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Posteromedial opening wedge high tibial osteotomy has favourable outcomes in simultaneous medial meniscus posterior root repair and varus medial knee osteoarthritis patients without concomitant root tear

Ali Engin Dastan[1,2*], Elcil Kaya Bicer[1*], Huseyin Kaya[1], Mehmet Argin[3] and Emin Taskiran[1]

Abstract

Purpose To evaluate the radiological and clinical outcomes in two patient groups: first, varus aligned medial meniscus posterior root tear (MMPRT) patients who underwent posteromedial open wedge high tibial osteotomy (PMOWHTO) and simultaneous root repair; second, patients with varus medial knee osteoarthritis without MMPRT who underwent PMOWHTO.

Methods Patients had MMPRT repair concomitant with PMOWHTO and varus medial knee osteoarthritis without concomitant root tear patients who underwent PMOWHTO and were reviewed. Radiographic parameters, medial meniscus extrusion (MME) and Knee Society Scores [KSSs, including the following subscores: knee score (KS) and knee function score (KFS)] were evaluated. Continious variables are expressed as the median and interquartile range (IQR) [IQR: (Q1;Q3); Q1: median of lower half, Q3: median of upper half]. The minimum follow-up period was 24 months [29 (28;35) months].

Results A total of 36 knees of 34 patients underwent PMOWHTO were included. Patients were divided into two groups according to the presence or absence of a MMPRT. Nineteen of the 36 knees had MMPRTs, and all of them had concomitant root repair (Group 1). Seventeen of the 36 patients did not have MMPRTs (Group 2). The posterior tibial slope (PTS) decreased postoperatively in a total of 36 knees ($p < 0.001$). There were no significant changes in MME postoperatively in any intragroup comparison. The preoperative and follow-up MMEs of Group 1 were greater than those of Group 2 ($p < 0.001$). The KSs and KFSs in both Group 1 and Group 2 increased during follow-up [KS; Group 1: 43 (36;53) vs. 86 (84;95), $p < 0.001$. Group 2: 49 (45;57) vs. 89 (80;93), $p < 0.001$. KFS; Group 1: 60 (50;60) vs. 90 (80;100),

*Correspondence:
Ali Engin Dastan
aengind@gmail.com
Elcil Kaya Bicer
elcil.kaya@ege.edu.tr
Full list of author information is available at the end of the article

$p < 0.001$. Group 2: 60 (50;60) vs. 80 (80;90), $p < 0.001$]. All knees achieved minimal clinically important difference (MCID) in terms of KSs. Eighteen (95%) knees achieved MCID in Group 1, and 17 (100%) achieved MCID in Group 2 in terms of KFSs. There were no differences between Groups 1 and 2 in terms of preoperative and follow-up KSs or preoperative KFSs. The follow-up KFSs in Group 1 was significantly greater than that in Group 2 ($p = 0.032$).

Conclusions PMOWHTO has favourable clinical and radiological outcomes and prevents PTS increase in simultaneous MMPRT repair and varus medial knee osteoarthritis patients without concomitant root tear.

Level of evidence Level IV, case series.

Keywords High tibial osteotomy, Posteromedial high tibial osteotomy, Tibial slope, Meniscus root tear, Root repair, Pull-out repair, Meniscus extrusion, Medial collateral ligament

Introduction

The incidence of knee osteoarthritis is increasing worldwide [1, 2]. The medial compartment is the most affected area in patients with knee osteoarthritis [3]. High tibial osteotomy (HTO) with or without concurrent procedures is a reliable treatment option for high demanding, physically active patients those who have varus-aligned knee osteoarthritis [4–6]. Following developments in implant technology, open wedge high tibial osteotomy (OWHTO) has become the most popular osteotomy technique in these cases, and satisfactory results have been published [7].

OWHTO has several issues that need to be addressed. The increase in the posterior tibial slope (PTS) is one of the main problems [8–13]. An increased PTS leads to anterior cruciate ligament (ACL) overloading, causes anterior tibial translation and is a risk factor for medial meniscus posterior root tears [12, 14–17]. In a recent study, a technical modification of OWHTO to decrease PTS was described [18]. In this posteromedial OWHTO (PMOWHTO) technique, the insertion of the medial collateral ligament (MCL) was preserved, the osteotomy site remained posterior to the MCL, and the osteotomy was directed from the posteromedial aspect of the tibia towards its anterolateral site [13]. The hinge is placed more anteriorly compared to conventional HTO techniques, while distraction is done from the posteromedial, thus, an increase in the tibial slope is avoided [18].

Varus alignment is a risk factor for medial meniscus posterior root tear (MMPRT) and a poor prognostic factor for root repair [19–23]. High tibial osteotomy (HTO) with or without root repair has gained popularity in the treatment of MMPRTs, and improved clinical outcomes have been published [24, 25]. HTO reduces the overload in the medial compartment, thus, accelerate healing [24–27].

The purpose of the current study was to evaluate the radiological and clinical outcomes in two patient groups: first, varus aligned MMPRT patients who underwent PMOWHTO and simultaneous root repair; second, patients with varus medial knee osteoarthritis without MMPRT who underwent PMOWHTO. The authors hypothesised that PMOWHTO may provide satisfactory radiological and clinical outcomes in both groups.

Materials and methods

Patients

The present study was based on a retrospective analysis of prospectively collected data. Local ethics committee approval was obtained (Ege University, decision number: 18-10.2/55). The records of patients who underwent PMOWHTO for medial knee osteoarthritis and PMOWHTO simultaneous with MMPRT repair between January 2014 and December 2017 were reviewed. Patients who had both initial and follow-up magnetic resonance imaging (MRI), standing full leg and lateral plain radiographs, and clinical scores were included. Patients who had concomitant ligament surgery, do not have control MRI and have follow-up period of less than 24 months were excluded. During the specified period, 81 knees underwent PMOWHTO. Ten knees were excluded due to concomitant ligament surgery. Twenty-eight knees of the remaining 71 knees were excluded due to the absence of a control MRI, and 7 knees were excluded for a follow-up period of less than 24 months. The remaining 36 knees of 34 patients were included in the study. Patients were divided into 2 groups according to the presence or absence of an MMPRT. Nineteen of the 36 knees had MMPRTs, and all of them had concomitant root repair (Group 1). Seventeen of the 36 knees did not have MMPRTs (Group 2) (Fig. 1). Initial clinical and radiological data were obtained from each patient's first admission. During the follow-up period, a control MRI was asked to evaluate meniscal status. Follow-up data, including clinical scores, radiographs and MRIs, were obtained during the same follow-up visit.

Surgical technique

In the authors' department, arthroscopic examination is performed in all PMOWHTO cases before starting osteotomy to evaluate intra-articular pathologies and intervene if necessary. In varus aligned MMPRT patients, root repair is performed simultaneously with PMOWHTO.

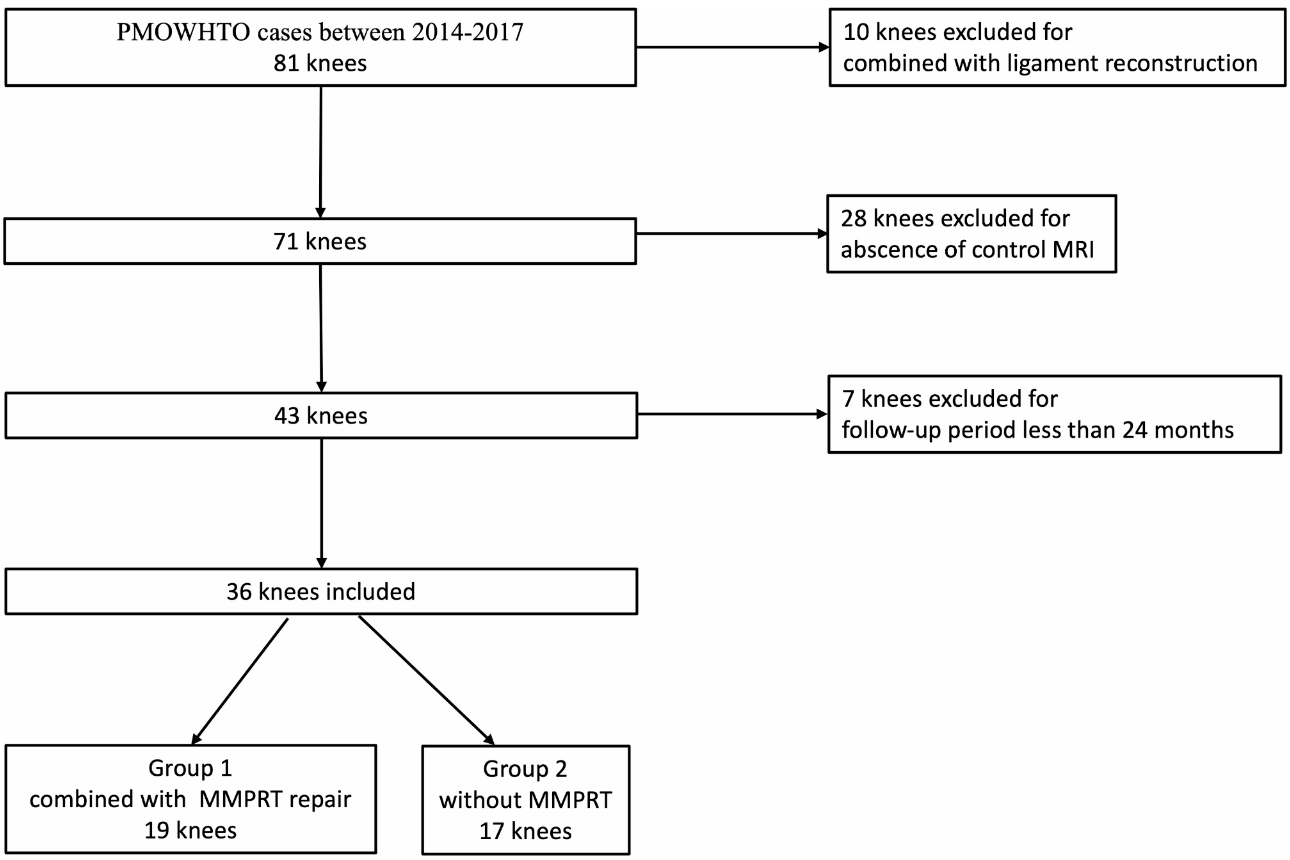

Fig. 1 Flow chart of patient selection. PMOWHTO: posteromedial opening wedge high tibial osteotomy, MMPRT: medial meniscus posterior root tear

Classical anteromedial and anterolateral portals were used during arthroscopic procedure. A 30° scope was used to intraarticular visulasition. Intraarticular examination is performed and if a root tear was detected, repair was performed before osteotomy. A cannulated needle was inserted percutaneously from the soft spot in the posteromedial portal location of the knee and this needle was passed through the meniscus root. A nylon traction suture was passed through the cannulated needle and the traction suture was taken out from the anteromedial portal. A 2.0 nonabsorbable suture was tied to the traction suture and the nonabsorbable suture was passed through the meniscus using the traction suture. The nonabsorbable suture passed through the meniscus was carried out from the anteromedial portal using a suture retriever. Depending on the morphology and size of the tear, the same procedure can be repeated a second time. The aim of surgical intervention in MMPRTs is to fix the root in its anatomical position, which is just anteromedial to the posterior cruciate ligament (PCL).

The fixation area was prepared via an arthroscopic shaver and curette. An ACL drill guide was placed from the anteromedial portal. With this guide, a K-wire sent from the anteromedial tibia was used to target the fixation area of the meniscus root and a tunnel was created. Nonabsorbable sutures passing through the meniscus were taken out through this tunnel and secured. After this, the PMOWHTO procedure was performed. When the PMOWHTO was completed, these sutures were pulled, the meniscus root was reduced into its anatomical position, and the sutures were fixed using a cortical screw (Figs. 2 and 3) [28].

After the arthroscopic procedures were completed, PMOWHTO was started. The correction angle was planned preoperatively. A longitudinal skin incision was made between the tibial tubercle and the posteromedial part of the tibia. The sartorius fascia was incised, and the posterior border of the MCL was incised longitudinally. The MCL was not cut and was released while keeping its insertion intact. A Hohman retractor was placed posterior to the tibia to protect nerves and vessels. Two parallel Kirschner wires were inserted into the posteromedial tibia above the level of the pes anserinus tendons, and the anterolateral surface of the tibia was directed. Uniplanar osteotomy was performed posterior to the MCL. The osteotomy direction ranged from posteromedial to anterolateral. The anterior cortex was cut with osteotomes at the level of the tibial tubercle. A distractor was inserted posterior to the MCL, and distraction was made. The intact MCL guaranteed the posteromedial

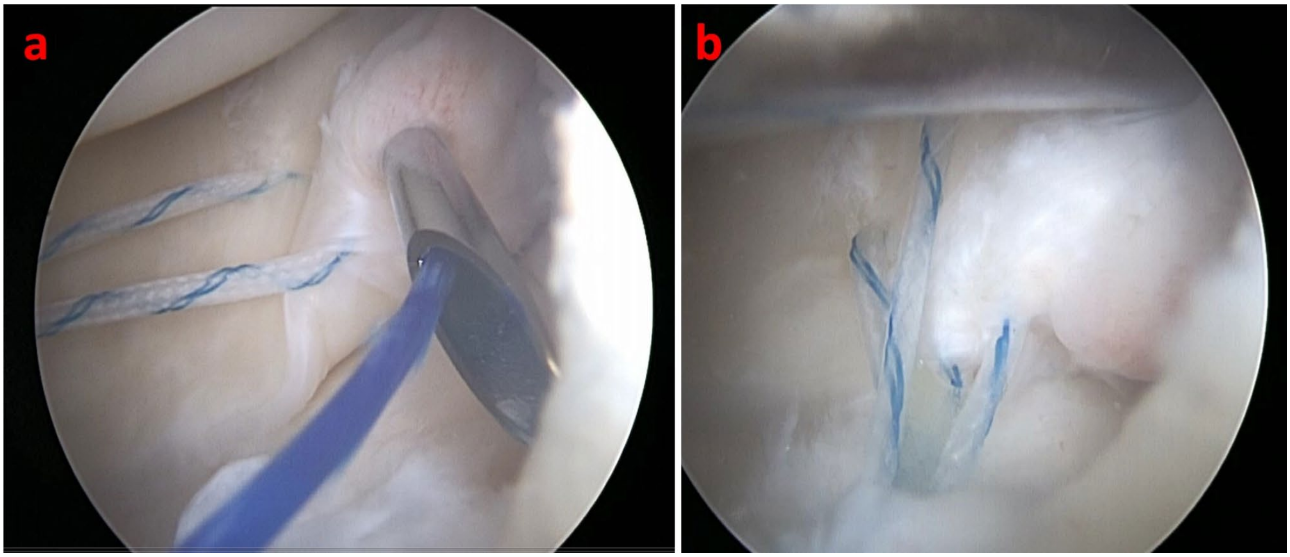

Fig. 2 Arthroscopic images of the medial meniscus posterior root tear (MMPRT) repair procedure in the left knee viewing from the anterolateral portal. **(a)** The first nonabsorbable suture was passed through the posterior root of the meniscus. It is seen that the nylon traction suture was loaded through the cannulated needle that is inserted percutaneously to pass the second nonabsorbable suture through the root. **(b)** The sutures were passed through the tunnel and the meniscus root is reduced by pulling the sutures

distraction, resulting in a larger posterior than anterior gap. A TomoFix plate was used for fixation (DePuy Synthes, Raynham, MA, USA). The osteotomy site was filled with an autologous iliac crest bone graft (Figs. 3 and 4) [18].

Postoperative care and rehabilitation

Mechanical prophylaxis was immediately started postoperatively to prevent deep vein thrombosis (DVT). For chemoprophylaxis, during hospitalisation, low-molecular-weight heparin was administered. After discharge, oral acetylsalicylic acid was prescribed for four weeks. Knee flexion exercises were started the day after surgery and the flexion angle was gradually increased. On the first postoperative day, patients were mobilised with two crutches and allowing toe-touch weight bearing. At the 6th week, the patient was allowed to walk with a single crutch allowing weight bearing as tolerated. At the 12th week, the patient was allowed to walk without a crutch and with full weight bearing. For patients who underwent root repair, deep knee flexion was forbidden for a total of 12 weeks.

MRI evaluation

Preoperative MR images of 16 patients were obtained at the authors' hospital, and 20 patients were obtained at other centres. MRIs obtained at the authors' hospital were performed via a Siemens Magnetom Verio 3T MRI scanner (Siemens, Erlangen, Germany). An eight-channel knee coil was used. The patient was placed in a supine position, and the knee was extended. The images were acquired via spin−echo T1-weighted sagittal sequences, as well as via proton density-weighted, fat-suppressed sagittal, coronal, and axial sequences. The images obtained in external centres were acquired via various brands of 1.5-Tesla MR scanners and consisted of T1- and proton density-weighted images or T2-weighted images.

All follow-up MR images were taken via a Siemens Magnetom Amira 1.5 Tesla device (Siemens, Erlangen, Germany) and an imaging program called Slice Encoding for Metal Artifact Correction (SEMAC; Siemens, Erlangen, Germany). A twenty-four-channel knee coil was used. The patient was placed in a supine position, and the knee was extended. T1-weighted sagittal, three-plan proton-weighted, and coronal fat-suppressed short tau inversion recovery (STIR) sequences were obtained.

The measurements of medial meniscus extrusion (MME) on the MR images were performed via Sectra software (Sectra AB, Linköping, Sweden). MME was measured in coronal MR slices in which the medial tibial spine apex was detected; [29] it was defined as the distance between the outer margin of the medial tibial plateau and the outer margin of the meniscus (Fig. 5). MME was measured twice by an experienced musculoskeletal radiologist (fourth author) and an orthopaedic surgeon (first author) at two-week intervals. Although the radiologist was blinded to the intraoperative findings, the orthopaedic surgeon was not. The averages of the measurements were used for analysis. Intraobserver and interobserver agreement was assessed with the intraclass correlation coefficient (ICC).

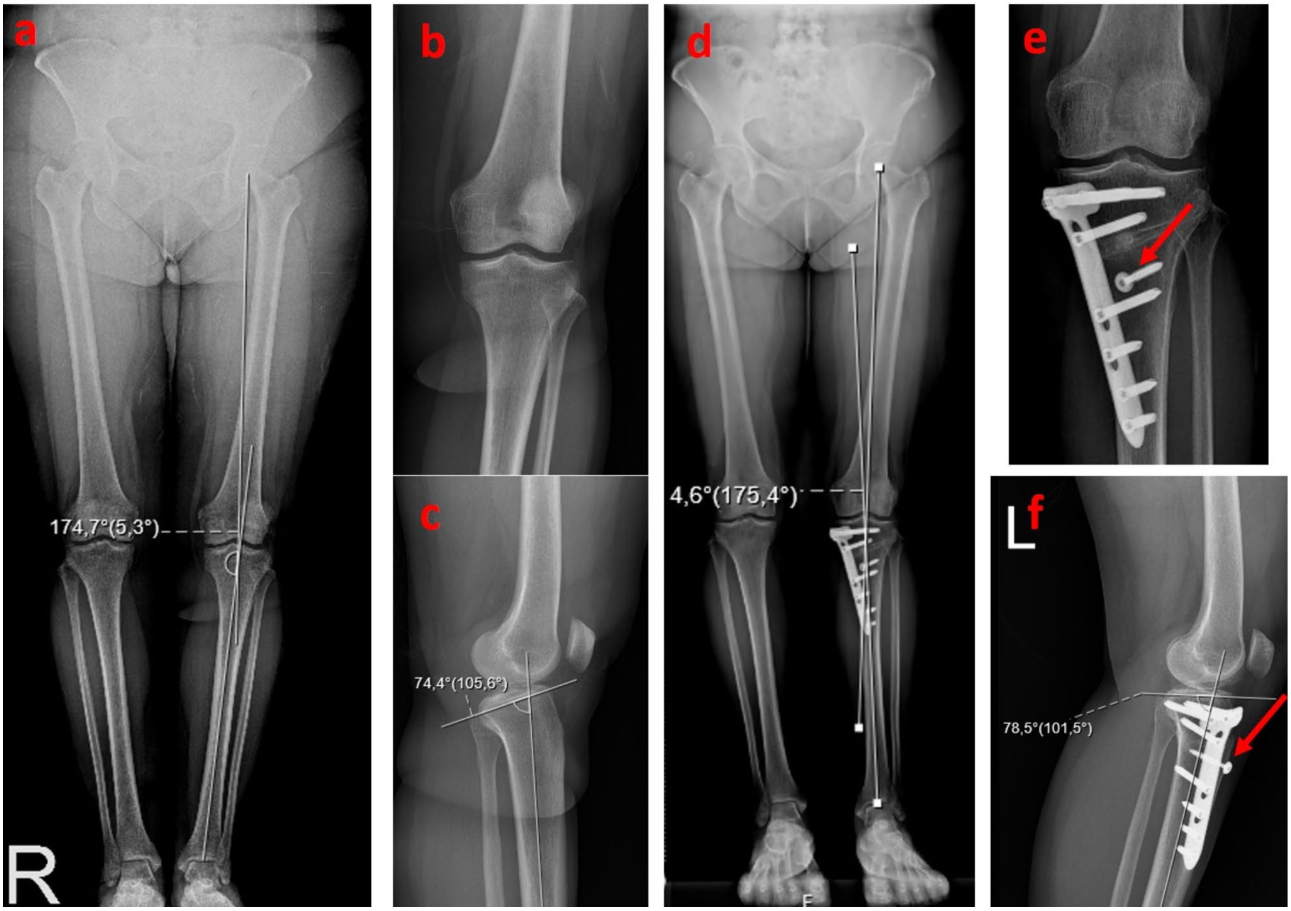

Fig. 3 **(a)** Preoperative weight-bearing full-leg length radiograph of a patient who had left medial meniscus root tear. Mechanical tibiofemoral angle of the left lower extremity was 5.3°. **(b)** Anterior-posterior radiograph of left knee. **(c)** Lateral radiograph of left knee. Posterior tibial slope was measured as 15.6°. **(d)** Postoperative weight-bearing full-leg length radiography after simultaneous medial meniscus posterior root repair and posteromedial opening wedge high tibial osteotomy. 4.6° of valgus alignment was measured. **(e, f)** Postoperative anterior–posterior and lateral views. The red arrows indicate the cortical screws used for pullout suture repair. Posterior tibial slope was measured as 11.5°

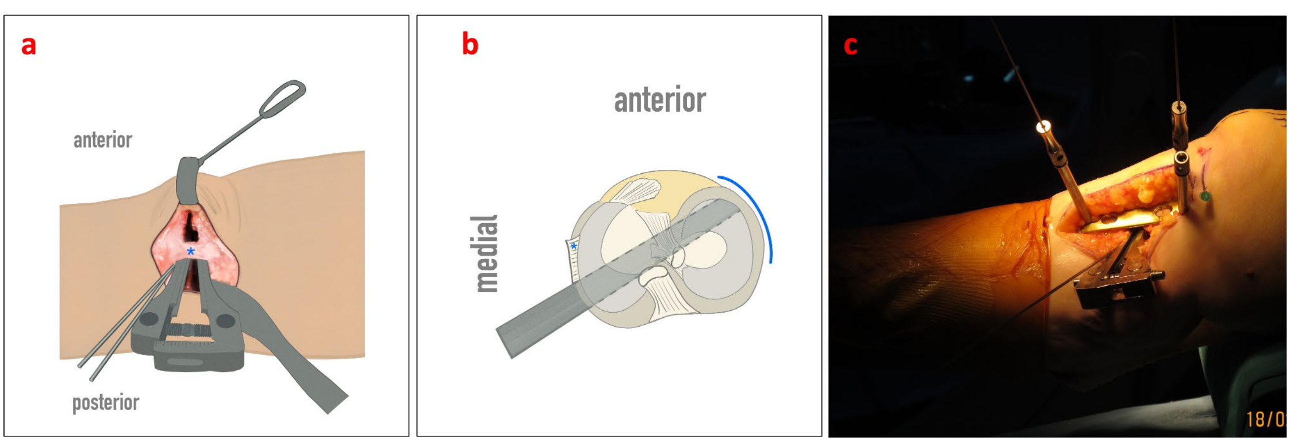

Fig. 4 **(a)** The medial collateral ligament (MCL) is not cut and is released while keeping its insertion intact. After the osteotomy is completed the distractor is inserted posterior to the MCL, and distraction iss made. The intact MCL guarantees the posteromedial distraction, resulting in a larger posterior than anterior gap. The asterisk indicates the MCL. **(b)** Superior view of the tibia during posteromedial opening wedge high tibial osteotomy (PMOWHTO) procedure. Note the projection of the distractor placed posterior to the MCL. The asterisk indicates the MCL, the blue line indicates the projection of the hinge. **(c)** Intraoperative view of a PMOWHTO procedure

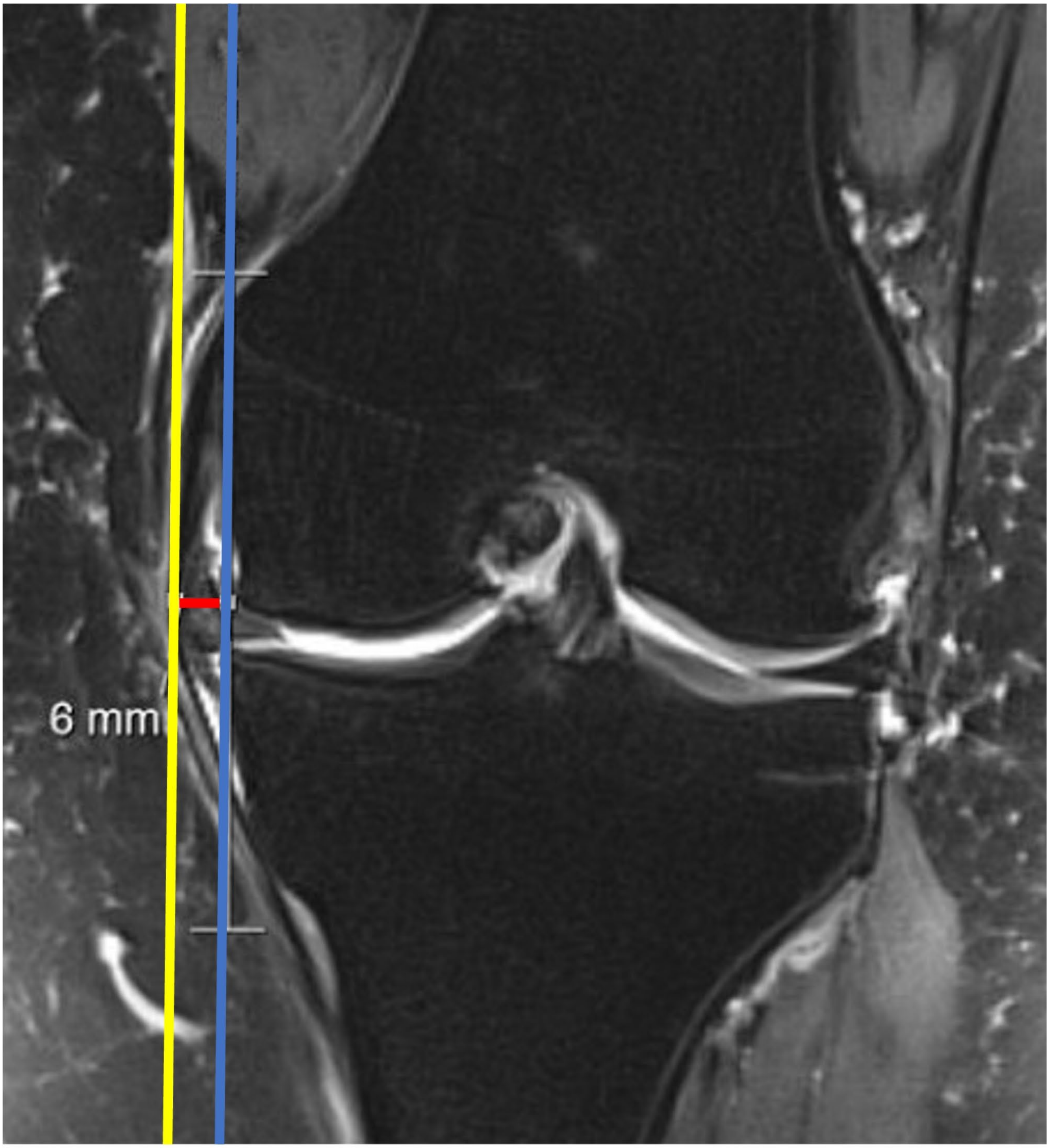

Fig. 5 Measurement of medial meniscus extrusion of the left knee. On a proton density-weighted coronal magnetic resonance imaging section, the medial tibial spine apex was detected. A blue line was drawn at the outer margin of the medial tibial plateau. A yellow line was drawn at the outer margin of the meniscus. The distance between the blue and yellow lines was the MME (red line)

Evaluation of the radiographs

The X-ray measurements were performed via Sectra software. They were performed by two orthopaedic surgeons (first author and third author) at two-week intervals. The investigators were not blinded to the intraoperative findings. The averages of the measurements were used for analysis. Intraobserver and interobserver reliability were assessed with the intraclass correlation coefficient (ICC).

The mechanical tibiofemoral angle (MTFA) was measured on weight-bearing full-leg length radiographs taken with the patient in a double-leg stance.

PTS was calculated by measuring the angle between the medial tibial plateau and the tibial anatomical axis on lateral knee radiographs.

Patellar height measurements were performed via the Caton–Deschamps index (CDI) [30] and the Insall–Salvati index [31].

Clinical evaluation

Clinical data were collected from medical records. Knee Society scores [KSSs, including the knee score (KS) and knee function score (KFS)] were utilised to assess knee function [32]. Preoperative and postoperative assessments were performed via face-to-face consultation by an orthopaedic surgeon who was not blinded to the intra-operative findings. Half of the standard deviation of the Δ values was calculated as the minimal clinically important difference (MCID) for the KSs and KFSs to meet the threshold values.

Statistical analysis

Continious variables are expressed as the median and interquartile range (IQR) [IQR: (Q1;Q3); Q1: median of lower half, Q3: median of upper half]. Categorical variables are expressed as numbers and percentages. The data were analysed via SPSS 26.0 (Chicago, IL, USA). The normality of the distribution was analysed via the Shapiro–Wilk test. None of the data had a normal distribution; therefore, nonparametric tests were used for analysis. The Mann–Whitney test was used for comparisons of the continuous variables of groups, and the Wilcoxon test was used for repeated measurements. Comparisons of the categorical variables between groups were investigated with the Pearson chi-square test. The interobserver and intraobserver reliability and reproducibility of the measurements were tested via the intraclass correlation coefficient (ICC) with a 95% confidence interval. The level of significance was set at <0.05.

Post hoc power analysis was performed via G*Power software (version 3.1.9.7; Dusseldorf, Germany). The effect size was set at 0.5, and the alpha error probability was 0.05. The power for difference analysis between Groups 1 and 2 via the Mann–Whitney test was 0.27. The powers of the preoperative and postoperative difference analyses via the Wilcoxon test were as follows: 0.77 for a total of 36 knees, 0.48 for Group 1 and 0.43 for Group 2. The power for the chi-square test was 0.62.

Results

The general characteristics of the patients, including the participants' age, sex, body mass indices (BMIs), sides of the operated extremities, and follow-up periods, are presented in Table 1. There was no significant difference between the groups in terms of general characteristics.

The clinical scores are presented in Table 2, and the radiological measurements are presented in Table 3. The ICC values were greater than 0.9.

Knee society scores

The KSs and KFSs of a total of 36 knees in Group 1 and Group 2 increased significantly during follow-up [KS; total: 48 (41;55) vs. 89 (84;94), $p<0.001$. Group 1: 43 (36;53) vs. 86 (84;95), $p<0.001$. Group 2: 49 (45;57) vs. 89 (80;93), $p<0.001$. KFS; total: 60 (50;60) vs. 80 (80;100), $p<0.001$. Group 1: 60 (50;60) vs. 90 (80;100), $p<0.001$. Group 2: 60 (50;60) vs. 80 (80;90), $p<0.001$]. The MCID of KS patients was calculated as 6.5, and 19 (100%) knees achieved the MCID in Group 1, whereas 17 (100%) achieved the MCID in Group 2. The MCID of the KFS was calculated as 6, and 18 (95%) knees achieved the MCID in Group 1, whereas 17 (100%) achieved the MCID in Group 2. There were no differences between Groups 1 and 2 in terms of preoperative and follow-up KSs or preoperative KFSs. The follow-up KFSs in Group

Table 1 General characteristics of the patients

	Total (*n*:36)	**Groups**		
		Group 1 (*n*:19)	**Group 2 (*n*:17)**	
	n (%)	**n (%)**	**n (%)**	***P** (Group 1 vs. Group 2)**
sex				-
female	34 (94.4)	19	15	
male	2 (5.6)	0	2	
side				0.325
right	17 (47.2)	**7**	10	
left	19 (52.8)	12	7	
	Med (IQR)	Med (IQR)	Med (IQR)	P** (Group 1 vs. Group 2)
Age (years)	54 (51;56)	52 (50;57)	54 (52;56)	0.324
Body mass index	32 (29;35)	32 (29;36)	31 (28;34)	0.506
Folllow-up period (months)	29 (28;35)	30 (28;37)	28 (27;31)	0.337

Group 1: posteromedial opening wedge high tibial osteotomy (PMOWHTO) concomitant with medial meniscus posterior root tear (MMPRT) repair, Group 2: PMOWHTO without MMPRT. * Chi square test. ** Mann–Whitney Test. Med: median. IQR: Interquartile range (Q1;Q3); Q1: median of lower half, Q3: median of upper half.

Table 2 Knee society scores

	Total (*n*:36)	Groups		
		Group 1 (*n*:19)	Group 2 (*n*:17)	
	Med (IQR)	**Med (IQR)**	**Med (IQR)**	***P**** **(Group 1 vs. Group 2)**
Knee score				
preoperative	48 (41;55)	43 (36;53)	49 (45;57)	0.053
follow-up	89 (84;94)	86 (84;95)	89 (80;93)	0.787
Δ	37 (29;49)	44 (28;54)	32 (31;39)	0.140
*P*** (preoperative* vs. *follow-up)*	**< 0.001**	**< 0.001**	**< 0.001**	
Knee function score				
preoperative	60 (50;60)	60 (50;60)	60 (50;60)	0.896
follow-up	80 (80;100)	90 (80;100)	80 (80;90)	**0.032**
Δ	30 (20;40)	40 (20;40)	20 (20;30)	**0.033**
*P*** (preoperative* vs. *follow-up)*	**< 0.001**	**< 0.001**	**< 0.001**	

Bold values indicate level of significance at $p < 0.05$. Group 1: posteromedial opening wedge high tibial osteotomy (PMOWHTO) concomitant with medial meniscus posterior root tear (MMPRT) repair, Group 2: PMOWHTO without MMPRT. * Mann–Whitney Test. ** Wilcoxon Signed Ranks Test. Med: Median. IQR: Interquartile range (Q1;Q3); Q1: median of lower half, Q3: median of upper half. Δ: follow-up – preoperative value.

Table 3 Radiological measurements

	Total (*n*:36)	Groups		
		Group 1 (*n*:19)	Group 2 (*n*:17)	
	Med (IQR)	**Med (IQR)**	**Med (IQR)**	***P**** **(Group 1 vs. Group 2)**
Meniscal extrusion (milimeters)				
preoperative	3.89 (3.00;5.22)	4.50 (4.00;6.38)	3.30 (2.70;3.87)	**< 0.001**
follow-up	4.70 (3.05;5.95)	5.50 (4.20;6.25)	3.00 (2.20;4.90)	**< 0.001**
Δ	0.25 (-0.91;1.1)	0.40 (-1.38;1.12)	0.00 (-0.79;0.98)	0.751
*P*** (preoperative* vs. *follow-up)*	0.467	0.494	0.733	
Posterior tibial slope (degrees)				
preoperative	12.3 (8.4;14.5)	11.2 (8.4;14)	12.8 (8.0;15.2)	0.579
follow-up	7.3 (5.4;11.4)	7.1 (5.5;9.6)	8.5 (4.7;12.4)	0.680
Δ	-3.05 (-5.6;-0.8)	-3.90 (-5.80;-1.90)	-2.30 (-5.40;-0.40)	0.216
*P*** (preoperative* vs. *follow-up)*	**< 0.001**	**< 0.001**	**< 0.005**	
Mechanical tibiofemoral angle (degrees)				
preoperative	7.00 (5.45;9.70)	6.31 (4.22;9.00)	8.10 (6.77;10.64)	**0.049**
follow-up	-4.05 (-5.90;-1.74)	-5.60 (-6.40;-2.50)	-3.00 (-4.61;-1.50)	**0.022**
Δ	-11 (-14;-9)	-10.4 (-14;-8)	-11 (-14;-9)	0.912
*P*** (preoperative* vs. *follow-up)*	**< 0.001**	**< 0.001**	**< 0.001**	
Insall-Salvati Index				
preoperative	1.04 (0.95;1.17)	1.01 (0.93;1.17)	1.05 (0.97;1.29)	0.646
follow-up	1.05 (0.97;1.26)	1.04 (0.96;1.26)	1.06 (0.98;1.25)	0.849
Δ	0.01 (-0.05;0.09)	0.01 (-0.05;0.12)	0.01 (-0.05;0.07)	0.601
*P*** (preoperative* vs. *follow-up)*	0.266	0.286	0.585	
Caton-Deschamps Index				
preoperative	0.87 (0.78;0.92)	0.88 (0.67;0.95)	0.86 (0.81;0.88)	0.924
follow-up	0.63 (0.58;0.74)	0.62 (0.58;0.76)	0.63 (0.58;0.73)	0.874
Δ	-0.16 (-0.29;-0.08)	-0.16 (-0.30;-0.04)	-0.19 (-0.26;-0.13)	0.578
*P*** (preoperative* vs. *follow-up)*	**< 0.001**	**0.004**	**< 0.001**	

Bold values indicate level of significance at $p < 0.05$. Group 1: posteromedial opening wedge high tibial osteotomy (PMOWHTO) concomitant with medial meniscus posterior root tear (MMPRT) repair, Group 2: PMOWHTO without MMPRT. negative values indicates valgus alignment in mechanical tibiofemoral angle. * Mann–Whitney Test. ** Wilcoxon Signed Ranks Test. Med: Median. IQR: Interquartile range (Q1;Q3); Q1: median of lower half, Q3: median of upper half. Δ: follow-up – preoperative value.

1 was significantly greater than that in Group 2 ($p = 0.032$) (Table 2).

Medial meniscus extrusion

There were no significant changes in MME postoperatively in any intragroup comparison. The preoperative and follow-up MMEs of Group 1 were greater than those of Group 2 [preoperative: 4.50 (4.00;6.38) vs. 3.30 (2.70;3.87); $p < 0.001$. follow-up: 5.50 (4.20;6.25) vs. 3.00 (2.20;4.90); $p < 0.001$]. (Table 3).

Posterior tibial slope

The PTS decreased postoperatively in a total of 36 knees [12.3 (8.4;14.5) vs. 7.3 (5.4;11.4); $p < 0.001$], Group 1 [11.2 (8.4;14) vs. 7.1 (5.5;9.6); $p < 0.001$] and Group 2 [12.8 (8.0;15.2) vs. 8.5 (4.7;12.4); $p < 0.005$]. There was no significant difference between the groups in terms of PTS (Table 3).

Mechanical tibiofemoral angle

There were significant differences in the initial and follow-up MTFA angles between Group 1 and Group 2. (Table 3).

Patellar height measurements

There was no statistically significant difference between the groups in terms of the preoperative and follow-up ISIs or CDIs. In terms of the ISI, there was no significant difference between the preoperative and follow-up values in Groups 1 and 2. However, regarding the CDI, a statistically significant decrease was observed in both groups (Table 3).

Discussion

The results of the current study suggest that, PMOWHTO has favourable clinical outcomes and helps avoid PTS increases in varus aligned MMPRT patients who underwent PMOWHTO concomitant with MMPRT repair and patients with varus medial knee osteoarthritis without MMPRT who underwent PMOWHTO.

Although OWHTO is an effective treatment method for varus knee osteoarthritis, it generally increases the PTS [10]. To avoid this, several techniques, such as posterior structural grafting, hinge axis modification, anterolateral hinge, posterior plating, fixation with knee hyperextension, and computer simulation, have been published [13, 18, 33–37]. In the present study, previously published PMOWHTO was used [18]. Kaya et al. reported that it is possible to avoid PTS increases via PMOWHTO. In the present study, which is compatible with the study of Kaya et al., PTS increase was avoided.

There has been increased interest in root tears over the last decade. Biomechanical consequences of the meniscus root tear are similar to meniscectomy. In order to avoid osteoarthritis progression repair of the root is recommended [38, 39]. However, the ideal surgical technique and whether complete healing of the root is possible remain controversial. The relationship between varus alignment and MMPRTs has led to an increase in the popularity of HTO in the treatment of MMPRTs. Nha et al. [24] reported second-look arthroscopic findings in MMPRT patients treated via OWHTO without meniscus intervention. They concluded that after OWHTO procedures, high rates of root-tear healing were achieved. However, they suggested that healing of the meniscus was not associated with improved clinical outcomes [24]. Karatekin et al. reported that MME progression and radiological worsening of osteoarthritis were avoided in MMPRTs via HTO alone [40]. Several studies in the literature have evaluated the outcomes of MMPRT repair concomitant with OWHTO. Although performing simultaneous osteotomy positively affects meniscal root healing, there is no correlation between meniscus repair and outcomes [41–44]. In a cadaveric biomechanical study, Park et al. reported that MMPRT repair decreases the contact pressure and increases the contact area, irrespective of whether OWHTO is performed [45]. In a recent systematic review, Wang et al. reported that the outcomes of concomitant MMPRT repair and HTO were similar to those of HTO alone [46]. Choi et al. reported that MMPRT repair during OWHTO improved root healing [47]. In the current study, via MMPRT repair with PMOWHTO, clinical improvement was achieved, and an increase in MME was avoided.

MME greater than 3 mm is associated with medial meniscus root tear and degenerative joint pathologies [48–51]. In the present study, MME was higher in Group 1, which consisted of MMPRT cases. No statistically significant change was found in extrusion in either group during the follow-up period. The failure to reduce MME after root tear repair is an issue that has not been clarified in the literature [52]. In a systematic review and meta-analysis, Perry et al. reported that, although biomechanical and clinical results improve after MMPRT repair, there is no significant decrease in MME. The results of the current study are consistent with Perry's study; although clinical improvement was achieved, MME could not be reduced. Moreover, it has been published that the healing capacity is low in degenerative root tears with osteoarthritic changes [42, 52]. In the current study, the root tear cases consisted of middle-aged patients with degenerative root tears, and the failure to reduce extrusion may be due to their low healing capacity.

In the current study, preoperative MTFA is higher in Group 1. It has been previously published that varus is a risk factor in medial meniscus root tear [19]. The patients in Group 1 had MMPRT and the higher varus can be explained by this. When postoperative MTFAs were examined, it was seen that while both groups were in valgus alignment, the amount of valgus in Ggroup 1 was greater. The senior surgeon aims for hypercorrection when performing PMOWHTO. For this reason, both groups may be in valgus alignment. However, the senior surgeon does not aim for more correction in patients with MMPRT than in patients without MMPRT. The reason why Group 1 is in more valgus alignment in the follow-up may be that an error was made during the intraoperative verification phase while performing the correction.

Another possible reason could be that the patients' follow-up radiographs were obtained at least in the second year. Although there was no difference in the postoperative MTFAs between the groups at the beginning, there may have been a progression towards valgus in the MMPRT cases during the follow-up. This situation may be a result of the medial structures with different biomechanical properties in the MMPRT knees. This argument should be evaluated in further studies.

An increased PTS leads to ACL overload, causes anterior tibial translation and is a risk factor for medial meniscus posterior root tears [14–17]. In the present study, although a total of 36 knees had a median preoperative PTS of 12.3°, there were no significant differences between Group 1 (the MMPRT group) and Group 2 (without the MMPRT). These results may be related to the relationship between PTS and MMPRTs in young patients. However, the cohort included elderly patients with medial knee osteoarthritis in the current study.

Because increased PTS is associated with MMPRTs [14–16], the authors of the current study suggested that preventing PTS increase during MMPRT repair with PMOWHTO may positively affect root healing. Although increase in MME was avoided and improvement in clinical scores were achieved, to assess the healing status of the MMPRTs was not possible due to the absence of second-look arthroscopy in the current study.

Some authors have recommended releasing the MCL to avoid undesired reloading at the osteotomy site [53]. However, overreleasing the MCL may cause valgus laxity [54–56]. In the present study, the inserted MCL was kept intact and favourable clinical and radiological outcomes were achieved.

The medial meniscus has an attachment to the deep layer of the MCL [57]. Furthermore, the extruded meniscus stretches the MCL and causes oedema [58, 59]. The authors of the current study argued that, owing to the attachment between the deep MCL and the medial meniscus and the association between MME and MCL oedema, cutting or total release of the MCL in OWHTO may increase MME. In the present study, the MCL insertion was kept intact during PMOWHTO, and an increase in MME was avoided. However, it may be argued that the medial meniscus attaches deep to the MCL, and typically, the superficial MCL is released during OWHTO. Therefore, the arguments of authors about keeping the MCL intact may not be true. This argument may be the subject of previous studies.

In a meta-analysis, Bin et al. reported that patellar height decreased after OWHTO [60]. They concluded that when the change in patellar height was assessed via ISI, a statistically significant change was not observed. In the current study, the ISI did not change, and the CDI decreased; these outcomes are compatible with the findings of this meta-analysis.

In the present study, clinical scores improved in both groups during follow-up. When comparing between groups, no statistically significant difference was found between the KSs of the two groups, while the follow-up KFSs of Group 1 was found to be statistically significantly higher than that of Group 2. It has been published that meniscus root tears disrupt knee biomechanics equivalent to meniscectomy, while root repair restores biomechanics [38]. At first glance, the higher KFSs in Group 1 in the current study may be thought to be due to MMPRT repair restoring biomechanical properties. However, it should not be overlooked that the two groups in the current study were different in terms of the presence of root tears. In addition, the small number of patients in the study causes low power, especially in comparisons between the two groups (the power of Mann-Whitney test was 0.27). Before generalizing the results, it is crucial to acknowledge that not only in clinical scores but also in other data, the power was even lower in comparisons between the two groups.

The present study has several limitations. First, it has a retrospective design with a limited sample size. Second, the patients did not undergo a second-look arthroscopic evaluation. Although assessing knee joints arthroscopically is the gold standard, it is also an invasive procedure. Therefore, evaluating knees via MRI is preferable. Third, postoperative knee MRIs were obtained with plates. To minimise artifacts, dedicated software was used. Fourth, the cohort was almost exclusively female (94.4%), this may not allow for conclusions to be extended to male patients. It may be that there were unrepresentative patients. However, this situation may be explained by the sociodemographic characteristics, lifestyle and body morphology of the population inthe country where the study was conducted. Furthermore, 52.8% of the cohort consisted of MMPRTs, and female sex is a risk factor for root tears [19]. The fact that the patient group consisted mostly of women may be related to this. Fifth, two of the three investigators (authors 1 and 3) who performed the radiological measurements and the surgeon who performed the clinical evaluation were not blinded to the intraoperative findings; this may be a potential assessment bias. In addition, although clinical assessment is performed by an orthopaedic surgeon who is experienced in knee surgery, clinical scores are obtained by one investigator and one face-to-face consultation. There are no intrarater or interrater reliability values for clinical assessment. Sixth, to evaluate the contribution of PMOWHTO performed simultaneously with MMPRT repair to root healing, a comparison is needed with an MMPRT group that underwent PMOWHTO alone and a group that underwent MMPRT repair alone. Additionally, patient groups undergoing different OWHTO techniques are needed to compare PMOWHTO and other OWHTO techniques in terms of their effects on root tears.

Conclusion

PMOWHTO has favourable clinical and radiological outcomes and prevents PTS increase in simultaneous MMPRT repair and varus medial knee osteoarthritis patients without concomitant root tear. However, long termed prospective randomized controlled trials with larger sample size are needed to prove this conclusion.

Author contributions

Ali Engin DASTAN: Data curation, investigation, methodology, writing; Elcil Kaya BICER: data curation, investigation, methodology, conceptualization, critical review, supervision; Huseyin KAYA: data curation, investigation; Mehmet ARGIN: data curation, investigation; Emin TASKIRAN: methodology, conceptualization, critical review, supervision.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethical approval

This study was performed in accordance with the ethical standards in the 1964 Declaration of Helsinki. Local ethics committee approval was obtained (Ege University, decision number: 18-10.2/55).

Competing interests

Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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Informed consent

Written informed consent was obtained from participants. The authors affirm that human research participants provided informed consent for publication of the images in Figs. 2, 3, 4 and 5.

Author details

[1]Department of Orthopedics and Traumatology, Faculty of Medicine, Ege University, Bornova 35100, Izmir, Turkey
[2]Department of Hand Surgery, Izmir City Hospital, Bayrakli, Izmir 35540, Turkey
[3]Department of Radiology, EMOT Hospital, Kahramanlar 35230, Izmir, Turkey

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