Comparison of Patient-Reported Outcomes for Immediate Unrestricted Weightbearing Versus Restricted Rehabilitation Protocols After Osteochondral Allograft Transplantation to the Distal Femur

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Background: There is no standardized rehabilitation protocol after osteochondral allograft (OCA) transplantation surgery to the distal femur. The spectrum of recommendations includes restrictions to toe-touch weightbearing (TTWB) for 6 weeks and immediate weightbearing as tolerated (WBAT).

Purpose/Hypothesis: The purpose of this study was to compare outcomes for immediate unrestricted WBAT to restricted TTWB after OCA transplantation to the distal femur. It was hypothesized that the immediate WBAT protocol would be noninferior to delayed, restricted TTWB.

Study Design: Retrospective cohort study.

Methods: A total of 74 patients who underwent press-fit, dowel technique OCA transplantation to the femoral condyle(s) for contained (International Cartilage Repair Society grade 3-4) lesions were identified in the Metrics of Osteochondral Allograft multicenter database: 36 patients (18 women/18 men) who were prescribed TTWB were allocated to the control cohort and 38 patients (21 women/17 men) who were prescribed WBAT were allocated to the test cohort. Baseline characteristics were similar except for larger grafts in test patients (3.4 vs 2.7 cm^2; P = .004) and higher body mass index (BMI) in control patients (27.8 vs 24.9 kg/m^2; P = .01). Failure rates, final patient-reported outcome (PRO) scores, and PRO score changes from baseline were compared between the cohorts. Multiple regression was used to control for potential confounders and investigate noninferiority using minimal clinically important differences (MCIDs).

Results: The mean follow-up was 2 years (range, 1-5 years) in both cohorts. Both cohorts showed significant improvement in all PRO scores, with no significant between-group differences in failure rates, final PRO scores, or PRO changes from baseline. There were 3 cases of failure in each cohort (control cohort: allograft revision [n = 2], debridement [n = 1]; test cohort: chondroplasty [n = 2], conversion to total knee arthroplasty [n = 1]). Regression analysis showed that adjusted differences in final PRO scores based on weightbearing protocol were minor and less than MCIDs when controlling for age, sex, graft size, BMI, and allograft location. Analysis of the MCIDs with respect to the lower bounds of the confidence intervals indicated that WBAT was noninferior to TTWB with a reasonable degree of confidence (range, 84.1%-99.9% confidence).

Conclusion: Results indicated that immediate unrestricted WBAT after OCA transplantation to the distal femur was equally safe and effective compared to restricted TTWB.

Keywords: osteochondral allograft; weightbearing; rehabilitation; knee

Osteochondral allograft (OCA) transplantation is a surgical procedure in which mature, viable hyaline cartilage and subchondral bone is taken from a donor and used to treat

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osteochondral defects in the recipient.[4,18,20,27] OCA transplantation is often considered a viable treatment option for patients with health limits secondary to osteochondral injury or disease, and when applied to the knee, it may be used to treat lesions in the femoral condyles, tibial plateau, patella, and trochlea. Current indications for the use of OCA transplantation include osteochondritis dissecans, failed previous cartilage repair procedures, avascular necrosis, traumatic lesions, and more; however, regardless of indication, this procedure is widely regarded as an effective treatment modality for osteochondral defects in a diverse spectrum of patients.[6,8,13,17,20,21,25,26] Prior studies have shown that outcomes after OCA transplantation to the knee vary based on a variety of factors, including age, sex, graft size, and body mass index (BMI), though conclusions are somewhat variable.[6,10,13,17,21,22,26] To date, no study has specifically investigated the impact of postoperative weightbearing on outcome.

Various rehabilitation protocols are employed after OCA transplantation surgery, which are often directed on a patient-specific basis. Most commonly, restrictive postoperative weightbearing protocols are employed that consist of toe-touch weightbearing (TTWB) for the first 6 to 8 weeks, with the intention of limiting compressive and/or shear forces on the transplanted allograft.[7,12-14,16,23,25,27] In 2021, the Metrics of Osteochondral Allograft (MOCA) Group released a consensus statement supporting the use of this restricted weightbearing protocol considering there were no published studies specifically investigating the safety and/or efficacy of any one rehabilitation protocol over another.[15] More specifically, at the time of the MOCA Group consensus, there were no available studies that evaluated the safety and/or efficacy of accelerated, unrestricted weightbearing protocols (eg, immediate unrestricted weightbearing as tolerated [WBAT] the same night as surgery) relative to the more commonly prescribed restricted protocols (eg, TTWB for 6 weeks).[12,16] However, MOCA Group contributors have observed and published cohorts of patients who are prescribed immediate WBAT and who achieve patient-reported outcome (PRO) scores similar to those in previously published restricted cohorts.[¶] An equally important observation stems from the observed benefits of early, normalized ambulation on patient convenience and overall surgical experience. Further adding to this is the well-established importance of normalized ambulation and weightbearing on cartilage health and atrophy/thinning prevention.[2,9,15,24] Therefore, if they are safe and effective, accelerated, unrestricted WBAT protocols after OCA transplantation surgery may have practical and physiologic benefits that allow the field to continue building on the previously established work of the MOCA Group.

In recognition of this gap in evidenced-based medicine, we undertook a preliminary proof-of-concept investigation to compare immediate, unrestricted weightbearing as tolerated (WBAT) versus delayed, restricted weightbearing (TTWB) protocols after OCA transplantation surgery to the distal femur. The principal goal of our investigation was to identify the relative safety and efficacy of a more permissive weightbearing prescription relative to the more common restrictive option. A secondary, indirect goal was to help guide orthopaedic surgeons when managing patients undergoing OCA transplantation surgery in the early postoperative period. We hypothesized that immediate WBAT would be noninferior to delayed, restricted TTWB.

METHODS

Study Cohort

After receiving institutional review board approval for the study protocol, the MOCA multicenter database was queried to identify two cohorts of patients, both of which underwent OCA transplantations to the femoral condyle(s) but differed in their respective weightbearing protocols: a control cohort that was prescribed restricted TTWB for 6 weeks and a test cohort that was prescribed immediate unrestricted WBAT. As a function of different institutional practices related to postoperative rehabilitation protocols, allocation to either the TTWB (control) cohort or WBAT (test) cohort was a function of the institution at which the patient received treatment.

To be included in the study, patients must have undergone press-fit, dowel-technique OCA transplantation to the medial femoral condyle (MFC) and/or lateral femoral condyle (LFC) for contained International Cartilage Repair Society (ICRS) grade 3 or 4 lesions (varying etiology). All

[¶]References 1, 3, 6, 10, 11, 13, 17, 21, 22, 25, 26.

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Ethical approval for this study was obtained from Oregon Health & Science University (ref No. STUDY00017035).

patients in the MOCA database were screened for inclusion. All patients underwent surgery with the same proprietary standardized equipment. Complete sets of International Knee Documentation Committee (IKDC) score and Knee injury and Osteoarthritis Outcome Score (KOOS) data were collected at baseline and at a minimum of 1 year postoperatively (range, 1-5 years). Patients with inadequate baseline or follow-up data within the 1- to 5-year timeframe were excluded. Patients were also excluded if they had undergone major concomitant surgeries, defined as tibial osteotomies, anterior cruciate ligament surgery, and meniscal transplants/repairs.

Postoperative Rehabilitation Protocols

In the control (TTWB) cohort, for the first 6 weeks after surgery, patients were instructed to limit weightbearing on their surgical side to only the weight from resting their toe/heel on the ground while seated. Formal physical therapy was prescribed to all patients to maintain range of motion and protect against atrophy, and all patients were encouraged to remove the brace for strengthening exercises and active range of motion as tolerated starting the night of surgery. Patients were also instructed to keep their surgical knee locked in full extension while upright and during ambulation with crutches for the first 6 weeks and while sleeping for the first 2 weeks. After the first 6 weeks, patients were permitted to remove the knee brace and progress from partial to full weightbearing as tolerated. Full weightbearing range of motion was eventually permitted for all patients, but high-impact, repetitive activities were restricted until 1 year postoperatively.

In the test cohort, all patients were given prescriptions for immediate WBAT using crutches (to protect from falls) starting the same night as surgery. Knee braces locked in full extension were worn for postoperative weightbearing for the first 3 days (and discontinued thereafter) until the continuous femoral nerve block wore off, but patients were instructed to unlock the brace for open chain active and passive range-of-motion exercises starting the same night as surgery. Formal physical therapy was prescribed to all patients to prevent atrophy and preserve range of motion. Crutches were discontinued for normal ambulation once a limp was no longer noticeable. High-demand occupational/recreational activity was permitted no earlier than 3 months postoperatively or after a computed tomography (CT) scan showed bony incorporation of the transplanted allograft (data not presented).

PRO Metrics

The IKDC and KOOS were the PROs utilized to determine postoperative improvement. The IKDC includes various Likert scale questions, with sections for knee symptoms, function, and sports activities. Scores range from 0 (lowest level of function or highest level of symptoms) to 100 (highest level of function and lowest level of symptoms). Similarly, the KOOS includes various Likert scale questions, with 5 subscales: Symptoms; Pain; Sports and Recreation (Sports/Rec); Activities of Daily Living (ADL); and Quality of Life (QoL). Similar to the IKDC, the KOOS ranges from 0 (extreme problems) to 100 (no problems).[5]

The minimal clinically important difference (MCID) for PROs can be used to assess surgical knee improvement by determining the smallest meaningful change in score that is considered clinically relevant. MCIDs differ based on the procedure to which they are being applied. Specific to OCA transplantation surgery, previous research has established the following MCIDs or MCID ranges for the IKDC and KOOS subscales: 9.8 for IKDC; 2.5 to 6.3 for KOOS-Symptoms; 16.7 for KOOS-Pain; 25 for KOOS-Sports/Rec; 3.7 to 9.2 for KOOS-ADL; and 3.7 to 9.3 for KOOS-QoL.[19] For the PROs with MCID ranges, the upper limit was considered as the MCID for purposes of noninferiority testing. For example, 6.3 for KOOS-Symptoms, 9.2 for KOOS-ADL, and 9.3 for KOOS-QoL.

Statistical Analysis

The final PRO scores (ie, the IKDC and KOOS subscores), PRO score changes from baseline, and rates of failure (defined as needing additional surgery to re-treat the index condition) were compared between the TTWB and WBAT cohorts. It should be noted that regarding all cases of failure, the PRO metrics included in the statistical analyses were obtained before the revision surgery was performed.

Differences in cohort baseline characteristics were evaluated using 2-sided *t* tests, and 1-sided *t* tests were performed on final PRO scores and PRO score changes from baseline between cohorts to give a preliminary (ie, unadjusted) evaluation of the noninferiority hypothesis. Failure rates for each cohort were compared using the Fisher exact test. A significance level of $P < .05$ was used for all statistical testing.

Multiple regression analyses were performed to investigate adjusted differences in final PRO scores based on weightbearing protocol when controlling for various factors. Final PRO scores were specified as the dependent variables, with age, sex, allograft size (cm^2), location (MFC or LFC), allograft depth (mm), BMI (kg/m^2), and weightbearing protocol (WBAT or TTWB) as the independent variables. Linear relationships were assessed via scatterplots, multicollinearity was not indicated by the Farrar-Glauber test, heteroscedasticity was not indicated by the Breusch-Pagan test, and quantiles of the residuals were visually compared to normal quantiles via ***Q-Q*** (quantile-quantile) plots.

Using the confidence intervals from the regression models, noninferiority was investigated by comparing the lower bound of the confidence interval to the negative MCID for each respective PRO. Precise confidence values at the MCID were calculated to more specifically evaluate noninferiority.

RESULTS

Baseline Characteristics

A total of 74 patients were included in the study, with 36 patients (18 women, 18 men) in the control cohort

TABLE 1
Baseline Characteristics of the Study Cohorts[a]

Variable	Control: TTWB (n = 36)	Test: WBAT (n = 38)	*P*
Sex			—
Female	18 (50.0)	21 (55.3)	
Male	18 (50.0)	17 (44.7)	
Age, y	33.8 ± 11.6 (16-54)	33.1 ± 13.3 (14-58)	.82
BMI, kg/m^2	27.7 ± 5.7 (18.4-42.6)	24.9 ± 3.1 (19.6-35.7)	**.01**
Allograft size, cm^2	2.7 ± 1.0 (1.77-5.09)	3.4 ± 1.0 (1.77-6.7)	**.004**
Allograft depth, mm	7.8 ± 1.7 (6-15)	7.9 ± 2.3 (5-16)	.80
Allograft placement location			—
MFC, single graft	19 (52.8)	14 (36.8)	
LFC, single graft	13 (36.1)	21 (55.3)	
MFC, snowman	4 (11.1)	1 (2.6)	
MFC/LFC, single graft at each	0 (0)	2 (5.3)	
Concomitant surgeries/procedures, n	Meniscectomy (2), patellar/trochlear chondroplasty (1), trochlear chondroplasty (1), BMAC (5), loose body removal (1)	Meniscectomy (1), patellar chondroplasty (1), MPFL repair (2), lateral release (3), loose body removal (16)	—
Indications for surgery	Osteochondral defect, 21 (58.3); osteoarthritis, 6 (16.7); OCD, 6 (16.7); failed BioCartilage, 1 (2.8); failed microfracture, 1 (2.8); failed prior allograft, 1 (2.8)	Osteochondral defect, 9 (23.7); osteoarthritis, 4 (10.5); OCD, 22 (57.9); osteonecrosis, 1 (2.6); failed microfracture, 2 (5.3)	—
Baseline IKDC	41.3 ± 13.0 (15-72)	41.5 ± 18.2 (8-82)	0.94
Baseline KOOS-Symptoms	60.9 ± 16.8 (14-96)	55.3 ± 17.6 (7-89)	0.16
Baseline KOOS-Pain	57.5 ± 14.8 (14-83)	60.3 ± 18.8 (25-100)	0.47
Baseline KOOS-Sports/Rec	30.4 ± 21.6 (0-85)	30.0 ± 26.0 (0-85)	0.94
Baseline KOOS-ADL	67.7 ± 18.2 (20-99)	67.8 ± 22.5 (16-100)	0.98
Baseline KOOS-QoL	26.6 ± 15.6 (0-56)	23.8 ± 20.2 (0-75)	0.51

[a]Data are presented as n (%) or mean ± SD (range) unless otherwise indicated. Dashes indicate areas not applicable. Boldface *P* values indicate statistically significant difference between groups ($P < .05$). BMAC, bone marrow aspirate concentrate; BMI, body mass index; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; LFC, lateral femoral condyle; MFC, medial femoral condyle; MPFL, medial patellar femoral ligament; OCD, osteochondritis dissecans; TTWB, toe-touch weightbearing; WBAT, weightbearing as tolerated.

(TTWB) and 38 patients (21 women, 17 men) in the test cohort (WBAT). The mean follow-up was 2.1 years (range, 1-5 years) in both cohorts. The vast majority of included patients (88%) received single allografts. All allografts were implanted within 10 to 28 days of harvest, allowing enough time to check records and obtain final cultures before tissue expiration.

Indications for OCA transplantation included osteochondral defects (40.5%), osteochondritis dissecans (37.8%), focal osteoarthritis (13.5%), failed microfracture (4.1%), osteonecrosis (1.4%), failed prior allograft (1.4%), and failed BioCartilage extracellular matrix (1.4%). There were no intraoperative complications in either cohort. Concomitant procedures performed included loose body removal (n = 17), bone marrow aspirate concentrate applied to allograft (n = 5, all in the TTWB cohort), meniscectomy (n = 3), lateral release (n = 3), medial patellofemoral ligament repair (n = 2), trochlear chondroplasty (n = 2), and patellar chondroplasty (n = 2).

A detailed summary of all baseline characteristics can be found in Table 1. Mean age at time of surgery was 33.8 ± 11.6 years (range, 16-54 years) in the control cohort and 33.1 ± 13.3 years (range, (14-58 years) in the test cohort. Baseline IKDC and KOOS subscores were not different between cohorts, nor were most patient characteristics, with the exceptions of mean graft size (given as total transplanted area; used as a surrogate for lesion size), which was 2.7 ± 1.0 cm^2 (range, 1.77-5.09 cm^2) in the control cohort and 3.4 ± 1.0 cm^2 (range, 1.77-6.70 cm^2) in the test cohort (P = .004), and mean BMI, which was 27.7 ± 5.7 kg/m^2 (range, 18.4-42.6 kg/m^2) in the control cohort and 24.9 ± 3.1 kg/m^2 (range, 19.5-35.7 kg/m^2) in the test cohort (P = .01).

Outcomes

Statistically significant improvements in PRO scores from baseline to final follow-up were seen in both cohorts ($P <$ .001 for all) (Table 2). Mean final scores were not statistically different between cohorts. Furthermore, the differences between mean scores at final follow-up fell within the MCID for all included PRO metrics. PRO score changes (Δ) from baseline were not significantly different between

TABLE 2
Final PRO Scores and Score Changes from Baseline (Δ) in the Study Cohorts[a]

	Control: TTWB (n = 36)	Test: WBAT (n = 38)	*P* (vs Baseline)[b]	*P* (TTWB vs WBAT)
Final IKDC	65.8 ± 21.2 (26 to 100)	67.8 ± 22.8 (20 to 99)	<.001	.65
Final KOOS-Symptoms	75.1 ± 20.9 (18 to 100)	75.9 ± 18.1 (36 to 100)	<.001	.57
Final KOOS-Pain	78.2 ± 19.6 (14 to 100)	78.6 ± 21.5 (22 to 100)	<.001	.53
Final KOOS-Sports/Rec	64.9 ± 29.1 (0 to 100)	59.9 ± 32.3 (0 to 100)	<.001	.25
Final KOOS-ADL	85.6 ± 17.7 (22 to 100)	84.4 ± 20.7 (19 to 100)	<.001	.40
Final KOOS-QoL	55.9 ± 29.3 (0 to 100)	52.7 ± 30.3 (0 to 100)	<.001	.32
Δ_{IKDC}	26.0 ± 20.7 (–9.2 to 83)	26.0 ± 20.0 (–18 to 83)	—	.50
$\Delta_{\text{KOOS-Symptoms}}$	16.1 ± 23.2 (–21 to 78)	20.7 ± 21.1 (–25 to 79)	—	.81
$\Delta_{\text{KOOS-Pain}}$	22.7 ± 22.3 (–25 to 86)	18.3 ± 21.3 (–31 to 69)	—	.20
$\Delta_{\text{KOOS-Sports/Rec}}$	35.0 ± 26.8 (–20 to 100)	29.9 ± 29.0 (–20 to 95)	—	.22
$\Delta_{\text{KOOS-ADL}}$	20.3 ± 21.2 (–21 to 79)	16.6 ± 18.1 (–24 to 62)	—	.21
$\Delta_{\text{KOOS-QoL}}$	29.7 ± 27.4 (–19 to 100)	28.9 ± 26.0 (–13 to 94)	—	.45
Failure rate[c]	3 (8.3)	3 (7.9)	—	.64

[a]Data are presented as n (%) or mean ± SD (range). ADL, Activities of Daily Living; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, Quality of Life; Sports/Rec, Sports and Recreation; TTWB, toe-touch weightbearing; WBAT, weightbearing as tolerated.

[b]In both cohorts, the final PRO scores were significantly improved compared with baseline ($P < .05$ for all, paired t test).

[c]Failure was defined as needing repeat surgery to retreat the index condition. In the control cohort, the 3 failures comprised 2 allograft revisions and 1 debridement; in the test cohort, the 3 failures comprised 2 chondroplasties and 1 conversion to total knee arthroplasty.

groups (Table 2). A visual representation of baseline versus final PRO scores can be seen in Figure 1.

There were 3 cases of failure in the control cohort (3/36; 8.3%) and 3 cases of failure in the test cohort (3/38; 7.9%). In the control cohort, 2 patients required subsequent allograft revisions and 1 patient required a debridement procedure. In the test cohort, 2 patients required subsequent chondroplasty and 1 patient required conversion to total knee arthroplasty. The results of the Fisher exact test showed no statistically significant difference in failure rates between cohorts (Table 2).

Multiple Regression Analysis

Results from each regression model showed that adjusted absolute differences in final PRO scores between cohorts (based on rehabilitation protocol) are very small in magnitude (smaller than the MCIDs): 1.68 for IKDC; 1.30 for KOOS-Symptoms; 0.78 for KOOS-Pain; 3.39 for KOOS-Sports/Rec; 1.86 for KOOS-ADL; and 4.23 for KOOS-QoL (Table 3). When analyzing MCIDs with respect to the lower bounds of the confidence intervals (and calculating precise confidence levels), our regression models suggested that immediate WBAT was noninferior to TTWB in terms of IKDC (95.8% confidence), KOOS-Symptoms (84.1% confidence), KOOS-Pain (99.9% confidence), KOOS-Sports/Rec (99.5% confidence), KOOS-ADL (87.6% confidence), and KOOS-QoL (92.8% confidence) (Figure 2).

DISCUSSION

The present study is the first of its kind to compare PROs after uncomplicated OCA transplantation to the femoral condyles using 2 cohorts with distinctly different postoperative weightbearing protocols (ie, WBAT starting the same night as surgery compared to TTWB for 6 weeks). Previous studies have established the efficacy of OCA transplantation to treat a variety of knee pathologies in an array of patients, with findings illustrating various perioperative factors that may or may not influence outcomes (ie, sex, age, graft size, BMI, etc).[1,6,8,13,17,20,21,25,26] However, postoperative weightbearing has not to our knowledge been the focus of interest until the present study.

The importance and relevance of the current investigation stems from a lack of research aimed at comparing the safety and efficacy of immediate, unrestricted weightbearing compared to delayed, restricted weightbearing. The current literature suggests that most orthopaedic surgeons routinely employ the latter (ie, TTWB with crutches for the first 6 weeks) in hopes of protecting the newly transplanted allograft from compressive and/or shear forces, though no standardized protocol is universally prescribed.[1,7,10,14-18]

The MOCA Group[14] agreed that this more restricted protocol is justified in its 2021 consensus statement, given that less restrictive protocols had not yet been comparatively investigated. The present study fills this gap in evidence-based medicine, and its results indicate that the commonly applied restricted approach to weightbearing may not be necessary. In addition, findings from this study suggest that immediate, unrestricted weightbearing protocols (ie, WBAT the same night as surgery) will produce similar PROs. Though not explicitly investigated in this study, immediate WBAT may also yield additional benefits such as improved day-to-day convenience, quicker return to work/sports, better overall surgical experience, and potential reductions in cartilage atrophy/thinning. As such, immediate weightbearing after OCA surgery may

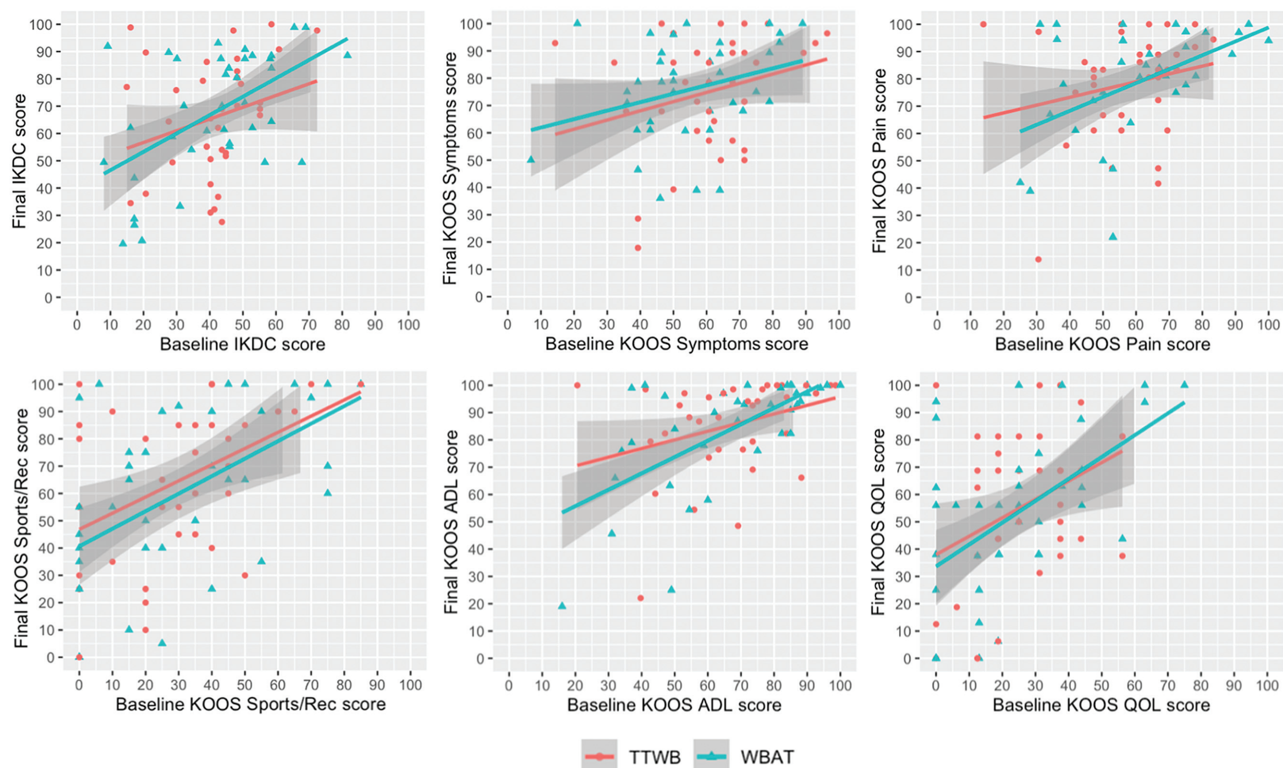

Figure 1. Scatterplots showing final and baseline IKDC and KOOS subscores for each cohort. Shaded areas indicate standard error. IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; Sports/Rec, Sports and Recreation; ADL, Activities of Daily Living; QoL, Quality of Life; TTWB, toe-touch weightbearing; WBAT, weightbearing as tolerated.

have both practical and physiology benefits for patients.[2,9,15,24]

The impact of immediate weightbearing on graft incorporation is not included in the present study as measured on CT imaging or magnetic resonance imaging. Postoperative imaging to evaluate the structural integrity of the graft is a crucial aspect of the transplantation's success or unidentified failure; however, prior studies have found no significant correlation between PRO scores (to include IKDC and KOOS scores) and the findings seen on 6-month postoperative CT scans.[1] Thus, we do not feel the lack of CT imaging data interferes with the ability to adequately compare PROs between cohorts. Nonetheless, we feel that the impact of early weightbearing on graft incorporation on CT is highly important and worthy of investigation before definitive recommendations can be made. As such, a future prospective study is planned using the MOCA database that will compare CT imaging findings based on weightbearing protocol.

Though not the primary focus of this investigation, in addition to providing insight into our noninferiority hypothesis, the findings from our regression model also provide insight into various other factors (aside from weightbearing) that may or may not influence PROs after OCA transplantation in the knee. For example, age was found to be a statistically significant variable insofar as final IKDC scores were concerned (P = .041), suggesting that older age is associated with slightly lower final IKDC scores, though only by a small margin (similarly small-magnitude but nonsignificant age associations were also seen in all KOOS subscores). In addition, baseline PRO scores were found to be statistically significant predictors of all final PRO scores achieved, which is not surprising and may hint at a ceiling effect in terms of OCA benefit in an already compromised joint. Weightbearing protocol (WBAT vs TTWB), sex (male vs female), graft size, graft depth, BMI, and allograft location (MFC vs LFC) were not found to be statistically significant predictors of final PRO scores, and indeed, in most cases, the association magnitudes were quite small.

Limitations

Admittedly, a major limitation of this study is the relatively small sample size (n = 74) that almost entirely comprised patients who received single allografts for contained lesions and were prescribed weightbearing prescriptions in a nonrandomized fashion. Very few patients had allografts placed in a snowman fashion, and there were no cases of allografts using the BioUni procedure. Thus, it is important to mention that our initial (proof-of-concept)

TABLE 3
Multiple Regression Analysis of Final PRO Score Against Weightbearing Rehabilitation Protocol While Controlling for Age, Sex, BMI, Allograft Location on Femoral Condyle, Allograft Total Area and Depth, and Baseline PRO Score[a]

	Final IKDC		Final KOOS-Symptoms		Final KOOS-Pain		Final KOOS-Sports/Rec		Final KOOS-ADL		Final KOOS-QoL	
	β (95% CI)	*P*	β (95% CI)	*P*	β (95% CI))	*P*	β (95% CI)	*P*	β (95% CI)	*P*	β (95% CI)	*P*
Age	–0.46 (–0.91 to −0.02)	**.041**	–0.33 (–0.75 to 0.09)	.123	–0.37 (–0.80 to 0.06)	0.090	–0.31 (–0.92 to 0.29)	.309	–0.23 (–0.60 to 0.15)	.232	–0.54 (–1.13 to 0.05)	.071
Sex (female [ref] vs male)	–2.58 (–13.01 to 7.86)	.623	1.57 (–8.49 to 11.62)	.756	1.43 (–8.66 to 11.52)	0.777	–0.49 (–14.87 to 13.89)	.946	0.99 (–7.78 to 9.77)	.821	–5.80 (–19.63 to 8.03)	.405
BMI	0.11 (–0.98 to 1.21)	.837	–0.15 (–1.19 to 0.89)	.781	0.05 (–1.01 to 1.11)	0.924	0.77 (–0.73 to 2.27)	.309	–0.09 (–1.01 to 0.83)	.848	0.74 (–0.71 to 2.19)	.311
Allograft location (LFC [ref] vs MFC)[b]	2.15 (–8.79 to 13.09)	.696	0.94 (–9.24 to 11.13)	.854	6.45 (–4.22 to 17.12)	0.232	3.80 (–10.97 to 18.57)	.609	4.85 (–4.35 to 14.05)	.296	8.16 (–6.57 to 22.88)	.272
Allograft total area	0.60 (–4.70 to 5.86)	.822	1.29 (–3.66 to 6.24)	.605	–0.08 (–5.14 to 4.97)	0.974	0.89 (–6.24 to 8.04)	.802	1.63 (–2.75 to 6.01)	.460	–0.976 (–7.64 to 6.12)	.826
Allograft depth	–0.17 (–2.76 to 2.42)	.896	–0.32 (–2.71 to 2.07)	.792	–0.17 (–2.67 to 2.33)	0.895	0.18 (–3.33 to 3.70)	.917	–0.15 (–2.31 to 2.00)	.886	–1.06 (–4.41 to 2.30)	.531
Baseline PRO score	0.59 (0.26 to 0.92)	**<.001**	0.32 (0.05 to 0.59)	**.023**	0.42 (0.12 to 0.72)	**0.007**	0.63 (0.34 to 0.91)	**<.001**	0.50 (0.28 to 0.71)	**<.001**	0.83 (0.45 to 1.21)	**<.001**
Rehab protocol (TTWB [ref] vs WBAT)	1.68 (–9.37 to 12.79)	.764	1.30 (–9.28 to 11.89)	.806	0.78 (–9.95 to 11.51)	0.885	–3.39 (–18.62 to 11.83)	.657	–1.86 (–11.21 to 7.49)	.693	4.23 (–10.54 to 18.99)	.569

[a]Boldface *P* values indicate statistical significance ($P < .05$). ADL, Activities of Daily Living; BMI, body mass index; PRO, patient-reported outcome; IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, Quality of Life; Ref, reference variable; Rehab, rehabilitation; Sports/Rec, Sports and Recreation; LFC, lateral femoral condyle; MFC, medial femoral condyle; TTWB, toe-touch weightbearing; WBAT, weightbearing as tolerated.

[b]The 2 patients in the WBAT cohort with allografts to both the MFC and LFC (1 graft each) were not included in the regression analysis to more accurately assess the relationship between allograft location and outcome.

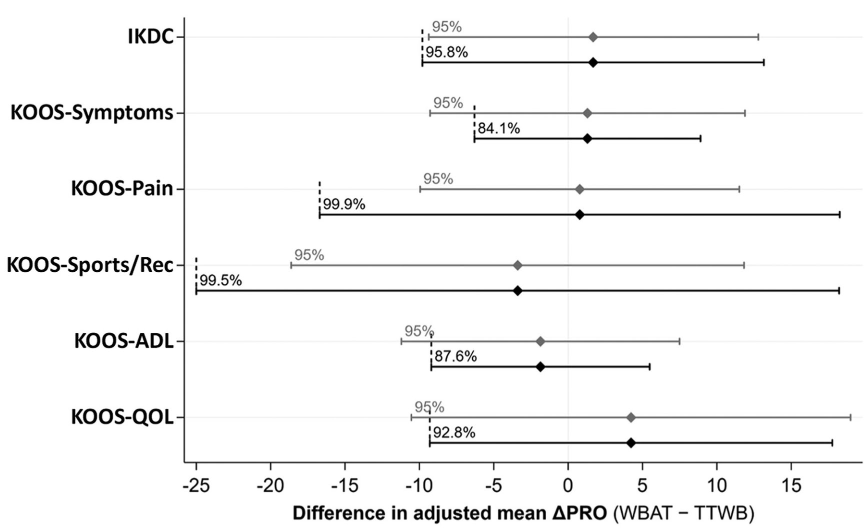

Figure 2. Visual summary of the differences in adjusted mean PRO changes between cohorts. Included are the precise confidence intervals at the minimal clinically important difference for each PRO subscore (represented by dashed vertical lines). IKDC, International Knee Documentation Committee; KOOS, Knee injury and Osteoarthritis Outcome Score; QoL, Quality of Life; Sports/Rec, Sports and Recreation; ADL, Activities of Daily Living; TTWB, toe-touch weightbearing; WBAT, weightbearing as tolerated; PRO, patient-reported outcome.

investigation applied almost exclusively to patients with single allografts. Another limitation of this study rests in cohort differences in mean allograft size ($P = .004$), which were used as a surrogate for lesion size. Allografts in the WBAT cohort were approximately 0.6 cm^2 larger on average compared with the TTWB cohort. However, we attribute much of this difference in mean graft size to 2 outliers in the WBAT cohort with graft sizes of 6.7 and 5.7 cm^2, respectively. Additionally, BMI values were found to be slightly higher in the control cohort compared to the test cohort (P = .01) and could be viewed as a limitation. However, similar to graft sizes in the WBAT cohort, the higher mean BMI in the TTWB cohort was likely due to 2 patient outliers with BMIs of 42.6 and 41.6 kg/m^2, respectively. Nonetheless, regression models showed that neither graft size nor BMI contributed to final PROs to a significant degree. Other potential confounding factors and limitations include differences in brace use, potential differences in number of physical therapy visits, lack of confirmation related to weightbearing status adherence, lack of data on muscle strength, and the inclusion of patients with a follow-up <2 years, which may have excluded PRO changes reflective of impending graft failure.

In full acknowledgement of the limitations of the current study, early investigation of our noninferiority hypothesis indicated that immediate, unrestricted WBAT may be equally safe and effective compared to delayed, restricted weightbearing protocols (eg, TTWB). However, before definitive recommendations can be made, future prospective studies using larger cohorts, imaging studies, and in-depth assessments of clinical outcomes to assess graft health should be completed. Additional studies should be conducted to evaluate the relative safety and efficacy of unrestricted weightbearing in cases of more complex graft architecture, including uncontained lesions, as well as the potential positive effects of immediate weightbearing after OCA transplantation, such as decreased physical therapy utilization, earlier return to work, reduced dependence on crutches, and improved quadriceps function. Nonetheless, the findings of the present study are encouraging, as immediate postoperative weightbearing may offer a less restrictive, more convenient, and physiologically beneficial surgical experience for patients undergoing OCA transplantation to the femoral condyles.

CONCLUSION

Study results indicated that immediate (same night as surgery), unrestricted WBAT after OCA transplantation to the distal femur may be equally safe and effective compared with delayed, restricted TTWB, potentially offering patients a less restrictive, more convenient, and physiologically beneficial surgical experience. Future prospective studies with larger cohorts, postoperative imaging, and assessment of clinical outcomes to evaluate graft health are needed to develop definitive recommendations.

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