral allograft transplantation for primary treatment of cartilage lesions in the knee. *Cartilage.* 2015;6(4):203-7.
20. Gracitelli GC, Meric G, Briggs DT, Pulido PA, McCauley JC, Belloti JC, *et al.* Fresh osteochondral allografts in the knee: comparison of primary transplantation versus transplantation after failure of previous subchondral marrow stimulation. *Am J Sports Med.* 2015;43(4):885-91.
21. Fulkerson JP. Anteromedialization of the tibial tuberosity for patellofemoral malalignment. *Clin Orthop Relat Res.* 1983;(177):176-81.
22. McCulloch PC, Kang RW, Sobhy MH, Hayden JK, Cole BJ. Prospective evaluation of prolonged fresh osteochondral allograft transplantation of the femoral condyle: minimum 2-year follow-up. *Am J Sports Med.* 2007;35(3):411-20.
23. Cotter EJ, Frank RM, Wang KC, Totlis T, Poland S, Meyer MA, *et al.* Clinical outcomes of osteochondral allograft transplantation for secondary treatment of osteochondritis dissecans of the knee in skeletally mature patients. *Arthroscopy.* 2018;34(4):1105-12.
24. Brittberg M, Gomoll AH, Canseco JA, Far J, Lind M, Hui J. Cartilage repair in the degenerative ageing knee. *Acta Orthop.* 2016;87(suppl 363):26-38.
25. Gomoll AH, Madry H, Knutsen G, van Dijk N, Seil R, Brittberg M, *et al.* The subchondral bone in articular cartilage repair: current problems in the surgical management. *Knee Surg Sports Traumatol Arthrosc.* 2010;18(4):434-47.
26. 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):718-26.
27. Farr J, Gomoll A. Osteochondral allograft. In: Farr J, Gomoll A, editors. *Cartilage restoration: practical clinical application.* New York: Springer; 2014. p. 131-43.
28. Kahn TL, Soheili A, Schwarzkopf R. Outcomes of total knee arthroplasty in relation to preoperative patient-reported and radiographic measures: data from the osteoarthritis initiative. *Geriatr Orthop Surg Rehabil.* 2013;4(4):117-26.
29. Riis A, Rathleff MS, Jensen MB, Simonsen O. Low grading of the severity of knee osteoarthritis pre-operatively is associated with a lower functional level after total knee replacement: a prospective cohort study with 12 months' follow-up. *Bone Joint J.* 2014;96-B(11):1498-502.
30. Scott CE, Oliver WM, MacDonald D, Wade FA, Moran M, Breusch SJ. Predicting dissatisfaction following total knee arthroplasty in patients under 55 years of age. *Bone Joint J.* 2016;98-B(12):1625-34.