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Impact of the Weightbearing Line on Cartilage Regeneration of the Medial Knee Compartment after Open-Wedge High Tibial Osteotomy, Based on Second-Look Arthroscopy

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Abstract

Objective. Cartilage regeneration is multifactorial. This study aimed to optimize the biomechanical factor of weightbearing loading allowing for cartilage regeneration and elucidate the association between cartilage regeneration and clinical outcomes after medial open-wedge high tibial osteotomy (OWHTO). *Design.* This was a retrospective, observational study of 142 patients who underwent OWHTO and subsequently underwent second-look arthroscopic assessment at a single orthopedic surgery center in Japan. Clinical and radiographic outcomes were compared between patients with (group R) and without (group D) cartilage regeneration, measured using the International Cartilage Repair Society grading system and the macroscopic staging system at the time second-look arthroscopy was performed. A receiver operating characteristic curve analysis was used to determine the optimal weightbearing line ratio (WBLR) for cartilage regeneration. *Results.* Group R included 82 knees, and group D 60 knees. The WBLR was higher in group R (60.9% $\pm$ 6.7%) than in group D (55.6% $\pm$ 7.6%) ($P < 0.001$) and was associated with a greater improvement in clinical outcomes, namely the Lysholm scale score and all subscales of the Knee Injury and Osteoarthritis Outcome Score ($P < 0.01$). The WBLR predicted cartilage regeneration with an odds ratio of 1.11 ($P = 0.001$) and an area under the curve of 0.718, for a WBLR value of 62%. *Conclusions.* A WBLR of 62% was associated with cartilage regeneration after OWHTO and high patient-reported clinical outcomes.

Keywords

knee cartilage, cartilage regeneration, open-wedge high tibial osteotomy

Introduction

Medial open-wedge high tibial osteotomy (OWHTO) is an established surgical procedure for the treatment of varus knee osteoarthritis (OA).[1,2] OWHTO improves the biomechanical environment of the knee joint by correcting the abnormal lower limb alignment with cartilage regeneration to produce the associated clinical outcomes and promote patient satisfaction.[3-7] Cartilage regeneration after high tibial osteotomy is influenced by multiple factors, including age, sex, body mass index (BMI), and postoperative knee alignment.[4] It should be noted, however, that the status of the articular cartilage at the time of second-look arthroscopy has not always been considered a predictor of clinical outcomes.[8,9] With regard to optimal lower limb alignment after OWHTO, Fujisawa *et al.*[10] reported good results when the weightbearing line (WBL) passed 30% to 40% lateral to the midpoint of tibial articular surface. In a subsequent study, this Fujisawa point was determined to be past WBL

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at 62.5% of the width of the tibial plateau, referenced to the medial edge of the plateau.[11] Overcorrection of the varus deformity is permitted, but should remain at ≤5° and not exceed 62.5% of WBL.[12] More recently, a neutral lower limb alignment has been indicated for active patients who want to return to sports.[13,14] Overall, these studies indicate that the optimal knee valgus angle after OWHTO remains an issue of clinical controversy.[15] To the best of our knowledge, cartilage regeneration after OWHTO has not been consistently reported until date. Accordingly, the purpose of our study was to optimize the biomechanical factor of weightbearing loading allowing for cartilage regeneration and elucidate the association between cartilage regeneration and clinical outcomes after OWHTO.

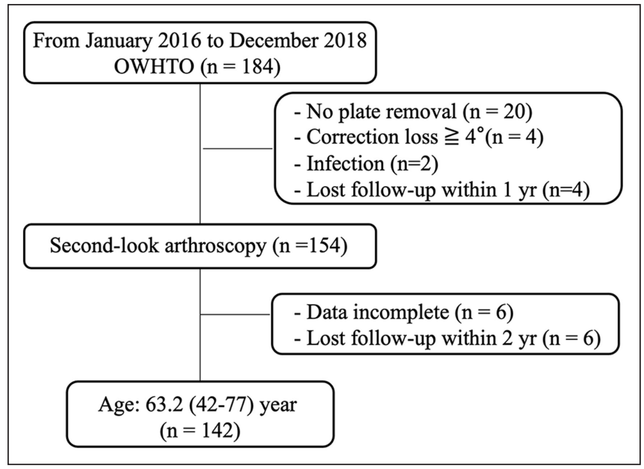

Figure 1. Patient selection flowchart. OWHTO = open-wedge high tibial osteotomy.

Methods

Research Ethics and Patient Consent

Ethical approval was obtained from our Institutional Review Board, with written informed consent obtained from all patients for treatment and the use of their clinical data for research and publication.

Surgical Indications

The surgical indications for OWHTO were medial compartment OA with varus malalignment localized in the tibia, BMI <35 kg/m^2, absence of or well-controlled diabetes mellitus, a knee flexion contracture ≤10°, and a minimum of 120° of knee range of motion (ROM). Prior to surgery, plate removal was recommended at 1 year after surgery to all patients. A total of 170 patients, contributing 184 knees, who underwent OWHTO between January 2016 and December 2019 were eligible for our study. Of these, second-look arthroscopy of the knee joint was performed in 154 knees. From this group, 12 knees were excluded for the following reasons: missing data on correction (n = 6) and lost follow-up within 2 years (n = 6). Ultimately, the results of second-look arthroscopy, performed approximately 12 months after OWHTO, were retrospectively evaluated for 142 knees (**Fig. 1**). The study group included 59 males and 83 females, with an average age of 63.2 ± 9.6 (range, 42-77) years and average BMI of 25.3 ± 4.3 (range, 18.6-33.7) kg/m^2. Second-look arthroscopy was performed at 13.5 ± 3.6 (range, 12.0-14.1) months after the index surgery, with the final follow-up performed at 31.0 ± 9.1 (range, 25.5-36.5) months (**Table 1**).

Table 1. Demographic Data.

	Data
Number (male/female)	142 (59/83)
Age	63.2 (9.6), 42-77
BMI	25.3 (4.3), 18.6-33.7
Interval from initial to second-look arthroscopy (months)	13.5 (3.6), 12.0-14.1
F/U period (months)	31.0 (9.1), 25.5-36.5

Data are expressed as M (SD) and range.
BMI = body mass index; F/U = follow-up.

Surgical Procedure and Assessment

The surgical procedure for OWHTO was performed as previously described.[16] Prior to surgery, the aiming point of the postoperative lower limb WBL was set at the lateral tibial eminence on coronal view that was calculated using digital planning software (TraumaCaD; BRAINLAB, Feldkirchen, Germany) from radiographs obtained in standing position with full weightbearing and stored in the picture archiving and communication system (PACS). All OWHTO procedures were performed by a single senior surgeon (S.O.), with arthroscopic examination of the knee joint performed in all patients at the time of surgery, and the degree of cartilage degeneration was quantified using the International Cartilage Repair Society (ICRS) grading system.[17]

Arthroscopic treatment of the knee joint at the time of OWHTO was individualized (**Table 2**). It included removal of meniscal flaps and degenerative tears and removal of loose bodies and osteophytes, particularly in the region of the intercondylar notch. No cartilage procedures were performed during the index surgery. For the OWHTO, the medial proximal tibia was exposed using a J-shaped incision and the superficial medial collateral ligament and 50% of the pes anserinus were released. Two Kirschner wires (K-wires) were inserted into the proximal tibiofibular joint, 35 to 40 mm inferior to the knee joint line, then fixed to the locking plate (TriS Medial HTO Plate System; OLYMPUS, Tokyo, Japan), and used as guides for the OWHTO. The gap

Table 2. Changes in ICRS Grade between Initial and Second-Look Arthroscopy.

	Second				
Initial	0-I	II	III	IV	Total
0-I	9	1	0	0	10
II	16	17	1	0	34
III	5	18	13	2	38
IV	0	1	33	26	60
Total	30	37	47	28	142

Group R is represented by gray background and group D is represented by white background.
ICRS = International Cartilage Repair Society.

created by the OWHTO was filled with β-tricalcium phosphate (OLYMPUS). Rehabilitation was initiated on postoperative day 2, with full weightbearing permitted, as tolerated by the patient.

Evaluation

At the second-look arthroscopy, knee joint cartilage damage was classified using the ICRS grading system, as during the initial arthroscopy at the time of OWHTO, with regenerated articular cartilage classified using the macroscopic staging system,[18] as follows: grade 0-I, normal or superficial fissure; grade II, damage to a depth of <50%; grade III, damage to a depth of >50%; and grade IV, exposure of subchondral bone. The most severe area of cartilage damage in the medial knee compartment was graded; this consisted of the femoral condyle in 40 knees and the tibial plateau in the remaining 102 knees. Representative cases of this grading are shown in **Figure 2**. For analysis, patients were classified into 2 groups according to the presence or absence of cartilage regeneration of the medial compartment at the time of the second-look operation, namely groups R and D, respectively. Group R was defined as those with preservation or regeneration of the medial cartilage as per the ICRS grade system. OA was evaluated using the Kellgren-Lawrence (K/L) grade. The following radiographic parameters were measured using whole-leg standing radiography and compared between the 2 groups: the weightbearing line ratio (WBLR)[19]; femorotibial angle (FTA), which is the lateral angle measured between the femoral and tibial shafts in standing position; and the medial proximal tibial angle (MPTA), which is the medial angle between the joint line and tibial shaft. The arthroscopic findings, ICRS grade, clinical variables (BMI and knee

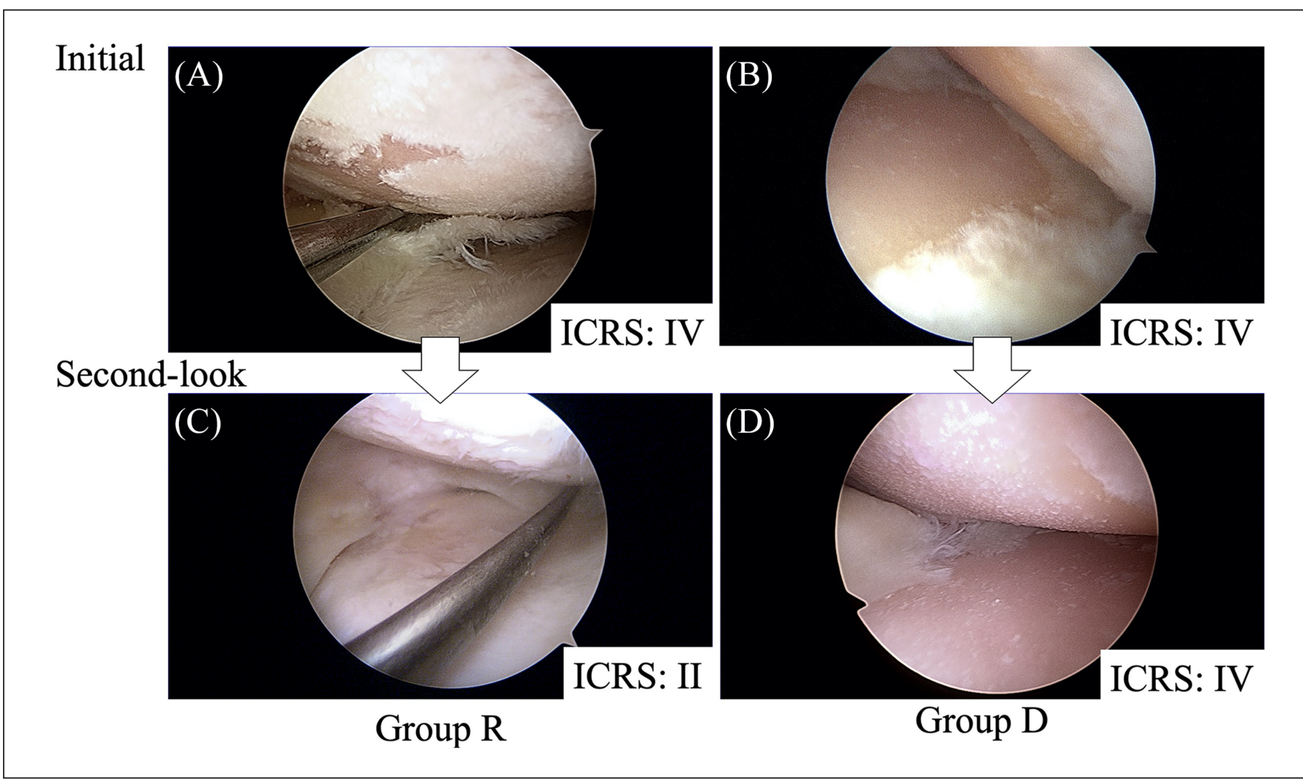

Figure 2. Assessment of cartilage degeneration as per the ICRS grading system. (**A**, **B**) Arthroscopic view during the index surgery (**C, D**). Second-look arthroscopy for the same cases as shown in (**A**, **B**). Cartilage regeneration is observed in group R (**A**, **C**), with no changes from the preoperative baseline in group D (**B**, **D**).
ICRS = International Cartilage Repair Society.

Table 3. Comparison of Patient Demographic Data.

	Group R (n = 82)	Group D (n = 60)	P value
Age (years)	61.3 (9.6)	66.2 (8.9)	0.004
Sex (male/female)	36 / 46	23 / 37	0.60
BMI (kg/m2)	25.1 (4.1)	25.8 (4.7)	0.88
K/L grade (I / II/ III / IV)	8/12/34/28	6/9/22/23	0.95
ICRS grade (I / II/ III / IV)			
Pre-op	9/16/23/34	1/18/15/26	0.12
Post-op	30/19/33/0	0/18/14/28	<.001
Meniscal tear			
No	18	10	
Yes (Suture/ meniscectomy)	64 (12/52)	50 (10/40)	0.43
ROM			
Pre-extension	−1.5 (2.9)	−1.7 (4.0)	0.72
Post-extension	−0.9 (2.4)	−1.7 (3.6)	0.11
Pre-flexion	141.8 (10.4)	140.9 (9.0)	0.58
Post-flexion	146.3 (7.7)	144.1 (6.3)	0.11

Wilcoxon test. K/L grade and ICRS grade were evaluated with Fisher test. Data are expressed as M (SD).
BMI = body mass index; K/L = Kellgren-Laurence; ICRS = International Cartilage Repair Society; ROM = range of motion; pre-op = preoperative; post-op = postoperative.

Table 4. Comparison of Radiographic Parameters.

	Group R (n = 82)	Group D (n = 60)	P Value
Correction angle (°)	9.5 (2.2)	9.2 (2.5)	n.s.
Pre-WBLR (%)	22.3 (11.4)	19.3 (11.7)	n.s.
Post-WBLR (%)	60.9 (6.7)	55.6 (7.6)	<0.0001
Pre-FTA (°)	180.4 (2.3)	181.1 (2.6)	n.s.
Post-FTA (°)	171.7 (1.6)	173.1 (2.2)	n.s.
Pre-MPTA (°)	83.0 (5.8)	82.8 (6.7)	n.s.
Post-MPTA (°)	92.4 (3.0)	91.1 (4.9)	n.s.

Wilcoxon test. Data are expressed as M (SD).
WBLR = weightbearing line ratio; FTA = femorotibial angle; MPTA = medial proximal tibial angle; pre- = preoperative; post- = postoperative.

joint ROM), and Lysholm scale score and Knee Injury and Osteoarthritis Outcome Score (KOOS) were also compared between the 2 groups.

Statistical Analysis

Between-group differences were evaluated using the Mann-Whitney U test and Wilcoxon signed-rank test for continuous variables and the chi-squared test for categorical variables. The relationships between preoperative and postoperative radiographic and clinical outcomes were evaluated using the Wilcoxon signed-rank test and multivariate regression analysis. Radiographic and arthroscopic findings were evaluated by 2 orthopedic surgeons (K.I. and S.O) for interobserver reliability, with measurements repeated at an interval of 4 weeks for intraobserver reliability. A receiver operating characteristic (ROC) curve analysis was used to determine the optimal WBLR for cartilage regeneration after OWHTO. A power analysis was performed to ensure sufficient representation to identify differences between the primary outcomes of the R and D groups at >80% power (G*power, version 3.1.9.6). All analyses were performed using JMP Pro (version 15.1.0; SAS, Cary, NC), with a P value <0.05 considered significant, and an odds ratio (OR) with a 95% confidence interval that does not include 1 was considered significant.

Results

The intraclass correlation coefficients for interobserver and intraobserver reliability of the measurements of radiographic parameters and ICRS were high overall (0.87 to 0.93 of WBLR, 0.71 to 0.91 of FTA, 0.71 to 0.90 of MPTA, and 0.84 to 0.91 of ICRS, respectively), indicative of high reliability.

Group R included 82 knees and group D 60 knees (**Table 2**), with a lower patient age for group R (61.3 ± 9.6 years) compared with group D (66.2 ± 8.9 years) (P = 0.004), with no between-group difference in BMI, K/L grade, meniscus treatment, or knee joint ROM (**Table 3**). Moreover, there were no between-group differences in the correction angle, FTA, and MPTA (**Table 4**). However, the postoperative WBLR was higher in group R (60.9±6.7%) than in group D (55.6±7.6%) (P < 0.001; **Table 4**). The improvement in the Lysholm score and all subscales of the KOOS was significantly greater for group R than group D (P < 0.01; **Table 5**). On multivariate logistic regression analysis, the WBLR was identified as an independent risk factor of cartilage regeneration (odds ratio, 1.11; 95% confidence interval, 1.04-1.18; P = 0.001; **Table 6**). The ROC analysis identified a WBLR cutoff value of 62% for cartilage regeneration based on an area under the curve of 0.718 (P < 0.01; **Fig. 3**).

Discussion

The most important finding of our study is the optimal cutoff WBLR value of 62% for cartilage regeneration, which is associated with better clinical outcomes after OWHTO. To date, cartilage regeneration after OWHTO has not been consistently reported. While some authors had demonstrated that articular cartilage regeneration of the medial compartment of the knee can be expected after medial OWHTO,[3,4,20-22] others did not identify a positive effect of OWHTO on cartilage regeneration or clinical outcomes.[8,9,23,24] The optimal correction angle for knee alignment for postoperative cartilage regeneration and associated clinical outcomes remains an issue of controversy.

Table 5. Comparison of Clinical Outcomes.

	Group R (n = 82)	Group D (n = 60)	P Value
Lysholm			
Pre-op	59.8 (9.1)	60.3 (8.6)	0.83
Post-op	86.9 (8.3)[a]	82.3 (9.1)[a]	0.002
KOOS symptom			
Pre-op	64.5 (19.4)	62.0 (18.6)	0.27
Post-op	82.7 (14.7)[a]	71.3 (16.9)[a]	<0.001
KOOS pain			
Pre-op	58.7 (17.5)	56.9 (14.2)	0.41
Post-op	83.2 (14.1)[a]	73.7 (14.5)[a]	<0.001
KOOS ADL			
Pre-op	74.1 (15.1)	69.6 (12.4)	0.08
Post-op	89.0 (9.8)[a]	81.3 (10.7)[a]	<0.001
KOOS sports			
Pre-op	36.3 (22.8)	31.3 (18.9)	0.09
Post-op	66.1 (24.9)[a]	45.5 (25.5)[a]	<0.001
KOOS QOL			
Pre-op	35.1 (22.0)	32.5 (16.7)	0.49
Post-op	66.3 (20.1)[a]	48.8 (21.6)[a]	<0.001

Wilcoxon test. Data are expressed as M (SD).
KOOS = Knee Injury and Osteoarthritis Outcome Score; ADL = activity of daily living; QOL = quality of life; pre- = preoperative; post- = postoperative.
[a]Significant difference between preoperative and postoperative outcomes by *t* test ($P < 0.05$).

Table 6. Results of Multivariate Logistic Regression Analysis of Independent Risk Factors of ICRS Improvement.

	OR (95% CI)	P Value
Age	0.958 (0.907-1.011)	0.113
BMI	0.977 (0.853-1.119)	0.742
Pre-WBLR (%)	1.013 (0.976-1.051)	0.502
Post-WBLR (%)	1.106 (1.036-1.182)	0.001
Pre-extension (°)	0.984 (0.856-1.129)	0.818
Post-extension (°)	1.073 (0.902-1.278)	0.418
Pre-flexion (°)	1.001 (0.959-1.045)	0.951
Post-flexion (°)	1.032 (0.966-1.102)	0.346

Mean (95% CI).
OR = odds ratio; CI = confidence interval; BMI = body mass index; WBLR = weightbearing line ratio; pre- = preoperative; post- = postoperative.

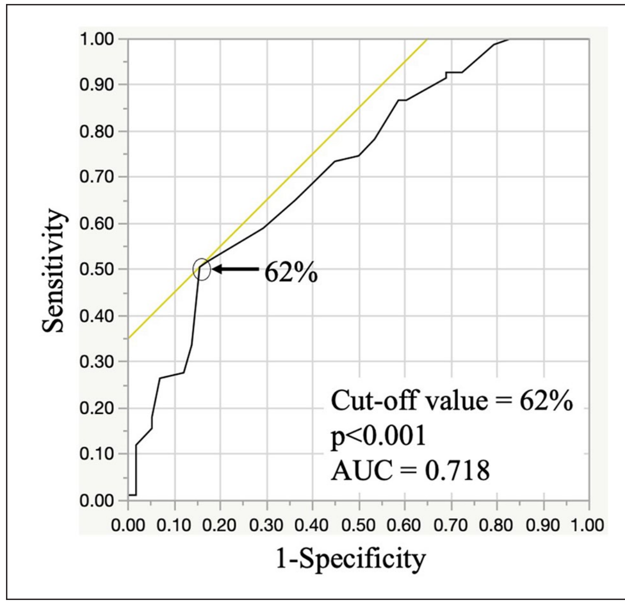

Figure 3. The ROC curves showing the accuracy of the cutoffs of the WBLR relative to an improvement in ICRS grade for a WBLR of 62%; the AUC was 0.718.
AUC = area under the ROC curve; ROC = receiver operating characteristic; ICRS = International Cartilage Repair Society.

Correction of knee alignment with OWHTO aims to either restore a "normal" lower limb alignment or change an "over-correction" into a valgus alignment, to unload the medial compartment with OA. Use of the "Fujisawa point," located at 62.5% of the width of the tibial plateau (from the medial side), has been recommended,[4,11,25]but its validity for all varus OA knees has been challenged.[26] Koshino *et al.*[27] reported that mature regeneration of knee joint cartilage was more likely for a lower limb valgus alignment >5°. As such, a postoperative WBLR within 60% to 70% would be desirable to optimize postoperative changes in the medial joint space and improve clinical outcomes.[9] This recommendation is supported by the findings of Lee *et al.*[6] that an undercorrection, defined as <3° hip-knee-ankle angle, was associated with worse clinical outcomes. However, overcorrection or undercorrection was not associated with clinical outcomes.[28,29] Kanto *et al.*[14] identified that a postoperative WBLR of 51.6% ± 8.4% improved outcomes after OWHTO among patients with knee OA who desired to continue sporting activities, producing a Tegner activity score ≥5 points after surgery. Saragaglia *et al.*[13] proposed that a neutral knee axis should be the target alignment for patients who practice sports such as running, tennis, jogging, and football. By contrast, Feucht *et al.*[30] proposed a target WBLR of 50% to 65% based on a patient's clinical characteristics. Overall, the target lower limb alignment after OWHTO varies rather widely among authors. Based on current evidence, for this study, we adopted the recommendation for a WBLR correction of 62% to support cartilage regeneration and associated good clinical outcomes after OWHTO. Our decision for a WBLR correction was based on evidence that severe varus knee deformity leads to loss of cartilage glycosaminoglycan in both the medial and lateral compartments,[31] indicating that overcorrection might induce lateral OA progression. On the contrary, cartilage quality, measured with the dGEMRIC index, was reported to be improved after OWHTO.[32] Furthermore, current study showed better clinical outcomes in cartilage regeneration rather than degeneration group in terms of the Lysholm score and all KOOS subcategories. Cartilage regeneration after OWHTO should be considered one of the biomarkers for patients' satisfaction.

This study has some limitations. Foremost, the retrospective and cross-sectional design does not allow for an evaluation of causational relationship between the WBLR and cartilage regeneration after OWHTO. Moreover, a longer follow-up period is needed to evaluate the relationship between cartilage regeneration and clinical outcomes. Again, owing to the retrospective, single-site design, selection bias cannot be excluded; this includes bias in terms of the patients who adhered to our preoperative suggestion to remove the plate at 1-year post-OWHTO. With regard to cartilage regeneration, we did not measure the size of the area, only its depth. Moreover, we did not include histological and biomechanical analyses of cartilage regeneration. However, the ICRS grading can be considered as a prospective follow-up comparing preoperative and postoperative cartilage status; the study revealed the causational relationship of one parameter, the optimal position of the WBL, which is very important in limb correction surgeries.

In conclusion, the likelihood of cartilage regeneration is associated with a postoperative WBLR with 62% being the optimal target point. In this study, cartilage regeneration is associated with better clinical outcomes after OWHTO.

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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.

Ethics Approval

The methods for this study were approved by our institutional ethics committee (registration number 2022-03).

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