World Journal of Orthopedics

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World J Orthop 2024 May 18; 15(5): 444-456

DOI: 10.5312/wjo.v15.i5.444

ISSN 2218-5836 (online)

ORIGINAL ARTICLE

Observational Study

Unicompartmental knee arthroplasty *vs* high tibial osteotomy for knee osteoarthritis: A comparison of clinical and radiological outcomes

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Specialty type: Orthopedics

Provenance and peer review: Invited article; Externally peer reviewed.

Peer-review model: Single blind

Peer-review report's classification

Scientific Quality: Grade A, Grade B

Novelty: Grade A, Grade C

Creativity or Innovation: Grade B, Grade B

Scientific Significance: Grade B, Grade C

P-Reviewer: DeSousa K, India; Yan ZQ, China

Received: January 23, 2024

Revised: March 5, 2024

Accepted: April 12, 2024

Published online: May 18, 2024

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Abstract

BACKGROUND

Unicompartmental knee arthroplasty (UKA) and high tibial osteotomy (HTO) are well-established operative interventions in the treatment of knee osteoarthritis. However, which intervention is more beneficial to patients with knee osteoarthritis remains unknown and a topic of much debate. Simultaneously, there is a paucity of research assessing the relationship between radiographic parameters of knee joint alignment and patient-reported clinical outcomes, preoperatively and following HTO or UKA.

AIM

To compare UKAs and HTOs as interventions for medial-compartment knee osteoarthritis: Examining differences in clinical outcome and investigating the relationship of joint alignment with respect to this.

METHODS

This longitudinal observational study assessed a total of 42 patients that had undergone UKA (n = 23) and HTO (n = 19) to treat medial compartment knee osteoarthritis. Patient-reported outcome measures (PROMs) were collected to evaluate clinical outcome. These included two disease-specific (Knee Injury and Osteoarthritis Outcome Score, Oxford Knee Score) and two generic (EQ-5D-5L, Short Form-12) PROMs. The radiographic parameters of knee alignment assessed were the: Hip-knee-ankle angle, mechanical axis deviation and angle of Mikulicz line.

RESULTS
Statistical analyses demonstrated significant ($P < 0.001$), preoperative to postoperative, improvements in the PROM scores of both groups. There were, however, no significant inter-group differences in the postoperative PROM scores of the UKA and HTO group. Several significant correlations associated a more distolaterally angled Mikulicz line with worse knee function and overall health preoperatively ($P < 0.05$). Postoperatively, two clusters of significant correlations were observed between the disease-specific PROM scores and knee joint alignment parameters (hip-knee-ankle angle, mechanical axis deviation) within the HTO group; yet no such associations were observed within the UKA group.

CONCLUSION
UKAs and HTOs are both efficacious operations that provide a comparable degree of clinical benefit to patients with medial compartment knee osteoarthritis. Clinical outcome has a limited association with radiographic parameters of knee joint alignment postoperatively; however, a more distolaterally angled Mikulicz line appears associated with worse knee function/health-related quality of life preoperatively.

Key Words: Arthroplasty; Osteotomy; Medial compartment; Osteoarthritis; Knee alignment; Patient reported outcome measures

Core Tip: A great deal of uncertainty exists in the literature about which operation, out of unicompartmental knee arthroplasty (UKA) or high tibial osteotomy (HTO), is more beneficial in the treatment of knee osteoarthritis. This study adds evidence to the existing literature base, concluding that HTOs and UKAs are equally efficacious operative interventions capable of providing a comparable degree of improvement in joint function and global health-related quality of life, to those with medial compartment knee osteoarthritis at one year postoperatively. This study is the first of its kind to report a correlation analysis between the angle of Mikulicz line and patient-reported health outcomes. It demonstrated that preoperatively, a more distolaterally angled Mikulicz line was associated worse knee function/health-related quality of life. The mechanisms underlying this relationship remain unknown and represent an avenue for future research; the authors of this study posit an association with the external knee adduction moment.

Citation: Wyatt FW, Al-Dadah O. Unicompartmental knee arthroplasty *vs* high tibial osteotomy for knee osteoarthritis: A comparison of clinical and radiological outcomes. *World J Orthop* 2024; 15(5): 444-456
URL: https://www.wjgnet.com/2218-5836/full/v15/i5/444.htm
DOI: https://dx.doi.org/10.5312/wjo.v15.i5.444

INTRODUCTION

In 2019 osteoarthritis was the 15th leading cause of years lived with disability worldwide, with knee osteoarthritis accounting for almost four fifths of this disease burden[1,2]. Isolated medial compartment knee osteoarthritis has been reported to account for up to one third of all cases of knee osteoarthritis; surgical interventions for this include high tibial osteotomy (HTO), total knee arthroplasty and unicompartmental knee arthroplasty (UKA)[3,4].

UKA and HTO are often indicated ahead of total knee arthroplasty as these joint-preserving operations represent less invasive alternatives that enable more elements of the native knee joint to be retained whilst providing the opportunity to delay, or even prevent, the need for total knee arthroplasty[3,5].

Previous research has established that, with the correct inclusion/exclusion criteria applied, HTOs and UKAs are safe and effective surgical interventions[5]. Despite this, which of these interventions is more beneficial in the treatment of isolated medial compartment knee osteoarthritis is yet to be clarified within the literature and remains a topic of much debate[6-8]. In particular, there is a paucity of research that assesses and compares the impact of these operations on patient-reported outcomes, with the majority of current literature centred around clinician-assessed objective outcomes [9]. This is of clinical significance as, despite "ideal" indications varying between HTO and UKA, there are many patients that would be considered eligible for both operations.

Further to this, only a small number of studies have directly compared the radiographic parameters of knee joint alignment of patients undergoing UKAs and HTOs; and even fewer studies have sought to assess the relationship of these parameters with patient-reported outcomes[4,7]. Defining such relationships would improve our understanding of the symptomatic manifestations of knee osteoarthritis; potentially augmenting the pre-existing value of such parameters as considerations in the planning and selection of surgical interventions for individuals with knee osteoarthritis.

The primary aim of this study was to assess and compare the patient reported outcome measures (PROMs) of patients undergoing HTO and UKA, to determine which of these interventions is more beneficial in the treatment of isolated medial compartment knee osteoarthritis, if indeed a significant difference were to exist. The secondary aim was to investigate the relationship between radiographic parameters of knee joint alignment and PROMs; preoperatively and

following UKA and HTO.

The authors developed three hypotheses with respect to the aforementioned aims. Hypothesis 1: HTO and UKA provide significant, preoperative to postoperative, improvements in patient-reported symptomatology. Hypothesis 2: UKA and HTO are equally efficacious operative interventions in the treatment of isolated medial compartment knee osteoarthritis. Hypothesis 3: Radiographic parameters of knee joint alignment do not correlate with PROM scores.

MATERIALS AND METHODS

Patient selection

Patients that had undergone an elective HTO or UKA for medial compartment knee osteoarthritis between 2015 and 2019, under the care of a single consultant orthopaedic surgeon with a specialist interest in knee surgery at a district general hospital, were screened for study eligibility. Inclusion criteria: Isolated medial compartment knee osteoarthritis and completion of relevant PROMs. Exclusion criteria: Revision surgery, cruciate or collateral ligament insufficiency and multi-compartment knee osteoarthritis. This study was exempt from Institutional Review Board/Ethics Committee approval as it was a pragmatic study evaluating the existing clinical practice of the senior author. This therapeutic research study constituted the first author's Masters dissertation.

Study design

This study adopted a longitudinal observational design. Data collection commenced during each patient's initial outpatient clinic consultation, in which they were first listed for surgery. Study participants underwent routine clinical and radiological assessment and completed PROM forms before and after surgery. A postoperative clinical and radiological assessment was conducted at 8 wk following surgery. Postoperative PROM data was collected at each patient's final follow-up clinic consultation, 12 months postoperatively.

Operative details

HTO group: A standard direct medial approach was used to perform the biplanar medial opening-wedge HTOs. A TomoFix Plate (DePuy Synthes, Pennsylvania, United States) was used to fixate the osteotomy site. The target limb alignment within the HTO group was such that the mechanical axis would intersect Fujisawa's point (marginally lateral to the lateral tibial spine). Preoperative planning, for all patients, was undertaken on AP long-leg alignment radiographs according to the technique described by Miniaci *et al*[10]. All HTO patients underwent a simultaneous knee arthroscopy and microfracture of the medial femoral condyle and medial tibial plateau. Those with degenerate meniscal tears also underwent a partial meniscectomy. All patients were mobilised non-weight bearing, but with full range of movement, for 6 wk following surgery. Thereafter, full weight bearing was commenced under the guidance of a structured postoperative physiotherapy lead rehabilitation programme.

UKA group: A minimally invasive, quadriceps sparing, approach was used to perform the UKAs. Each patient was treated with a cemented JOURNEY UNI (Smith and Nephew, Memphis, Tennessee, United States) medial unicompartmental knee system with a fixed-bearing, metal-backed tibial component and an oxinium femoral component as standard. All patients were mobilised full weight bearing and full range of movement from the day of surgery which was guided by a structured physiotherapy lead postoperative rehabilitation programme.

PROMs

Two generic and two disease-specific PROMs were obtained from each patient. The generic PROMs consisted of the Short Form-12 (SF-12) and EQ-5D-5L. Disease specific PROMs consisted of the Oxford Knee Score (OKS) and Knee Injury and Osteoarthritis Outcome Score (KOOS). Higher PROM scores were indicative of better health outcomes, and vice versa, for all the PROMs used within this study.

Two summary scores were derived from the SF-12: A mental component score and a physical component score[11,12]. The EQ-5D-5L consisted of a descriptive score and a visual analogue scale score[13]. KOOS assessed the impact of knee osteoarthritis across five subscales: Pain, activities of daily living (ADL), sports and recreation (Sport/Rec), knee-related quality of life (QoL), and other symptoms[14,15]. The OKS was calculated using the updated standardised scoring system [16,17]. Data regarding patient co-morbidities was collected *via* the Self-Administered Comorbidity Questionnaire: A validated, self-reported, generic-health questionnaire. Self-Administered Comorbidity Questionnaire scoring was conducted as outlined by Sangha *et al*[18].

Radiography

All digital films were stored, viewed, and evaluated - using software tools-on the Picture Archive and Communication System (Centricity version 6, GE Healthcare, Chicago). Measurements were accurate to within ± 0.05° and ± 0.05 mm.

Knee osteoarthritis severity was determined by assessing preoperative Rosenberg and long leg AP films using the Kellgren-Lawrence grading system[19]. Pre- and postoperative long-leg AP weight-bearing films were used to assess the lower limb mechanical axes of each patient, which were defined by proximal and distal joint-centre points as outlined by Paley and Pfeil[20]. These mechanical axes were used to determine the hip knee ankle angle (HKA), mechanical axis deviation (MAD) and angle of Mikulicz line (lower-limb mechanical axis) of each participant pre- and postoperatively.

The HKA is the medial angle subtended by the intersection of the mechanical axes of the femur and tibia (Figure 1). Varus and valgus deformities were represented by HKAs of < 180° and > 180° respectively. "Neutral" alignment, in non-arthritic individuals, rests in 1-1.5° of varus (178.5° < HKA < 179°)[21].

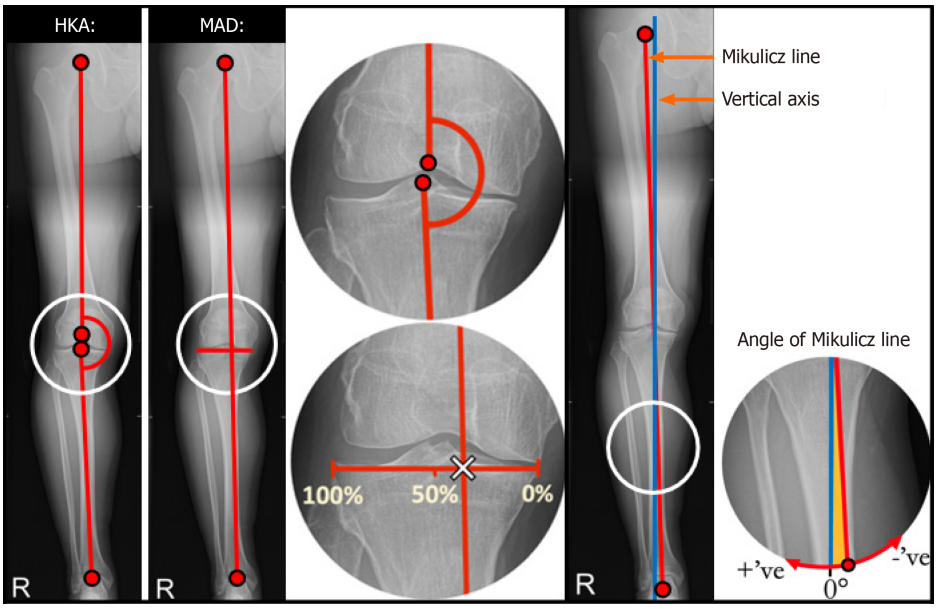

Figure 1 Radiographic representation of the hip knee ankle angle, mechanical axis deviation and the angle of Mikulicz line. The white cross represents the position through which the mechanical axis of the lower limb intersects the tibial plateau. HKA: Hip knee ankle angle; MAD: Mechanical axis deviation.

MAD is a quantitative measure of where the lower limb mechanical axis (Mikulicz line) passes through the knee joint. This parameter identifies the location through which load-transmission forces pass through the knee (Figure 1). To standardise against natural variations in physique, raw values for MAD were expressed as a percentage of overall tibial width[22]. Mechanical axes passing medially to the entire tibial plateau were ascribed negative values.

The mechanical axis of the lower limb (Mikulicz line) allows ground reaction forces, passing from the centre of the ankle to the femoral head, to be visualised. The angle of the Mikulicz line relative to the vertical axis was measured (Figure 1). Distolaterally oriented Mikulicz lines were ascribed positive values, whereas distomedially oriented Mikulicz lines were ascribed negative values.

Statistical analysis

The power calculation for this study was derived from the findings of a related previously published clinical study[23]. The sample sizes were based on a conventional alpha of 0.05 and a power of 80%. The calculation revealed that a sample size of approximately 17 subjects per group was required for a clinically relevant postoperative PROM score (International Knee Documentation Committee) between group mean difference of 11.1, based on a pooled standard deviation of 11.05. Plotted histograms with fitted curve lines, box-plots, normal Q-Q plots and the Kolmogorov-Smirnov statistic were used to confirm that a normal distribution was an appropriate assumption for all the continuous variables in the study. The relevant parametric statistical tests were used. The independent-sample Student's *t*-test was used for the between group analyses and the paired Student's *t*-test was used for the within group analysis. The Pearson product-moment test was used for the correlation analysis. To quantify the strengths of the observed linear relationships, correlation coefficient cut-off values were used as outlined by Chan[24]: > 0.8 (very strong), 0.6-0.8 (moderately strong), 0.3-0.5 (fair) and < 0.3 (poor). The level of statistical significance was set at $P < 0.05$. Statistical analysis was performed using SPSS for Windows version 26.0 (IBM Corp., Armonk, New York). The power calculation was performed using Minitab statistical software version 18 (Minitab LLC, State College, PA, United States).

RESULTS

Patient characteristics

A total of 42 patients (UKA group = 23, HTO group = 19) were included in this study. Table 1 displays the demographic data of the UKA and HTO group. Overall, the HTO group were slightly younger and had proportionately more males than the UKA group. These differences are a reflection of patient selection with respect to treatment suitability at the time of initial clinic consultation and also the treatment preferences of the patients once they had been engaged in a shared decision-making process.

Table 1 Demographics

	UKA group (*n* = 23)	HTO group (*n* = 19)
Age (years), mean (SD)	66.9 (8.6)	54.3 (10.8)
Sex (male:female)	12:11	18:1
Laterality (left:right)	15:8	11:8
Smoking, *n* (%)	1 (4.5)	1 (5.6)
Height (cm), mean (SD)	167.1 (10.0)	174.2 (9.1)
Weight (kg), mean (SD)	84.2 (18.4)	95.6 (16.8)
BMI (kg/m^2), mean (SD)	30.0 (4.6)	31.5 (4.8)
ASA, median (range)	2 (1 to 3)	2 (1 to 2)
SCQ, median (range)	3.5 (0 to 12)	3 (0 to 10)

UKA: Unicompartmental knee arthroplasty; HTO: High tibial osteotomy; BMI: Body mass index; ASA: American Society of Anesthesiologists Physical Status Classification System; SCQ: Self-administered co-morbidity questionnaire.

Preoperative PROM scores

There were no significant preoperative between-group differences for any of the preoperative PROM scores except for the SF-12 mental component score which was only of borderline significance (P = 0.043) (Table 2).

Table 2 Between-group comparison of preoperative and postoperative patient reported outcome measures scores

	Preoperative				Postoperative			
	UKA group mean (SD)	HTO group mean (SD)	*P* value[1]	95%CI	UKA group mean (SD)	HTO group mean (SD)	*P* value[1]	95%CI
KOOS:								
Pain	32.5 (8.2)	35.2 (17.7)	0.530	-5.8 to 11.1	91.1 (12.7)	87.2 (12.4)	0.419	-13.5 to 5.8
Symptoms	42.3 (17.8)	38.2 (17.8)	0.462	-15.2 to 7.1	87.0 (12.9)	73.0 (17.3)	0.012**a**	-24.6 to -3.3
ADLs	38.0 (9.1)	42.2 (17.3)	0.320	-4.2 to 12.6	90.6 (13.9)	90.2 (10.8)	0.936	-9.8 to 9.1
Sport/Rec	19.0 (21.3)	14.4 (12.4)	0.455	-16.9 to 7.7	78.7 (28.9)	71.8 (27.6)	0.549	-30.1 to 16.4
QoL	17.8 (11.9)	13.0 (11.9)	0.211	-12.5 to 2.9	80.1 (21.8)	67.8 (14.8)	0.107	-27.4 to 2.8
Overall	29.1 (7.9)	27.1 (13.1)	0.580	-9.3 to 5.3	85.2 (17.3)	78.4 (13.6)	0.295	-19.8 to 6.3
OKS	16.5 (5.6)	18.4 (7.8)	0.362	-2.3 to 6.1	42.4 (6.3)	42.1 (5.2)	0.872	-4.7 to 4.0
EQ-5D^{Index}	35.6 (24.0)	37.4 (29.7)	0.834	-15.4 to 19.0	84.7 (18.8)	80.8 (15.1)	0.557	-17.4 to 9.6
EQ-5D^{VAS}	72.4 (17.6)	64.8 (23.4)	0.237	-20.4 to 5.2	88.3 (12.7)	82.9 (9.6)	0.210	-14.0 to 3.2
SF-12 PCS	28.9 (5.8)	32.1 (7.7)	0.143	-1.1 to 7.5	50.9 (7.7)	50.0 (8.9)	0.983	-7.4 to 5.5
SF-12 MCS	51.0 (11.4)	42.9 (13.0)	0.043**a**	-15.9 to -0.3	51.8 (9.7)	50.8 (10.5)	0.511	-8.8 to 6.9

[1]Independent-sample Student's *t*-test.

[a]P < 0.05, statistically significant.

SD: Standard deviation; UKA: Unicompartmental knee arthroplasty; HTO: High tibial osteotomy; PROM: Patient reported outcome measures; KOOS: Knee injury and osteoarthritis outcome score; ADL: Activities of daily living; Sport/Rec: Sport and recreation; QoL: Quality of life ; OKS: Oxford knee score; EQ-5D^{index}: EuroQol–5 dimension descriptive component; EQ-5D^{vas}: EuroQol–5 dimension visual analogue scale; SF-12 PCS: 12 item Short Form survey physical component score; SF-12 MCS: 12 item Short Form survey mental component score.

Postoperative PROM scores

Overall, there were no significant differences in postoperative PROM scores between the HTO group and the UKA group (Table 2), except for the KOOS: Symptoms subscore (P = 0.012) in which UKA demonstrated a superior result.

Preoperative to postoperative PROM scores

The longitudinal within-group analysis (Table 3) demonstrated a significant improvement of all PROM scores following surgery, except for the EQ-5D-5L visual analogue score in the HTO group and SF-12 mental component score in both groups.

Table 3 Within-group comparison of preoperative *vs* postoperative patient reported outcome measures scores

	UKA Group				HTO Group			
	Pre-op mean (SD)	Post-op mean (SD)	*P* value[1]	95%CI	Pre-op mean (SD)	Post-op mean (SD)	*P* value[1]	95%CI
KOOS:								
Pain	32.5 (8.2)	91.1 (12.7)	< 0.001[a]	51.8 to 63.3	35.2 (17.7)	87.2 (12.4)	< 0.001[a]	37.5 to 63.0
Symptoms	42.3 (17.8)	87.0 (12.9)	< 0.001[a]	37.3 to 52.1	38.2 (17.8)	73.0 (17.3)	< 0.001[a]	25.7 to 49.5
ADLs	38.0 (9.1)	90.6 (13.9)	< 0.001[a]	47.6 to 57.1	42.2 (17.3)	90.2 (10.8)	< 0.001[a]	32.9 to 53.9
Sport/Rec	19.0 (21.3)	78.7 (28.9)	< 0.001[a]	44.9 to 76.5	14.4 (12.4)	71.8 (27.6)	< 0.001[a]	39.7 to 71.2
QoL	17.8 (11.9)	80.1 (21.8)	< 0.001[a]	53.9 to 71.6	13.0 (11.9)	67.8 (14.8)	< 0.001[a]	40.9 to 62.6
Overall	29.1 (7.9)	85.2 (17.3)	<0.001[a]	47.8 to 63.6	27.1 (13.1)	78.4 (13.6)	< 0.001[a]	37.7 to 58.1
OKS	16.5 (5.6)	42.4 (6.3)	< 0.001[a]	23.0 to 28.6	18.4 (7.8)	42.1 (5.2)	< 0.001[a]	16.4 to 27.8
EQ-5D^{Index}	35.6 (24.0)	84.7 (18.8)	< 0.001[a]	38.8 to 57.2	37.4 (29.7)	80.8 (15.11)	< 0.001[a]	23.8 to 48.9
EQ-5D^{VAS}	72.4 (17.6)	88.3 (12.7)	< 0.001[a]	8.6 to 23.0	64.8 (23.4)	82.9 (9.6)	0.069	-1.2 to 27.0
SF-12 PCS	28.9 (5.8)	50.9 (7.7)	< 0.001[a]	16.3 to 25.4	32.1 (7.7)	50.0 (8.9)	0.001**a**	9.1 to 25.8
SF-12 MCS	51.0 (11.4)	51.8 (9.7)	0.476	-3.0 to 6.2	42.9 (13.0)	50.8 (10.5)	0.115	-1.8 to 14.1

[1]Paired Student's *t*-test.

[a]*P* < 0.05, statistically significant.

SD: Standard deviation; UKA: Unicompartmental knee arthroplasty; HTO: High tibial osteotomy; Pre-op: Preoperative; Post-op: Postoperative; PROM: Patient reported outcome measures; KOOS: Knee Injury and osteoarthritis outcome score; ADL: Activities of daily living; Sport/Rec: Sport & recreation; QoL: Quality of life; OKS: Oxford knee score; EQ-5D^{index}: EuroQol–5 dimension descriptive component; EQ-5D^{vas}: EuroQol–5 dimension visual analogue scale; SF-12 PCS: 12 item Short Form survey physical component score; SF-12 MCS: 12 item Short Form survey mental component score.

Preoperative correlation analysis: Joint alignment and PROMs

To increase the power of this analysis, the data from both the HTO and UKA group were combined. This was deemed appropriate under the assumption that knee osteoarthritis, a factor common to both groups, was the principal cause of any preoperative correlations observed, and not confounding factors unique to either group. The angle of the Mikulicz line demonstrated significant negative correlations with: KOOS symptoms; KOOS: ADLs; KOOS: QoL; KOOS: Overall; OKS and the EQ-5D-5L descriptive score (Table 4). Each correlation was "fair" in strength, with r values between -0.3 ≥ r > -0.5[24]. These results suggest that, for patients with medial compartment knee osteoarthritis, a more distolaterally angled Mikulicz line is typically associated with worse knee joint function (KOOS-multiple, OKS) and health-related quality of life (EQ-5D-5L descriptive score). A single significant positive correlation was observed in isolation with respect to MAD; this was between MAD and the SF-12 physical component score. No significant correlations were observed with respect to HKA (Table 4).

Postoperative correlation analysis: Joint alignment and PROMs

Following surgery, the HKA and MAD both exhibited significant correlations within the HTO group with KOOS: Symptoms; KOOS: Overall and OKS (Table 5). MAD also displayed a significant correlation with KOOS: ADLs. Each of the observed significant correlations were of moderate strength, with r values between 0.6 ≤ r < 0.8[24]. These results suggest that more valgus knee positioning, and a further lateral position of the lower limb mechanical axis, is associated with improved knee function 1-year following HTO. The SF-12 mental component score was the only PROM within the UKA group to demonstrate a significant relationship with any of the radiographic parameters of joint alignment postoper-

Table 4 Correlation analysis: Preoperative radiographic parameters and preoperative patient reported outcome measures

	Angle of Mikulicz line	HKA	MAD
	r (*P* value[1])	r (*P* value[1])	r (*P* value[1])
KOOS:			
Pain	-0.18 (0.290)	-0.12 (0.484)	-0.01 (0.938)
Symptoms	-0.36 (0.022[a])	0.15 (0.352)	0.16 (0.336)
ADLs	-0.37 (0.020[a])	0.06 (0.707)	0.10 (0.534)
Sport/Rec	-0.04 (0.839)	0.06 (0.737)	0.16 (0.357)
QoL	-0.34 (0.040[a])	-0.23 (0.169)	-0.14 (0.415)
Overall	-0.38 (0.026[a])	-0.04 (0.844)	0.07 (0.698
OKS	-0.41 (0.010[a])	0.13 (0.422)	0.21 (0.201)
EQ-5D^{Index}	-0.45 (0.005[a])	-0.07 (0.670)	-0.02 (0.896)
EQ-5D^{VAS}	-0.29 (0.071)	0.03 (0.843)	0.06 (0.709)
SF-12 PCS	-0.23 (0.158)	0.26 (0.112)	0.34 (0.035**a**)
SF-12 MCS	-0.23 (0.173)	-0.05 (0.773)	-0.08 (0.641)

[1]Pearson's product-moment correlation analysis.

[a]*P* < 0.05, statistically significant.

r: Correlation co-efficient; UKA: Unicompartmental knee arthroplasty; HTO: High tibial osteotomy; PROM: Patient reported outcome measures; HKA: Hip knee ankle angle; MAD: Mechanical axis deviation; KOOS: Knee injury and osteoarthritis outcome score; ADL: Activities of daily living; Sport/Rec: Sport & recreation; QoL: Quality of life; OKS: Oxford knee score; EQ-5D^{index}: EuroQol–5 dimension descriptive component; EQ-5D^{vas}: EuroQol–5 dimension visual analogue scale; SF-12 PCS: 12 item Short Form survey physical component score; SF-12 MCS: 12 item Short Form survey mental component score.

Table 5 Correlation analysis: Post-operative radiographic parameters and post-operative patient reported outcome measures

	UKA Group			HTO Group		
	Angle of Mikulicz line, r (*P* value[1])	HKA, r (*P* value[1])	MAD, r (*P*-value[1])	Angle of Mikulicz line, r (*P*-value[1])	HKA, r (*P*-value[1])	MAD, r (*P*-value[1])
KOOS:						
Pain	-0.17 (0.483)	-0.15 (0.518)	-0.07 (0.760)	0.13 (0.716)	0.41 (0.238)	0.53 (0.119)
Symptoms	-0.17 (0.450)	-0.07 (0.772)	0.02 (0.922)	0.26 (0.436)	0.65 (0.032**a**)	0.62 (0.040[a])
ADLs	-0.22 (0.328)	-0.05 (0.837)	0.01 (0.961)	0.09 (0.790)	0.59 (0.055)	0.62 (0.041[a])
Sport/Rec	-0.21 (0.459)	0.15 (0.584)	0.28 (0.317)	0.46 (0.178)	0.5 (0.103)	0.53 (0.113)
QoL	-0.27 (0.249)	-0.11 (0.635)	-0.03 (0.898)	0.14 (0.693)	0.58 (0.080)	0.60 (0.065)
Overall	-0.26 (0.357)	-0.01 (0.959)	0.12 (0.676)	0.32 (0.373)	0.65 (0.041**a**)	0.68 (0.031**a**)
OKS	-0.34 (0.137)	-0.02 (0.950)	0.03 (0.884)	0.24 (0.481)	0.65 (0.032**a**)	0.61 (0.045**a**)
EQ-5D^{Index}	-0.23 (0.334)	-0.70 (0.768)	0.01 (0.974)	-0.13 (0.724)	0.47 (0.175)	0.45 (0.191)
EQ-5D^{VAS}	-0.23 (0.304)	-0.02 (0.942)	0.03 (0.881)	0.10 (0.776)	0.21 (0.534)	0.21 (0.544)
SF-12 PCS	-0.14 (0.584)	-0.13 (0.615)	-0.02 (0.929)	-0.07 (0.850)	0.15 (0.680)	0.18 (0.616)
SF-12 MCS	-0.49 (0.041**a**)	-0.24 (0.341)	-0.19 (0.455)	-0.02 (0.953)	0.38 (0.279)	0.29 (0.422)

[1]Pearson's product-moment correlation analysis.

[a]*P* < 0.05, statistically significant.

r: Correlation co-efficient; UKA: Unicompartmental knee arthroplasty; HTO: High tibial osteotomy; PROM: Patient reported outcome measures; HKA: Hip knee ankle angle; MAD: Mechanical axis deviation; KOOS: Knee injury and osteoarthritis outcome score; ADL: Activities of daily living; Sport/Rec: Sport & recreation; QoL: Quality of Life; OKS: Oxford knee score; EQ-5D^{index}: EuroQol–5 dimension descriptive component; EQ-5D^{vas}: EuroQol–5 dimension visual analogue scale; SF-12 PCS: 12 Item Short Form Survey Physical Component Score; SF-12 MCS: 12 Item Short Form survey mental component score.

atively. This correlation was observed between the SF-12 mental component score and the angle of Mikulicz line (Table 5).

Preoperative to postoperative joint alignment parameters

The UKA group demonstrated significant differences ($P < 0.001$) between the preoperative and postoperative values of the HKA and MAD. A far more anatomic knee joint alignment was achieved postoperatively within the UKA group, with the mean HKA increasing from a varus position (174.5° ± 2.7°) to a neutral one (180.2° ± 3.3°) resulting in the mechanical axis crossing the centre of the knee (postoperative MAD = 48.9%) as opposed to the medial compartment (preoperative MAD = 23.5%) (Table 6).

Table 6 Within-group comparison of preoperative *vs* post-operative radiographic parameters of joint alignment

	UKA Group				HTO Group			
	Pre-op mean (SD)	Post-op mean (SD)	*P* value[1]	95%CI	Pre-op mean (SD)	Post-op mean (SD)	*P* value[1]	95%CI
Angle of Mikulicz line (°)	0.3 (2.6)	-0.2 (1.8)	0.326	-1.6 to 0.6	0.7 (2.0)	0.2 (1.5)	0.951	-1.5 to 1.6
HKA (°)	174.5 (2.7)	180.2 (3.3)	< 0.001[a]	4.3 to 7.1	173.9 (4.0)	182.5 (2.8)	< 0.001[a]	5.2 to 12.0
MAD (%)	23.5 (10.8)	48.9 (13.6)	< 0.001[a]	20.7 to 30.0	22.3 (14.5)	59.9 (12.0)	< 0.001[a]	24.2 to 51.0

[1]Paired Student's *t*-test.

[a]$P < 0.05$, statistically significant.

SD: Standard deviation; UKA: Unicompartmental knee arthroplasty; HTO: High tibial osteotomy; Pre-op: Preoperative; Post-op: Postoperative; HKA: Hip knee ankle angle; MAD: Mechanical axis deviation.

The HTO group demonstrated significant differences ($P < 0.001$) between the preoperative and postoperative values of the HKA and MAD. HTOs are operative interventions that alter the angle of the tibia distal to the osteotomy site: the re-angulation of the tibial mechanical axis is, unsurprisingly, represented within the significantly different postoperative HKA and MAD values. The mean HKA, of the HTO group, increased from a varus position preoperatively (173.9° ± 4°), to a slight valgus position postoperatively (182.5° ± 2.8°). The goal of HTO is to relieve pressure from the medial compartment by redirecting joint loading forces through the lateral compartment. Preoperatively the mechanical axes typically passed through the medial compartment (mean MAD = 22.3%), yet postoperatively these had been successfully shifted to cross the lateral compartment (mean MAD = 59.9%) (Table 6).

DISCUSSION

Patients within both the UKA and HTO group demonstrated significant clinical improvements following surgery, as compared to their preoperative state. There was no significant difference in the generic and disease-specific postoperative PROM scores between the HTO and UKA groups, reflecting that both surgical interventions are equally as efficacious in terms of improving knee joint function and global health-related quality of life at one year postoperatively. Overall, radiographic parameters of knee joint alignment demonstrated limited correlation with PROM scores. However, two isolated clusters of significant correlations were observed with respect to PROMs and the angle of Mikulicz line preoperatively; and joint alignment (HKA and MAD) within the HTO group postoperatively.

HTO and UKA are both efficacious operative interventions

Significant preoperative to postoperative improvements were observed within almost all the PROM scores of the UKA and HTO group. Statistical significance does not always equate to clinical significance. Postoperative PROM scores are best contextualised with reference to 'patient acceptable symptom state' thresholds: PROM scores equating to the highest level of symptomatic burden that the average patient would consider acceptable postoperatively. PROM patient acceptable symptom state thresholds, for isolated medial compartment knee osteoarthritis, have previously been reported in the literature as follows: KOOS pain: 72.2, KOOS symptoms: 71.4, KOOS ADLs: 77.9, KOOS Sport/Rec: 40, KOOS QoL: 56.3, OKS: 41.5, SF-12 physical component score: 49.9 and SF-12 mental component score: 54.6[25,26]. Owing to the scarcity of relevant literature, knee osteoarthritis patient acceptable symptom state thresholds were unable to be identified for the EQ-5D-5L; and postoperative thresholds for both HTO and UKA groups were considered to be equal.

The mean postoperative score of each PROM that had increased significantly postoperatively, also superseded their corresponding PROM patient acceptable symptom state threshold; indicating that UKAs and HTOs are operative interventions capable of providing improvements in health outcomes that are clinically, as well as statistically, significant. This conclusion is widely accepted within current literature and is not surprising given that the principal purpose of undergoing surgery for knee osteoarthritis is to restore knee function and reduce symptom burden[5,6,27]. These results prove hypothesis 1 to be true.

HTO and UKA offer comparable postoperative health outcomes

This study found UKAs and HTOs to be comparable operative interventions for knee osteoarthritis as the postoperative PROM scores were, with the exception of KOOS: Symptoms, not significantly different between the two groups. The findings of this study prove hypothesis 2 to be true and are consistent with those of previous studies, with UKAs resulting in postoperative PROM scores that are not significantly different to those of HTOs at a minimum follow-up time of 1 year[23,28,29].

Conversely, retrospective comparative studies conducted by Ivarsson and Gillquist[30] and Ryu *et al*[7], with shorter follow up periods of 3-6 months, demonstrated statistically significant differences in postoperative PROM scores in favour of UKAs. These findings possibly reflect the lengthier rehabilitation process associated with HTOs: as more time elapses postoperatively, HTO patients report improved PROM scores that are eventually comparable to those of UKAs (which allow patients to fully weight-bear from the day of surgery). Yokoyama *et al*[31] estimated that the time required to functionally heal, following HTO, is approximately 6 months; a conclusion that supports this hypothesis and better contextualises the non-significance of the 1-year postoperative results of the current study (Table 2), relative to the significant inter-group differences observed by Ivarsson and Gillquist[30] and Ryu *et al*[7] at 3-6 months.

Despite the observed similarity in postoperative clinical outcomes achieved, UKAs and HTOs are fundamentally very different operations, associated with their own relative merits. HTOs are associated with an increased postoperative range of motion[4-6] and lower risk of revision surgery[32]; whereas patients undergoing UKA typically benefit from a shorter recovery period[5,33]. It is these differences, alongside postoperative health outcomes, that require careful consideration from both the surgeon and the patient in clinical practice. Within a patient-centred model of healthcare, which operative intervention is more beneficial in the treatment of knee osteoarthritis will, in part, depend upon the value-system of the patient and the significance that they ascribe to these differences.

Preoperative joint alignment and PROMs

Previous studies have identified abnormal knee joint biomechanics as a predictor of radiographic knee osteoarthritis disease progression[34]. There is, however, a paucity of research investigating the relationship between preoperative knee joint alignment and patient-centred health outcomes[35]. Currently available literature shows radiographic parameters of knee joint alignment to demonstrate poor relationships with patient-reported health outcomes[36]. This in keeping with the findings of the current study, in which conventional radiographic parameters of joint alignment (HKA, MAD) did not demonstrate significant correlations with the preoperative PROMs.

Owing to the multifactorial aetiology of knee osteoarthritis, PROM scores almost certainly depend upon the influence of a myriad of co-variates not visible on radiographic imaging, including dynamic joint kinematics and soft tissue changes. These co-variates may mask weaker correlations, and potentially have contributed to the observed non-significance, between conventional joint alignment parameters (HKA, MAD) and PROMs. Future research should seek to identify these co-variates; to provide an opportunity for factors that don't necessarily determine, but contribute to, patient reported symptomatology to be better understood.

The mechanical axis of the lower limb (Mikulicz line) allows ground reaction forces, passing from the ankle to the hip, to be visualised. The physiological angle of Mikulicz line, relative to the vertical axis, corresponds approximately to a 3° distomedial slope. There is, however, little mention of the angle of Mikulicz line in the literature beyond this[37,38]. Mikulicz line is required to calculate MAD and shares joint-centre points with the mechanical axes used to calculate the HKA. These parameters are frequently calculated in clinical practice, whereas the angle of Mikulicz line is not. Given the ease with which this angle can be calculated, and lack of associated literature surrounding it, this study included the angle of the Mikulicz line as an additional, non-conventional, parameter of interest. To our knowledge to date, this is the first study to report a correlation analysis between the angle of Mikulicz line and patient reported health-outcomes of any kind. The results of which demonstrated significant correlations observed across multiple PROMs.

Worse knee function (OKS, KOOS–multiple) and global health-related quality of life (EQ-5D-5L descriptive score) was associated with a wider stance, as represented by a Mikulicz line angled more distolaterally (Table 4). The external knee adduction moment is: A surrogate for medial tibiofemoral contact force during gait[39]; has been associated with pain[40-43], disability[41,42], osteoarthritis severity[44-46] and disease progression[47]; and is the target of many orthopaedic interventions[48-50]. A wider stance has been shown to reduce the external knee adduction moment[39,51]. It is therefore possible that the wider stance, observed within individuals with worse joint function, occurs as a result of a compensatory behavioural change: In an attempt to attain the symptomatic and functional relief associated with a reduced external knee adduction moment[40-43]. No correlations were observed between PROMs and preoperative HKA, therefore the observed correlations between PROMs and the angle Mikulicz line are not considered to be attributed to varus/valgus deformation at the level of the knee.

The identification of novel relationships such as these represents an important initial step in the process of further clarifying which factors are causative of poor health outcomes in knee osteoarthritis. Once identified, interventions can then be designed to target and attenuate these factors, thereby facilitating the advancement of patient care. Future research should seek to evaluate the reproducibility of, and better understand the mechanisms behind, the observed correlations between PROM scores and the angle of Mikulicz line preoperatively.

Postoperative joint alignment and PROMs

The findings of this study are in keeping with those of the wider literature, with virtually no significant correlations being observed between postoperative joint alignment and patient-reported health outcomes following UKA[52,53]. Conflicting evidence from Zuiderbaan *et al*[4] has, however, associated a residual varus of 1°-4° with optimised joint-function PROM scores following UKA. Other studies have proposed that a postoperative varus of 1°-4° decreases the risk of contralateral

compartment degeneration (associated with over-correction) and reduced prosthesis survival time (associated with under-correction): supporting this as a suitable target alignment angle range, irrespective of PROM scores and the observed discordance between the findings of the wider literature[53,54] and those of Zuiderbaan *et al*[4].

This study found greater postoperative HKA and MAD values to exhibit some association with superior knee function following HTO; a finding that is well supported within the current literature[55,56]. These results suggest that a more valgus knee positioning, and further lateral position of the lower limb mechanical axis, may be associated with improved knee function one year following HTO. When considering the clinical utility of this finding it is essential to maintain an awareness of the additional factors, beyond patient-reported outcomes, that are influenced by joint alignment (*e.g.* knee compartment degeneration). A seminal paper by Hernigou *et al*[57] concluded that, following HTO, a HKA of 183°-186° provides good functional results whilst simultaneously minimising the risk of lateral compartment degeneration, associated with a HKA > 186°.

The mean postoperative HKA of the HTO group was 182.5° (SD ± 2.8°), falling 0.5° short of the lower bound of Hernigou *et al*[57]'s recommended range. The mean postoperative MAD of the HTO group was 59.9%, which approximated Fujisawa's point: the target alignment point during preoperative planning, which is reported in the literature to be located at 62.5% of the tibial width (Table 6)[58]. Several studies, including a meta-analysis and systematic review, report under correction as the most common cause of unsatisfactory results following HTO[5,55,59]. Conversely, increased HKA/MAD values are associated with an increased risk of lateral compartment degeneration; which may ultimately necessitate the conversion of HTO to total knee arthroplasty[57]. Many surgeons would rather mitigate against this longer-term risk, than achieve the marginally enhanced PROM scores associated with an increased HKA/MAD: This offers a likely explanation for the increased frequency of under correction, relative to over correction, following HTO. The current study did not assess lateral compartment degeneration and, even if it had sought to, a follow-up time of 1-year is unlikely to be sufficiently long enough for such changes to manifest themselves to a detectable extent[53]. Therefore, the observed correlation between an increased HKA/MAD and superior knee function (Table 5) should be interpreted cautiously as these results do not account for the risk of lateral compartment degeneration, which is also associated with increased HKA/MAD values and may indeed manifest itself over a time period longer than that accounted for within the current study.

Hypothesis 3 was partially rejected: The majority of correlations investigated between joint alignment and PROMs were non-significant, however two clusters of significant correlations were observed with respect to PROMS and the angle of Mikulicz line preoperatively; and joint alignment (HKA and MAD) within the HTO group postoperatively.

Limitations

The current study was subject to some limitations. Firstly, all HTOs and UKAs were undertaken within a single centre, by a single surgeon specialising in knee surgery which may reduce the generalisability of the findings. Despite the relatively small groups of patients (which can increase the susceptibility of type II statistical errors), the number of patients included in each group still exceeded that determined by the power calculation. Furthermore, sufficient power was achieved to allow for the identification of numerous statistically significant findings. Sample sizes were restricted by the cancellation of routine clinic appointments and cessation of elective surgery during the COVID-19 pandemic. Thirdly, some demographic differences were noted between the two groups, namely age and gender distribution. Despite this, the only PROM score to demonstrate a significant between-group difference at baseline (preoperatively) was the SF-12 mental component score, thus assuring the inter-group comparability with respect to the remaining PROMs.

CONCLUSION

This study demonstrated that UKAs and HTOs are both efficacious operative interventions capable of providing significant clinical improvements to patients with isolated medial compartment knee osteoarthritis. This study concludes that patients treated with either UKA or HTO, for isolated medial compartment knee osteoarthritis, achieve a similar degree of joint function and overall health-related quality of life at one year postoperatively.

This study appears to be the first to examine the relationship between the angle of the Mikulicz line and health outcomes. Postoperatively, joint alignment parameters exhibited little association with PROMs within the UKA group, yet an increased HKA/MAD exhibited some association with superior joint function at one year post-HTO. Preoperatively, traditional measures of joint alignment (HKA, MAD) demonstrated little correlation with PROMs. However, a more distolaterally angled Mikulicz line was observed to be associated with worse knee function and overall health-related quality of life preoperatively. Future research should seek to assess the reproducibility of this finding and aim to characterise/better understand the mechanisms behind this relationship.

FOOTNOTES

Author contributions: Wyatt FW was responsible for the writing of the final manuscript and also contributed towards study design, data acquisition and interpretation of the analysed data; Al-Dadah O contributed towards study design, data acquisition, data analysis and reviewed/edited the final written manuscript; and both authors have read and approved the final manuscript.

Institutional review board statement: This was an observational study using existing data from routine clinical care, therefore IRB approval was not required.

Informed consent statement: This was an observational study using existing data from routine clinical care, therefore separate consent forms were not required.

Conflict-of-interest statement: All the authors report no relevant conflicts of interest for this article.

Data sharing statement: Technical appendix, statistical code, and dataset available from the corresponding author at frederick.wyatt2@northumbria-healthcare.nhs.uk.

STROBE statement: The authors have read the STROBE Statement—checklist of items, and the manuscript was prepared and revised according to the STROBE Statement—checklist of items.

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S-Editor: Che XX
L-Editor: A
P-Editor: Zhao YQ

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