



Comparison of Autologous Chondrocyte Implantation and Osteochondral Allograft Transplantation of the Knee in a Large Insurance Database: Reoperation Rate, Complications, and Cost Analysis

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Abstract

Objective. To compare (1) the reoperation rates, (2) risk factors for reoperation, (3) 30-day complication rates, and (4) cost differences between autologous chondrocyte implantation (ACI) and osteochondral allograft transplantation (OCA) of the knee in a large insurance database. **Design.** Subjects who underwent knee ACI (Current Procedural Terminology [CPT] code 27412) or OCA (CPT code 27415) with minimum 2-year follow-up were queried from a national insurance database. Reoperation was defined by ipsilateral knee procedure after index surgery. Multivariate logistic regression models were built to determine the effect of independent variables (age, sex, tobacco use, obesity, diabetes, and concomitant osteotomy) on reoperation rates. The 30-day complication rates were assessed using ICD-9-CM codes. The cost of the procedures per patient was calculated. Statistical comparisons were made. All *P* values were reported with significance set at $P < 0.05$. **Results.** A total of 909 subjects (315 ACI and 594 OCA) were included (mean follow-up 39.2 months). There was a significantly higher reoperation rate after index ACI compared with OCA (67.6% vs. 40.4%, $P < 0.0001$). Concomitant osteotomy at the time of index procedure significantly reduced the risk for reoperation in both groups (odds ratio [OR] 0.2, $P < 0.0001$ and OR 0.2, $P = 0.009$). The complication rates were similar between ACI (1.6%) and OCA (1.2%) groups ($P = 0.24$). Day of surgery payments were significantly higher after ACI compared with OCA ($P = 0.013$). **Conclusions.** Autologous chondrocyte implantation had significantly higher reoperation rates and cost with similar complication rates compared with OCA. Concomitant osteotomy significantly reduced the risk for reoperation in both groups.

Keywords

autologous chondrocyte implantation, osteochondral allograft, osteotomy, reoperations

Introduction

Knee chondral or osteochondral lesions are common with the reported prevalence as high as 66% in several studies.¹⁻⁴ These lesions have little potential for self-repair due to the avascular nature of articular cartilage.⁵⁻⁷ As such, if left untreated, these chondral defects may lead to osteoarthritis at an early age.^{8,9} Multiple surgical options for treating symptomatic cartilage defects in the knee have been described with an estimated 200,000 to 300,000 cartilage procedures performed annually in the United States.¹⁰⁻¹⁵

Debridement, microfracture, or osteochondral autograft transplantation are most commonly indicated in chondral defects less than 2 cm².^{12,13} However, in larger defects, autologous chondrocyte implantation (ACI) or osteochondral allograft transplantation (OCA) are more viable

options.^{11,14,15} Since it was first reported in 1994, studies have found favorable outcomes following the use of ACI with graft survivorship up to 87.5% at 10 years.¹⁵⁻¹⁹ Osteochondral allograft transplantation also has a long track record of success with graft survivorship up to 91.0% at 10-year follow-up and 86% of patients satisfied at 5 years following surgery.²⁰⁻²⁴

However, it is unclear which cartilage restoration technique is the most effective strategy for chondral defects as

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Table 1. Patient Demographics.

Variable	Autologous Chondrocyte Implantation, n = 315	Osteochondral Allograft Transplantation, n = 594	P
Age, years, mean \pm SD	30.2 \pm 10.7	32.1 \pm 12.1	0.014*
Female, n (%)	139 (44.1)	240 (40.4)	0.278
Pulmonary disease, n (%)	12 (3.8)	32 (5.4)	0.292
Diabetes, n (%)	6 (1.9)	13 (2.2)	0.776
Hyperlipidemia, n (%)	26 (8.3)	72 (12.1)	0.074
Myocardial infarction, n (%)	0 (0.0)	1 (0.2)	0.466
Tobacco use, n (%)	20 (6.4)	42 (7.1)	0.681
Cancer, n (%)	3 (1.0)	6 (1.0)	0.933
Obesity (BMI \geq 30 kg/m ²), n (%)	13 (4.1)	44 (7.4)	0.052
Mean CCI	0.11	0.14	0.407
Follow-up, months, mean \pm SD	40.8 \pm 21.5	38.4 \pm 17.5	0.056

BMI = body mass index; CCI = Charlson Comorbidity Index.

*Statistically significant.

there are limited data directly comparing ACI and OCA with regard to objective clinical outcomes. The purpose of this study was to compare (1) the reoperation rates, (2) risk factors for reoperation, (3) 30-day complication rates, and (4) cost differences between ACI and OCA of the knee in a large insurance database. The authors hypothesized that there would be no significant differences in (1) reoperation rates, (2) comorbidities would increase the risk for reoperations, (3) 30-day complications rates would be similar, and (4) cost would be similar between ACI and OCA of the knee.

Method

The MarketScan Commercial Claims and Encounters database (Truven Health Analytics, Ann Arbor, MI) from January 1, 2007 to December 31, 2016 was used for this study. This database is a collection of commercial inpatient, outpatient, and pharmaceutical claims. Only outpatient records in MarketScan were queried for this study. The MarketScan database contains International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) and 10th revision, Clinical Modification (ICD-10-CM), Current Procedural Terminology (CPT), Diagnosis-Related Group (DRG) codes as well as National Drug Codes (DEA).

Patients who underwent open ACI or open OCA of the knee in the outpatient setting with a minimum of 2-year follow-up were queried in the database using CPT codes 27412 and 27415, respectively. Records of the index surgery were reviewed for analysis. Patients without a CPT modifier for laterality (left or right) were excluded. Patients who had both procedures were excluded, thus making the cohorts mutually exclusive. Additionally, patients undergoing concomitant ligament reconstruction procedures were excluded. Patient-level variables, including age at time of

surgery, sex, and comorbidities (obesity, tobacco, myocardial infarction, congestive heart failure, peripheral vascular disease, cerebrovascular disease, dementia, chronic pulmonary disease, rheumatic disease, peptic ulcer disease, liver disease, diabetes, hemiplegia, renal disease, malignancy, AIDS/HIV, tobacco use) were recorded based on claims data (**Table 1**).

The primary outcome measure was rate of ipsilateral reoperation. Reoperation was defined by ipsilateral ACI (CPT code 27412), OCA (CPT codes 27415 or 29867), osteochondral autograft transplantation (CPT code 29866), synovectomy (CPT codes 29875 or 29876), chondroplasty (CPT code 29877), microfracture (CPT code 29879), manipulation under anesthesia (CPT code 27570), lysis of adhesions (CPT code 29884), arthroscopic loose body removal (CPT code 29874), debridement for infection (CPT codes 27301, 27303, 27310, 29871), osteotomy (CPT codes 27457, 27450, or 27418), partial knee replacement (CPT code 27446), and total knee replacement (CPT code 27447) that occurred after the index surgery date.

Ipsilateral reoperation was queried using CPT codes and the CPT modifiers for laterality to ensure that the procedures were reoperations and not contralateral procedures. The time period for potential reoperation was up to a maximum of 9 years postoperatively, depending on when the index ACI or OCA was performed. Multivariate logistic regression models were built for each cohort to determine the effect of independent variables (age, sex, tobacco use, obesity, diabetes, and concomitant osteotomy) on reoperation rates.

The 30-day postoperative complication rates were also assessed for both cohorts using the ICD-9-CM codes. These included bursitis, anemia, knee dislocation, infection, nerve injury, neurologic complications, cardiac complication, heterotopic ossification, sepsis, wound complication, deep vein thrombosis (DVT), pulmonary embolus (PE),

Table 2. Reoperations.

Variable	Autologous Chondrocyte Implantation, n = 315	Osteochondral Allograft Transplantation, n = 594	P
Overall reoperation rate, n (%)	213 (67.6)	240 (40.4)	<0.0001*
ACI	185 (58.7)	0 (0.0)	<0.0001*
OCA	7 (2.5)	203 (34.2)	<0.0001*
OAT	0 (0.0)	3 (0.5)	0.206
Osteotomy	58 (18.4)	28 (4.7)	<0.0001*
Osteotomy-DFO	2 (0.6)	6 (1.0)	0.564
Osteotomy-TTO	48 (15.2)	15 (2.5)	<0.0001*
Osteotomy-HTO	7 (2.2)	7 (1.2)	0.224
Arthroscopic	100 (31.7)	115 (19.4)	<0.0001*
Chondroplasty	39 (12.4)	35 (5.9)	0.0007*
Loose body removal	6 (1.9)	8 (1.4)	0.516
Lysis of adhesions	14 (4.4)	11 (1.9)	0.023*
Synovectomy	30 (9.5)	30 (5.1)	0.010*
Microfracture	7 (2.2)	24 (4.0)	0.151
Debridement for infection	1 (0.3)	3 (0.5)	0.684
Manipulation under anesthesia	4 (1.3)	7 (1.2)	0.905
Knee arthroplasty	4 (1.3)	19 (3.2)	0.078
UKA	1 (0.3)	3 (0.5)	0.684
TKA	3 (1.0)	16 (2.7)	0.081

ACI = autologous chondrocyte implantation; OCA = osteochondral allograft transplantation; OAT = osteochondral autograft transplantation; HTO = high tibial osteotomy; DFO = distal femoral osteotomy; TTO = tibial tubercle osteotomy; UKA = unicompartmental knee arthroplasty; TKA = total knee arthroplasty.

*Statistically significant.

hematoma, pulmonary complication, urinary tract infection (UTI), and delirium.

The cost of the procedures per patient was calculated using the DRG system. This included the entire reimbursement by the insurer on the day of surgery. The cumulative cost of the procedure per patient was also calculated at 9 months and 2 years postoperatively including the cost of reoperations.

Statistical comparisons of cohort demographics, reoperations, postoperative complications, and payments were made. The significance of differences in means of continuous variables between the two groups was determined by the Student *t* test. The differences in categorical variables between groups was determined by the chi-square test. Odds ratios (ORs) were calculated with respective 95% confidence intervals (CIs). Percentages in this study were a representation of proportion of the cohort. All *P* values were reported with significance set at *P* < 0.05.

As this study includes only analysis of secondary deidentified data, it was not considered human subject research and received exemption from the institutional review board approval at our institution.

Results

A total of 909 subjects (315 ACI and 594 OCA) out of 2,158 (682 ACI and 1476 OCA) met inclusion criteria and were

included in the study with a mean follow up of 39.2 months (**Table 1**). Demographics were similar between groups except subjects in the OCA group were statistically older (32.1 vs. 30.2 years old, *P* = 0.014).

There were significantly more patients who required ipsilateral reoperations after index autologous chondrocyte implantation (67.6%) compared to osteochondral allograft postoperatively (40.4%; *P* < 0.0001; **Table 2**). The most commonly reported reoperation was for revision ACI or OCA in each group, respectively. There were also significantly more patients who underwent osteotomy following ACI (18.4%) compared with OCA (4.7%; *P* < 0.0001; **Table 2**). Subjects undergoing ACI as the index procedure were also significantly more likely to undergo arthroscopic chondroplasty (12.4% vs. 5.9%, *P* = 0.0007), lysis of adhesions (4.4% vs. 1.9%, *P* = 0.023), and synovectomy (9.5% vs. 5.1%, *P* = 0.010) compared with patients who had OCA (**Table 2**). There were low rates of conversion to knee arthroplasty for ACI (1.3%) and OCA (3.2%) at final follow-up. There were no significant differences in unicompartmental and total knee arthroplasty rates between groups (**Table 2**).

There were no significant independent risk factors for reoperation after undergoing ACI in the current study (**Table 3**). Female sex was a significant risk factor for reoperation in the OCA group (OR 1.5, *P* = 0.017) (**Table 4**). Undergoing a concomitant osteotomy at the time of the ACI

Table 3. Multivariate Regression Analysis to Identify Predictors of Autologous Chondrocyte Implantation (ACI) Reoperation.

Variable	Odds Ratio (95% CI)	P
Age	1.0 (0.9-1.1)	0.973
Female vs. male	1.0 (0.6-1.7)	0.875
Tobacco use	1.2 (0.4-3.6)	0.784
Obesity	1.6 (0.4-7.8)	0.514
Diabetes	0.6 (0.1-4.4)	0.633
Concomitant osteotomy	0.2 (0.1-0.4)	<0.0001*

*Statistically significant.

Table 4. Multivariate Regression Analysis to Identify Predictors of Osteochondral Allograft Transplantation (OCA) Reoperation.

Variable	Odds Ratio (95% CI)	P
Age	1.0 (1.0-1.0)	0.238
Female vs. male	1.5 (1.1-2.1)	0.017*
Tobacco use	0.7 (0.4-1.4)	0.399
Obesity	0.8 (0.4-1.6)	0.572
Diabetes	0.8 (0.2-2.7)	0.785
Concomitant osteotomy	0.2 (0.1-0.7)	0.009*

*Statistically significant.

or OCA index procedure significantly reduced the risk for reoperation in both groups (OR 0.2, $P < 0.0001$ and OR 0.2, $P = 0.009$, respectively).

The overall complication rates were similar between the ACI (1.6%) and OCA (1.2%) groups ($P = 0.24$) (Table 5). The total day of surgery payments was significantly higher in the ACI group compared with OCA (\$15,397 vs. \$12,796, $P = 0.013$) (Table 6). This trend occurred at all time points in the study with a total 2-year cost of ACI at \$56,578 compared with the 2-year cost of OCA of \$33,426 including reoperations ($P < 0.0001$).

Discussion

Autologous chondrocyte implantation results in significantly higher reoperation rates, similar complication rates, and significantly higher cost compared to osteochondral allograft transplantation of the knee with concomitant osteotomy significantly reducing the risk for reoperation in both groups in a large insurance database.

Subjects undergoing autologous chondrocyte implantation as the index procedure had a significantly higher reoperation rate (67.6%) compared with those undergoing osteochondral allograft (40.4%) at final follow-up. The current study has significantly higher failure rates than previously reported in the literature for both the ACI and OCA groups. Previous studies have determined that ACI and OCA survivorship free from reoperation ranges from 71.0%

to 87.5% and 76.0% to 91.0% at up to 10 years following surgery, respectively.¹⁵⁻²⁴

This higher reoperation rate seen in both groups is likely multifactorial. In previous studies, graft failure was defined differently with the most commonly used definitions consisting of reoperation, revision surgery, need for knee arthroplasty, and failure to improve from baseline on patient reported outcomes scores postoperatively. As such, reoperation depends on the definition used. However, the study was able to perform an adequate comparison between cohorts by using the same definition of reoperation for subjects undergoing ACI and OCA treatments. This would seem to control for the varying definitions of failure seen in other studies.

Additionally, most of the peer-reviewed literature is from knee reconstruction experts with high-volume experience, usually of longer duration, and potentially greater familiarity with the procedures than the average orthopedic surgeon. As such, the current literature may underestimate the true reoperation rate in the general orthopedic surgeon population.²⁵ This becomes increasingly more evident after review of the present study with higher reoperation rates compared to the literature. Therefore, it is the opinion of the current authors that these surgeries be performed by high-volume surgeons with extensive experience in cartilage restoration in order to limit adverse outcomes and high reoperations.

Several patient demographic and anatomical factors have been identified that can affect the outcomes of ACI and OCA surgery. There were no independent predictors of reoperation in the current study utilizing multivariate logistic regression models for subjects undergoing autologous chondrocyte implantation. This is similar to a previous study by Jungmann *et al.* in which age, body mass index, smoking history, defect number, defect size, and defect location were not identified to be predictors of failure.²⁶ Two previous studies by Jaiswal *et al.*,^{27,28} however, did identify elevated body mass index and tobacco use as predictors of worse outcomes. However, this was based on patient-reported outcome scores and not failure or reoperation rates.

One potential explanation for the higher reoperation rate following ACI is the inclusion of multiple generations of ACI treatments. Although studies have shown similar clinical outcomes between the generations at two years, graft hypertrophy is significantly higher following ACI with periosteal patch (22%) compared to the using a membrane (6%), leading to higher reoperations.^{26,29-31} It is possible that the ACI cohort had a higher number of subjects that underwent use of periosteal patch resulting in reoperation compared to previous studies. As such, if subjects that underwent the older generation of ACI were excluded, the reoperation rate may more closely resemble that of the OCA cohort. However, this could not be reliably determined in the current study.

Table 5. Thirty-Day Complications.

Variable	Autologous Chondrocyte Implantation, n = 315	Osteochondral Allograft Transplantation, n = 594	P
Any complication, n (%)	5 (1.6)	7 (1.2)	0.243
Deficiency anemia, n (%)	0 (0.0)	2 (0.3)	0.303
Infection, n (%)	3 (1.0)	2 (0.3)	0.232
Sepsis, n (%)	1 (0.3)	0 (0.0)	0.170
Wound complication, n (%)	0 (0.0)	2 (0.3)	0.303
Deep vein thrombosis, n (%)	2 (0.6)	1 (0.2)	0.243
Hematoma, n (%)	0 (0.0)	2 (0.3)	0.303

Table 6. Procedure Payments.

Variable	Autologous Chondrocyte Implantation, n = 315	Osteochondral Allograft Transplantation, n = 594	P
Day of surgery payments	\$15,397	\$12,796	0.013*
Total payments			
9 months	\$29,749	\$22,266	<0.0001*
2 years	\$56,578	\$33,426	<0.0001*

*Statistically significant.

It is also possible that ACI was more frequently used in the patellofemoral joint. However, this is difficult to discern from the database. If that is the case, the reoperation rate in the current study would be more similar to that seen in the literature for patella ACI of 60% at up to 14 years postoperatively.³²

Multivariate logistic regression models in the osteochondral allograft cohort identified female gender as a predictor of reoperation. Previous studies had similar results with age, tobacco use, and obesity having no significant effect on reoperation rates.³³⁻³⁵ There are conflicting results with regards to the relationship between sex and graft failure in the literature, however. Frank *et al.*³³ demonstrated that males and females had similar outcomes following osteochondral allograft. This differs from the current study that demonstrated females to be predictive of reoperation. It is possible that the difference is due the study by Frank *et al.*³³ being underpowered to detect such a difference with only 170 subjects included compared with 594 in the present study.

Concomitant osteotomy was identified as an independent predictor of reduced reoperation in both the ACI and OCA cohorts in the present study. This confirms the results of several previous publications in the literature. With regard to ACI, several studies have found that concomitant osteotomy (distal femoral, high tibial, or tibial tubercle) results in improved clinical outcomes and graft survivorship.³⁶⁻³⁹ This same trend was also seen in patients following osteochondral allograft as residual malalignment was identified as a predictor for failure.^{40,41} Concomitant osteotomy unloads the affected compartment leading to reduced

contact pressures on the implanted graft which likely leads to improved graft survival and outcomes.⁴²⁻⁴⁵

Despite the increased reoperation rate following ACI compared with OCA, both cohorts had similar complication rates (1.6% vs. 1.2%, respectively, $P = 0.24$). These rates are similar to the previously reported complications following ACI and OCA.¹⁵⁻²⁴ However, it is possible that this complication rate may be underestimated. This is due to the presence of graft hypertrophy, which has been shown to occur in up to 22% of subjects following ACI with periosteal patch.³⁰ However, this is not a trackable code and may not have been identified in the present study other than potentially using postoperative chondroplasty as a surrogate for this risk factor for reoperation. This is important to note as periosteal patch is an independent predictor of reoperation following ACI.²⁶

The total day of surgery payments was significantly higher in the ACI group compared with OCA. The initial higher cost in the ACI group is likely due to initial differences in implant cost. However, this can be institution dependent with a prior study by Everhart *et al.*⁴⁶ demonstrating OCA to have a higher cost compared to ACI at a single academic institution. The same trend continued at 9 months and 2 years with the ACI group having a higher payout compared to the OCA cohort. At these later time points, the increased cost is likely due to the increased reoperation rate seen in the present study following ACI compared with OCA. The autologous chondrocyte implantation was used as the index surgery date with the initial cartilage biopsy not included in cost analysis. Additionally, prior to OCA implantation, many surgeons perform a staging

arthroscopy that would not be included in the cost analysis. Therefore, the total cost of both procedures would likely be even higher than reported in the present study, but the cost differences would likely remain the same.

Despite excellent outcomes and improved reoperation rates compared with ACI, the availability of osteochondral allografts internationally remains a concern.⁴⁷ This is likely due to cultural and educational differences among the populations with some countries reporting donor rates of only 1.1 per million people.⁴⁷ As such, the scarcity of fresh osteochondral allografts in some parts of the world may lead to osteochondral allografts having a higher cost compared with ACI or other cell-based cartilage restoration techniques.

It is important to note that despite the high cost of ACI and OCA, both remain a cost-effective option for the majority of subjects up to 10 years following the index procedure due to significant improvements in patient reported outcome scores.⁴⁶ This would continue to hold true even with a 50% increase in the cost of the procedures.⁴⁶ However, there is a point in which high reoperation rates make the procedure cost ineffective. Therefore, future research should continue to focus on the risk factors and potential causes of reoperations following ACI and OCA so that surgeons can mitigate this effect.

There are some limitations to this study inherent to all studies that use large databases. The analysis is dependent on the accuracy of the ICD and CPT codes reported. As such, inaccuracies, miscoding, or noncoding by physicians is a potential source of error. Additionally, patients can change insurances and therefore, leave the database. However, this was controlled for through inclusion of subjects with minimum 2-year follow-up. It is also possible that the database is not a true representation of the health care population in the United States. Additionally, the database only included records during a 9-year period from January 1, 2007 to December 31, 2016 so procedures (index or reoperation) that occurred outside that timeframe may have been missed. The current study also only identified complications that occurred within 30 days from the index procedure to increase the likelihood that the complications identified were related to the postoperative course following ACI and OCA and not another medical condition that arose. Thus, late complications that occurred outside the 30-day window were not captured in the present study. Cost analysis is based on the average, per patient total insurer payout per diagnosis at the time of surgery and follow-up time points including reoperations. This may not be representative of all institutions. There is also the limitation of not performing a formal chart review. Inherent to this type of study, there are multiple unknown confounding variables such as no direct physical contact, patient reported outcomes, or medical records access to determine diagnosis, prior procedures, meniscus status,

chondral defect size, chondral defect location, alignment, and all concomitant procedures.

In conclusion, ACI had significantly higher reoperation rates and cost with similar complication rates compared to OCA. Concomitant osteotomy significantly reduced the risk for reoperation in both groups.

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References

1. Aroen A, Loken S, Heir S, Alvik E, Ekeland A, Granlund OG, *et al.* Articular cartilage lesions in 993 consecutive knee arthroscopies. *Am J Sports Med.* 2004;32(1):211-5.
2. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31 516 knee arthroscopies. *Arthroscopy.* 1997;13(4):456-60.
3. Flanigan DC, Harris JD, Trinh TQ, Siston RA, Brophy RH. Prevalence of chondral defects in athletes' knees: a systematic review. *Med Sci Sports Exerc.* 2010;42(10):1795-801.
4. Hjelle K, Solheim E, Strand T, Muri R, Brittberg M. Articular cartilage defects in 1000 knee arthroscopies. *Arthroscopy.* 2002;18(7):730-4.
5. Newman AP. Articular cartilage repair. *Am J Sports Med.* 1998;26(2):309-24.
6. O'Driscoll SW. The healing and regeneration of articular cartilage. *J Bone Joint Surg Am.* 1998;80(12):1795-812.
7. Shapiro F, Koide S, Glimcher MJ. Cell origin and differentiation in the repair of full-thickness defects of articular cartilage. *J Bone Joint Surg Am.* 1993;75(4):532-53.
8. Lefkoe TP, Trafton PG, Ehrlich MG, Walsh WR, Dennehy DT, Barrach HJ, *et al.* An experimental model of femoral condylar defect leading to osteoarthritis. *J Orthop Trauma.* 1993;7(5):458-467.
9. 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):165-8.
10. Beris AE, Lykissas MG, Kostas-Agnantis I, Manoudis GN. Treatment of full-thickness chondral defects of the knee with autologous chondrocyte implantation: a functional evaluation with long-term follow-up. *Am J Sports Med.* 2012;40(3):562-7.
11. 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.
12. Gobbi A, Karnatzikos G, Kumar A. Long-term results after microfracture treatment for full-thickness knee chondral lesions in athletes. *Knee Surg Sports Traumatol Arthrosc.* 2014;22(9):1986-96.
13. 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.
14. 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.
15. Niemeyer P, Porichis S, Steinwachs M, Erggelet C, Kreuz PC, Schmal H, *et al.* Long-term outcomes after first-generation autologous chondrocyte implantation for cartilage defects of the knee. *Am J Sports Med.* 2014;42(1):150-7.
16. Brittberg M, Lindahl A, Nilsson A, Ohlsson C, Isaksson O, Peterson L. Treatment of deep cartilage defects in the knee with autologous chondrocyte transplantation. *N Engl J Med.* 1994;331(14):889-95.
17. 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.
18. Peterson L, Vasiliadis HS, Brittberg M, Lindahl A. Autologous chondrocyte implantation: a long-term follow-up. *Am J Sports Med.* 2010;38(6):1117-24.
19. Kon E, Filardo G, Gobbi A, Berruto M, Andriolo L, Ferrua P, *et al.* Long-term results after hyaluronan-based MACT for the treatment of cartilage lesions of the patellofemoral joint. *Am J Sports Med.* 2016;44(3):602-8.
20. Chahal J, Gross AE, Gross C, Mall N, Dwyer T, Chahal A, *et al.* Outcomes of osteochondral allograft transplantation in the knee. *Arthroscopy.* 2013;29(3):575-88.
21. Emmerson BC, Gortz S, Jamali AA, Chung C, Amiel D, Bugbee WD. Fresh osteochondral allografting in the treatment of osteochondritis dissecans of the femoral condyle. *Am J Sports Med.* 2007;35(6):907-14.
22. Levy YD, Gortz S, Pulido PA, McCauley JC, Bugbee WD. Do fresh osteochondral allografts successfully treat femoral condyle lesions? *Clin Orthop Relat Res.* 2013;471(1):231-7.
23. Raz G, Safir OA, Backstein DJ, Lee PT, Gross AE. Distal femoral fresh osteochondral allografts: follow-up at a mean of twenty-two years. *J Bone Joint Surg Am.* 2014;96(13):1101-7.
24. Sherman SL, Garrity J, Bauer K, Cook J, Stannard J, Bugbee W. Fresh osteochondral allograft transplantation for the knee: current concepts. *J Am Acad Orthop Surg.* 2014;22(2):121-33.
25. Pugely AJ, Martin CT, Harwood J, Ong KL, Bozic KJ, Callaghan JJ. Database and registry research in orthopaedic surgery: part I: claims-based data. *J Bone Joint Surg Am.* 2015;97(15):1278-87.
26. Jungmann PM, Salzmann GM, Schmal H, Pestka JM, Sudkamp NP, Niemeyer P. Autologous chondrocyte implantation for treatment of cartilage defects of the knee: what predicts the need for reintervention? *Am J Sports Med.* 2012;40(1):58-67.
27. Jaiswal PK, Bentley G, Carrington RW, Skinner JA, Briggs TW. The adverse effect of elevated body mass index on outcome after autologous chondrocyte implantation. *J Bone Joint Surg Br.* 2012;94(10):1377-81.
28. Jaiswal PK, Macmull S, Bentley G, Carrington RW, Skinner JA, Briggs TW. Does smoking influence outcome after autologous chondrocyte implantation? A case-controlled study. *J Bone Joint Surg Br.* 2009;91(12):1575-8.
29. Bartlett W, Skinner JA, Gooding CR, Carrington RW, Flanagan AM, Briggs TW, *et al.* Autologous chondrocyte implantation versus matrix-induced autologous chondrocyte implantation for osteochondral defects of the knee: a prospective, randomised study. *J Bone Joint Surg Br.* 2005;87(5):640-5.

30. Harris JD, Siston RA, Pan X, Flanigan DC. Autologous chondrocyte implantation: a systematic review. *J Bone Joint Surg Am.* 2010;92(12):2220-33.
31. Zeifang F, Oberle D, Nierhoff C, Richter W, Moradi B, Schmitt H. Autologous chondrocyte implantation using the original periosteum-cover technique versus matrix-associated autologous chondrocyte implantation: a randomized clinical trial. *Am J Sports Med.* 2010;38(5):924-33.
32. von Keudell A, Han R, Bryant T, Minas T. Autologous chondrocyte implantation to isolated patella cartilage defects. *Cartilage.* 2017;8(2):146-54.
33. Frank RM, Cotter EJ, Lee S, Poland S, Cole BJ. Do outcomes of osteochondral allograft transplantation differ based on age and sex? A comparative matched group analysis. *Am J Sports Med.* 2018;46(1):181-91.
34. Thomas D, Shaw KA, Waterman BR. Outcomes after fresh osteochondral allograft transplantation for medium to large chondral defects of the knee. *Orthop J Sports Med.* 2019;7(3):2325967119832299.
35. Wang D, Rebolledo BJ, Dare DM, Pais MD, Cohn MR, Jones KJ, *et al.* Osteochondral allograft transplantation of the knee in patients with an elevated body mass index. *Cartilage.* 2019;10(2):214-21.
36. Bode G, Schmal H, Pestka JM, Ogon P, Sudkamp NP, Niemeyer P. A non-randomized controlled clinical trial on autologous chondrocyte implantation (ACI) in cartilage defects of the medial femoral condyle with or without high tibial osteotomy in patients with varus deformity of less than 5°. *Arch Orthop Trauma Surg.* 2013;133(1):43-9.
37. Ferruzzi A, Buda R, Cavallo M, Timoncini A, Natali S, Giannini S. Cartilage repair procedures associated with high tibial osteotomy in varus knees: clinical results at 11 years' follow-up. *Knee.* 2014;21(2):445-50.
38. Trinh TQ, Harris JD, Siston RA, Flanigan DC. Improved outcomes with combined autologous chondrocyte implantation and patellofemoral osteotomy versus isolated autologous chondrocyte implantation. *Arthroscopy.* 2013;29(3):566-74.
39. Zarkadis NJ, Belmont PJ Jr, Zachilli MA, Holland CA, Kinsler AR, Todd MS, *et al.* Autologous chondrocyte implantation and tibial tubercle osteotomy for patellofemoral chondral defects: improved pain relief and occupational outcomes among US Army Servicemembers. *Am J Sports Med.* 2018;46(13):3198-208.
40. Leon SA, Mei XY, Safir OA, Gross AE, Kuzyk PR. Long-term results of fresh osteochondral allografts and realignment osteotomy for cartilage repair in the knee. *Bone Joint J.* 2019;101-B(1_Suppl_A):46-52.
41. Krych AJ, Hevesi M, Desai VS, Camp CL, Stuart MJ, Saris DBF. Learning from failure in cartilage repair surgery: an analysis of the mode of failure of primary procedures in consecutive cases at a tertiary referral center. *Orthop J Sports Med.* 2018;6(5):2325967118773041.
42. Stephen JM, Lumpaopong P, Dodds AL, Williams A, Amis AA. The effect of tibial tuberosity medialization and lateralization on patellofemoral joint kinematics, contact mechanics, and stability. *Am J Sports Med.* 2015;43(1):186-94.
43. Rue JP, Colton A, Zare SM, Shewman E, Farr J, Bach BR Jr, *et al.* Trochlear contact pressures after straight anteriorization of the tibial tuberosity. *Am J Sports Med.* 2008;36(10):1953-9.
44. Quirno M, Campbell KA, Singh B, Hasan S, Jazrawi L, Kummer F, *et al.* Distal femoral varus osteotomy for unloading valgus knee malalignment: a biomechanical analysis. *Knee Surg Sports Traumatol Arthrosc.* 2017;25(3):863-8.
45. Mina C, Garrett WE Jr, Pietrobon R, Glisson R, Higgins L. High tibial osteotomy for unloading osteochondral defects in the medial compartment of the knee. *Am J Sports Med.* 2008;36(5):949-55.
46. Everhart JS, Campbell AB, Abouljoud MM, Kirven JC, Flanigan DC. Cost-efficacy of knee cartilage defect treatments in the United States. *Am J Sports Med.* 2020;48:242-51.
47. Schmidt S, Schulte A, Schwarz S, Hofmann N, Tietz S, Boergel M, *et al.* Fresh osteochondral allografts-procurement and tissue donation in Europe. *Injury.* 2017;48(7):1296-301.