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Patients with varus knee osteoarthritis undergoing high tibial osteotomy exhibit more femoral varus but similar tibial morphology compared to non-arthritic varus knees

Hamid Rahmatullah Bin Abd Razak^{1,2} · Grégoire Micicoi^{3,4} · Raghbir S. Khakha⁵ · Matthieu Ehlinger⁶ · Ahmad Faizan⁷ · Sally LiArno⁷ · Matthieu Ollivier⁴

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Abstract

Purpose The aim of this study was to compare alignment parameters between patients undergoing high tibial osteotomy (HTO) for knee osteoarthritis (OA) and non-arthritic controls.

Methods Pre-operative computed tomography images from 194 patients undergoing HTO for medial knee OA and 118 non-arthritic controls were utilized. All patients had varus knee alignment (mean age: 57 ± 11 years; 45% female). The hip-knee-ankle (HKA) angle, mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA) and non-weight-bearing joint line convergence angle (nwJLCA) were compared between “control group” and “HTO group”. Femoral and tibial phenotypes were also assessed and compared between groups. Variables found on univariate analysis to be different between the groups were entered into a binary logistic regression model.

Results The mean age was lower ($\Delta = 4 \pm 6$ years, $p = 0.024$), body mass index (BMI) was higher ($\Delta = 1.1 \pm 2.8$ kg/m², $p = 0.032$) and there were more females ($\Delta = 14\%$, $p = 0.020$) in the HTO group. The HTO group had more overall varus ($7^\circ \pm 4.7^\circ$ vs $4.8^\circ \pm 1.3^\circ$, $p < 0.001$). There was a significant difference in the mean mLDFA between the two groups with the HTO group having more femoral varus ($88.7 \pm 3.2^\circ$ vs $87.3 \pm 1.8^\circ$, $p < 0.001$). MPTA was similar between the groups ($p = 0.881$). Age was found to be a strong determinant for femoral varus ($p = 0.03$).

Conclusion Patients undergoing HTO for medial knee OA have more femoral varus compared to non-arthritic controls while tibial morphology was similar. This will be an important consideration in pre-operating planning for realignment osteotomy in patients presenting with medial knee OA and warrants further investigation.

Level of evidence III, retrospective comparative study.

Keywords Knee · Joints · Osteotomy · Femur · Tibia · Morphology · Phenotype · Osteoarthritis

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Introduction

There is controversy with regard to the optimal alignment following high tibial osteotomy (HTO). Several studies have shown that the accuracy of correction in relation to preoperative planning is critical for a successful outcome following HTO [3, 5, 11, 17]. There is a high variability in the phenotype of knee alignment in a non-arthritic population [15] and neutral alignment resulting from tibia vara and femoral valgus appears to be one of the more common phenotypes in healthy patients [13, 20]. Prevalence of constitutional varus alignment in a non-arthritic population varies from 17 to 32% without affecting the joint line orientation in the coronal plane [26] and 88% of patients with medial knee osteoarthritis (OA) have varus alignment of the proximal tibia [8]. There are only a few studies that have investigated the coronal alignment and the phenotype of OA knees. In a systematic review, it was indicated that the morphological variability was significant in OA knees despite the most common phenotype being varus [12]. To date, there is ambiguity with regard to the differences in phenotypes of alignment between non-arthritic knees and OA knees. One recent study compared the distribution of femoral and tibial coronal alignment in a large primary osteoarthritic cohort destined for total knee arthroplasty with a young non-osteoarthritic cohort [24]. They found that there was more femoral varus in patients with OA [24]. This information is useful for planning the realignment strategy following total knee arthroplasty. In offering realignment osteotomy to patients with medial knee OA, one should address the specific extra-articular deformities contributing to the varus malalignment rather than creating new extra-articular deformities post-surgery.

Currently, there is a lack of comparative data with regard to the phenotype of coronal alignment between non-arthritic varus knees and osteoarthritic varus knees planned for HTO. Knowing where the extra-articular deformity lies which enables the osteotomy surgeon to plan for specific osteotomies to correct the overall alignment of the knee. Therefore, the aim of this study was to compare alignment parameters between patients undergoing HTO for knee OA and non-arthritic controls. The hypothesis was that there will be significant differences in the alignment parameters of the distal femur and proximal tibia between the two groups.

Methods

From 2016 to 2019, a cross-sectional analysis of a prospectively collected pre-operative computed tomography (CT)-scan database of 678 patients undergoing knee

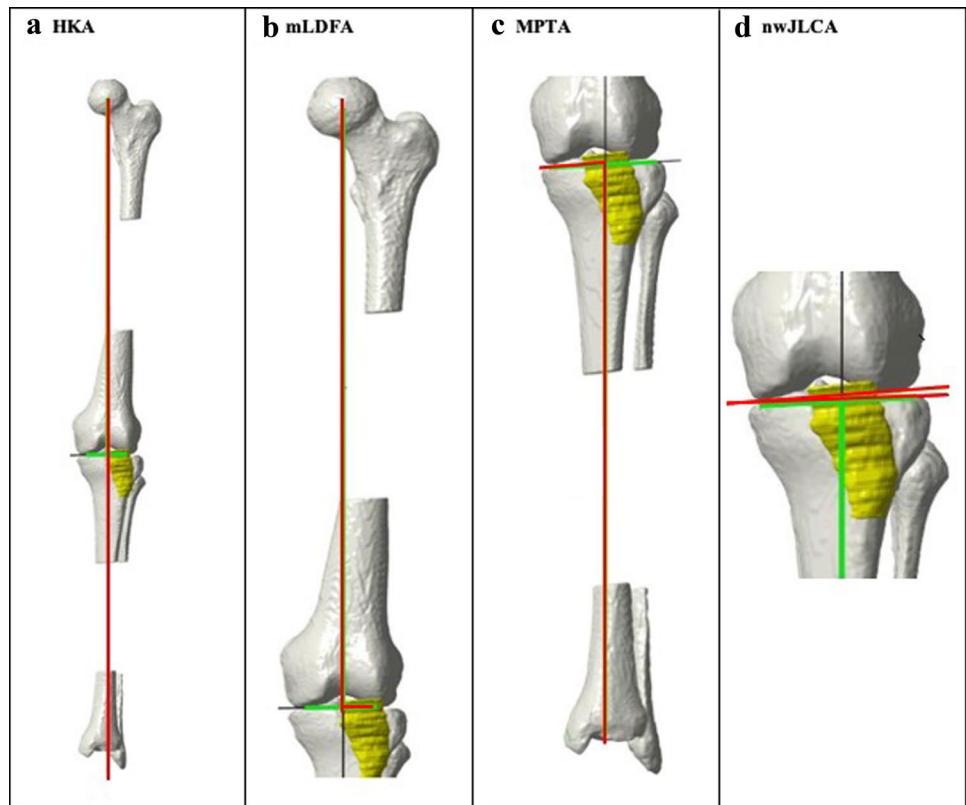
osteotomy with patient-specific cutting guides (Newclip Technics database, Haute-Goulaine, France) identified 194 patients who underwent HTO for medial knee OA with varus deformity. All patients had a hip-knee-ankle (HKA) angle $\geq 3^\circ$ and complete data for the anatomical parameters studied. The CT scan protocol consisted of one acquisition centred on the femoral head, one on the knee that captured the distal femur and proximal tibia and one centred over the ankle. The slice thickness was 0.625 mm for the knee and 2 mm for the hip and ankle [22]. Twenty-eight institutions contributed to this database. A control group was extracted from a computed tomography (CT) scan-based modelling and analysis system from the SOMA database (SOMA, Stryker, Mahwah, New Jersey). This is an extensive database which includes information from over 25,000 bone models obtained from over 3600 patients globally. CT scans were acquired exclusively for medical indications, such as polytrauma, CT angiography and other reasons, such as total knee replacement. [25]. Inclusion criteria for the control group were (1) varus coronal alignment with HKA $\geq 3^\circ$ varus, (2) no radiological or clinical diagnosis of OA and (3) complete CT imaging. The study was performed with full ethics board approval.

The HKA angle, mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA) and non-weight-bearing joint line convergence angle (nwJLCA) were calculated for each knee (Fig. 1). These measurements were then profiled to each bone on the database by the automated software, resulting in reproducible and consistent parameters for each subject and associated margin of error of less than 2 mm and less than 1° [1].

The HKA angle, mLDFA and MPTA were determined following a previously described method [16]. The HKA angle was determined by the lines connecting the centre of the femoral head, the knee and the ankle, respectively. The mLDFA was determined by the angle subtended by the distal femoral axis and the femoral mechanical axis in the coronal plane. The distal femoral axis is the line connecting the most distal points on the medial and lateral femoral condyles. The MPTA was determined by the angle subtended by the proximal tibial axis connecting the medial and lateral tibial compartments and the tibial mechanical axis of the tibia in the coronal plane. Finally, the angle connecting the distal femoral axis and the proximal tibial axis in the coronal plane was defined as the nwJLCA.

Femoral mechanical angle (FMA) and tibial mechanical angle (TMA) phenotypes was assessed as described by Hirschmann et al. [14]. The nomenclature for FMA is defined by the letter 'F' for femur, either 'VAR' (varus), 'NEU' (neutral) or 'VAL' (valgus) and the angular degree (0° , 3° or 6°). Therefore, a knee with a femoral varus of 6° will be classified as 'FVAR 6° '. The nomenclature for TMA is defined similarly except for the letter 'T' representing

Fig. 1 **a** The HKA angle is the angle subtended by the lines connecting the centre of the femoral head, the knee and the ankle, respectively (highlighted in red). **b** The mL DFA is the angle subtended by the distal femoral axis and the femoral mechanical axis in the coronal plane (highlighted in red). The distal femoral axis is the line connecting the most distal points on the medial and lateral femoral condyles. **c** The MPTA is the angle subtended by the proximal tibial axis connecting the medial and lateral tibial compartments and the tibial mechanical axis of the tibia in the coronal plane (highlighted in red). **d** The nwJLCA is the angle subtended by the distal femoral axis and the proximal tibial axis in the coronal plane (highlighted in red)



tibia, in place of ‘F’. Therefore, a knee with a tibial valgus of 3° will be classified as ‘TVAL3°’.

Demographic (age and gender), anthropometric (body mass index, side of the knee) and alignment parameters (HKA angle, mL DFA, MPTA, nwJLCA) were compared between “Control Group” and “HTO Group”. The total frequencies of FMA (FVAR6°, FVAR3°, FNEU0°, FVAL3°, FVAL6°) and TMA (TVAR6°, TVAR3°, TNEU0°, TVAL3°, TVAL6°) phenotypes were then calculated for the entire study population. Phenotype combinations were also charted for each group. Proportion of FMA and TMA phenotypes within the study population between the two groups was then compared.

Statistical analysis

Mean and standard deviations (SDs) were determined for all continuous variables. Categorical variables were expressed in percentages. Tests for normality were performed for all variables. Univariate analysis was performed using the Student’s *t* test (parametric data) and Mann–Whitney test (non-parametric data) to estimate differences between groups. The Z-test was utilized for comparison of proportions between groups. Variables were also analyzed for correlational effect. Finally, a binary logistic regression model based on the presence or absence of distal femoral varus was developed to establish variables significantly predicting the presence of

distal femoral varus. A priori computation of the required sample size based on the estimated mL DFA measurement (mL DFA = 87.3° ± 2°) for a required level of significance of $\alpha = 0.05$, and a power of $1 - \beta = 0.9$ showed that 46 specimens would be required in each group for an effect size $d = 0.7$. A *p* value < 0.05 was considered significant. All statistical analyses were performed on IBM SPSS Statistics, Version 26.0 (IBM Corp., Armonk, NY, USA).

Results

The mean age was lower in the HTO group ($\Delta = 4 \pm 6$ years, $p = 0.024$), body mass index (BMI) was slightly higher ($\Delta = 1.1 \pm 2.8$ kg/m², $p = 0.032$) and there were more females ($\Delta = 14\%$, $p = 0.020$) in the HTO group (Table 1).

There was a significant difference in the HKA angle ($\Delta = 2.2^\circ \pm 0.7^\circ$, $p < 0.001$) between the control and HTO groups. There was more femoral varus in the HTO group ($\Delta = 1.4^\circ \pm 0.3^\circ$, $p < 0.001$) compared to the control group. Tibial anatomy (MPTA) and nwJLCA were found to be similar between the control and HTO groups (Table 1).

Frequencies of FMA and TMA phenotypes and combinations can be seen in Tables 2 and 3. The most common phenotype combination for knee coronal alignment was FNEU0° with TVAR3° represented in 27.9% of the study population and the next most common knee phenotype was FVAR3° with

Table 1 Comparison of demographic, anthropometric and alignment parameters between groups

Parameter	Control group (<i>n</i> = 118)	HTO group (<i>n</i> = 194)	<i>p</i> value
Mean age, years ± SD (range)	59 ± 13 (33–89)	55 ± 11 (30–69)	0.024
BMI, kg/m ² ± SD (range)	23.9 ± 3.1 (17.6–31.9)	25.0 ± 4.4 (15.6–41.6)	0.032
Gender, number (%)	Female: 43 (36) Male: 75 (64)	Female: 97 (50) Male: 97 (50)	0.020
Sidedness, number (%)	Right: 61 (52) Left: 57 (48)	Right: 105 (54) Left: 89 (46)	0.677
Mean HKA angle, ° ± SD (range)	4.8 ± 1.28 varus (3.1–8.4)	7.0 ± 4.7 varus (3.0–10.2)	<0.001
Mean mL DFA, ° ± SD (range)	87.3 ± 1.8 (82.6–92.5)	88.7 ± 3.2 (82.6–99.7)	<0.001
Mean MPTA, ° ± SD (range)	83.5 ± 2.0 (77.5–88.7)	83.5 ± 3.6 (66.9–90)	0.881
Mean nwJLCA, ° ± SD (range)	1.4 ± 1.1 (0–6.1)	1.8 ± 2.2 (0–7.7)	0.440

HTO high tibial osteotomy, SD standard deviation, BMI body mass index, HKA hip-knee-ankle, mL DFA mechanical lateral distal femoral angle, MPTA medial proximal tibial angle, nwJLCA non weight-bearing joint line congruency angle

Table 2 Frequencies of femoral and tibial phenotypes among the entire population (*n* = 312)

FMA				TMA			
Groups (°)	Phenotypes	<i>N</i>	%	Groups (°)	Phenotypes	<i>N</i>	%
87° ± 1.5°	FVAR6°	28	9.0	81° ± 1.5°	TVAR6°	85	27.2
90° ± 1.5°	FVAR3°	90	28.8	84° ± 1.5°	TVAR3°	165	52.9
93° ± 1.5°	FNEU0°	145	46.5	87° ± 1.5°	TNEU0°	54	17.3
96° ± 1.5°	FVAL3°	49	15.7	90° ± 1.5°	TVAL3°	8	2.6
99° ± 1.5°	FVAL6°	0	0	93° ± 1.5°	TVAL6°	0	0
Total		312	100	Total		312	100

FMA femoral mechanical angle, TMA tibial mechanical angle, FVAR femoral varus, FNEU femoral neutral, FVAL femoral valgus, TVAR tibial varus, TNEU tibial neutral; TVAL tibial valgus

Table 3 Frequencies (percentage) of phenotype combination in study population (*n* = 312)

	FVAR6°	FVAR3°	FNEU0°	FVAL3°	FVAL6°
TVAR6°	8 (3)	17 (6)	34 (11)	26 (8)	0 (0)
TVAR3°	14 (4)	45 (14)	87 (27)	19 (6)	0 (0)
TNEU0°	6 (2)	22 (7)	22 (7)	4 (1)	0 (0)
TVAL3°	0 (0)	6 (2)	2 (1)	0 (0)	0 (0)
TVAL6°	0 (0)	0	0 (0)	0 (0)	0 (0)
Subtotal	28 (9)	90 (29)	145 (46)	49 (16)	0 (0)
Total	312 (100)				

FMA femoral mechanical angle, TMA tibial mechanical angle, HTO high tibial osteotomy, FVAR femoral varus, FNEU femoral neutral, FVAL femoral valgus, TVAR tibial varus, TNEU tibial neutral, TVAL tibial valgus

TVAR3° at 14.4% (Table 3). This was similar when the study group was stratified into control and HTO groups (Table 4). When comparing proportions of FMA and TMA phenotypes between the two groups, it was found that there was more femoral varus in the HTO group (*p* < 0.001) (Table 5, Figs. 1

and 2). Of note, only 2% of the control group had FVAR6° compared to 13% of patients in the HTO group (*p* < 0.001). The proportion of FNEU0° was higher in the control group compared to the HTO group (57% vs. 40%; *p* = 0.002). We also found that the proportion of TNEU0° was slightly lower in the control group compared to the HTO group (12% vs. 20%; *p* = 0.048).

Of the variables that were found to be significantly different between the groups in univariate analysis, age and gender were found to have correlational effect on femoral varus. The Kendall's Tau values were 0.135 (*p* = 0.003) and 0.149 (*p* = 0.005), respectively, for age and gender. The distribution of FMA phenotypes by gender is illustrated in Fig. 3. However, only age was found to be a significant determinant in the final binary logistic regression model (*p* = 0.03) (Fig. 4).

Table 4 Frequencies (percentage) of phenotype combination in study population ($n=312$)

	FVAR6°	FVAR3°	FNEU0°	FVAL3°	FVAL6°
Control group					
TVAR6°	0 (0)	1 (1)	20 (17)	14 (12)	0 (0)
TVAR3°	2 (2)	16 (14)	44 (37)	5 (4)	0 (0)
TNEU0°	0 (0)	10 (8)	4 (3)	0 (0)	0 (0)
TVAL3°	0 (0)	2 (2)	0 (0)	0 (0)	0 (0)
TVAL6°	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Subtotal	2 (2)	29 (25)	68 (57)	19 (16)	0 (0)
Total	118 (100)				
HTO Group					
TVAR6°	8 (4)	16 (9)	14 (7)	12 (6)	0 (0)
TVAR3°	12 (6)	29 (15)	43 (23)	14 (7)	0 (0)
TNEU0°	6 (3)	12 (6)	18 (9)	4 (2)	0 (0)
TVAL3°	0 (0)	4 (2)	2 (1)	0 (0)	0 (0)
TVAL6°	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Subtotal	26 (13)	61 (32)	77 (40)	30 (15)	0 (0)
Total	194 (100)				

FVAR femoral varus, FNEU femoral neutral, FVAL femoral valgus, TVAR tibial varus, TNEU tibial neutral, TVAL tibial valgus

Table 5 Comparison of FMA and TMA proportions between groups ($n=312$)

	Control group ($n=118$)	HTO group ($n=194$)	<i>p</i> value
FVAR6°	2 (2)	26 (13)	<0.001
FVAR3°	29 (25)	61 (32)	0.194
FNEU0°	68 (57)	77 (40)	0.002
FVAL3°	19 (16)	30 (15)	0.881
FVAL6°	0 (0)	0 (0)	–
TVAR6°	35 (30)	50 (26)	0.455
TVAR3°	67 (56)	98 (51)	0.282
TNEU0°	14 (12)	40 (20)	0.048
TVAL3°	2 (2)	6 (3)	0.449
TVAL6°	0 (0)	0 (0)	–

FMA femoral mechanical angle, TMA tibial mechanical angle, HTO high tibial osteotomy, FVAR femoral varus, FNEU femoral neutral, FVAL femoral valgus, TVAR tibial varus, TNEU tibial neutral, TVAL tibial valgus; percentages in parantheses

Discussion

The most important finding of this study is that patients with varus OA of the knee undergoing HTO presented with more varus of the femur but similar tibial morphology when compared to a non-arthritic cohort (mLDFA = 87.3° vs. 88.7°; FVAR6° = 2% vs. 13%). This is an important finding which underpins the fact that osteotomy surgeons

should question the underlying pathomorphological factors of knee OA and plan patient-specific corrections rather altering what might be normal morphology. This difference in femoral varus between groups was previously reported by Sappey-Marinié et al. [24]. In their study, it was found that although the tibial coronal alignment was similar between osteoarthritic and non-arthritic populations, there was a higher degree of femoral varus in the osteoarthritic population. This study reaffirms that femoral varus is uncommon in non-arthritic populations but is often found in patients with varus knee osteoarthritis. However, Sappey-Marinié et al. looked at a cohort of patients who underwent total knee arthroplasty and did not investigate the correlation between alignment parameters and demographic parameters, such as age and gender. It may be argued that the statistically significant difference in the mLDFA between our study groups was within only two degrees and that there might not be any clinical significance. However, the fact that tibial morphologies were similar between the two groups suggests that there should be more attention paid to the utilization of distal femoral osteotomies in patients with varus knee OA.

“Reduced femoral valgus” has previously been implicated as a predisposing factor in the pathogenesis for varus OA [9]. In an early study, Nishiyama et al. reported that altered femoral geometry arose from significant remodelling of the femur during the disease process of OA itself [23]. Subsequently, Matsumoto et al. conducted a cross-sectional study suggesting that femoral condylar orientation rather than medial tibial bowing might be the main contributor to worsening of varus deformity in knee OA [19]. There is no biomechanical study to date to explain the exact role of distal femoral morphology on the initiation and progression of OA. Most recently, Grammens et al. described a new knee morphotype which demonstrated an increased risk for medial compartment degeneration: a smaller medial femoral condyle and medial tibial plateau, a wider lateral femoral condyle and a wider distal femur on a smaller tibial plateau [10].

While age, BMI and gender were found to be different between the groups, only age was found to be significant in the final model. Radiographic analysis has shown that the femoral shaft transitioned from a valgus to varus with age [18, 19]. It has also been shown that proximal femur anatomy is dependent on age with lower neck shaft angles and higher femoral offset found in older non-arthritic individuals [4]. There is strong correlation between the morphology of the proximal femur and the geometry of the distal femur [27]. This could explain the relationship between age and distal femoral morphology found in this study as well as the potential confounding effect of age on our findings.

Contributions of the tibia to varus limb alignment are well recognized in the developmental conditions of the

Fig. 2 Bar chart showing distribution of femoral phenotypes according to groups

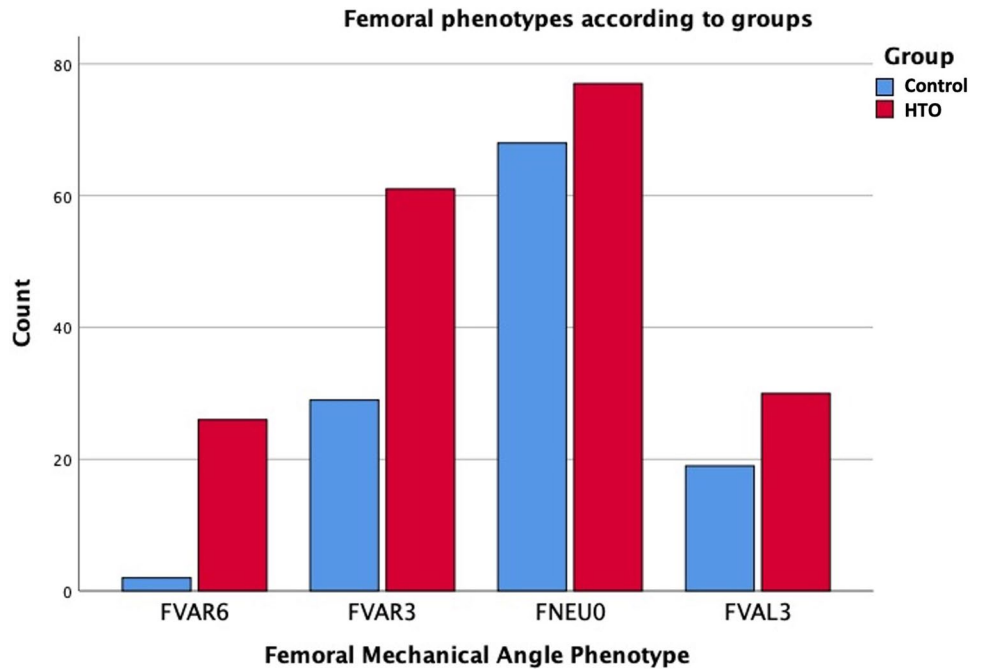
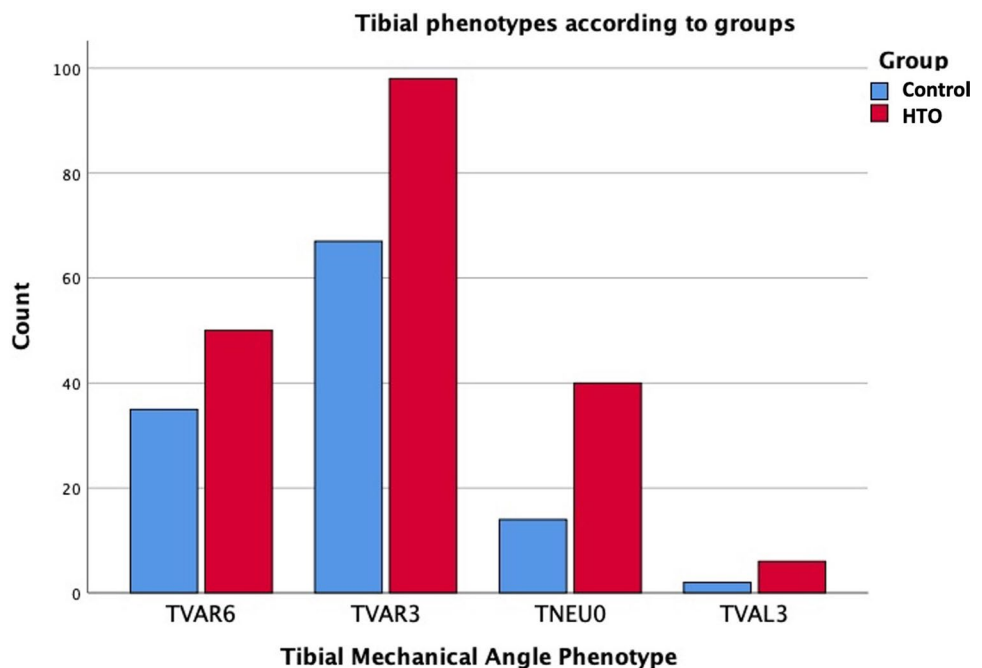


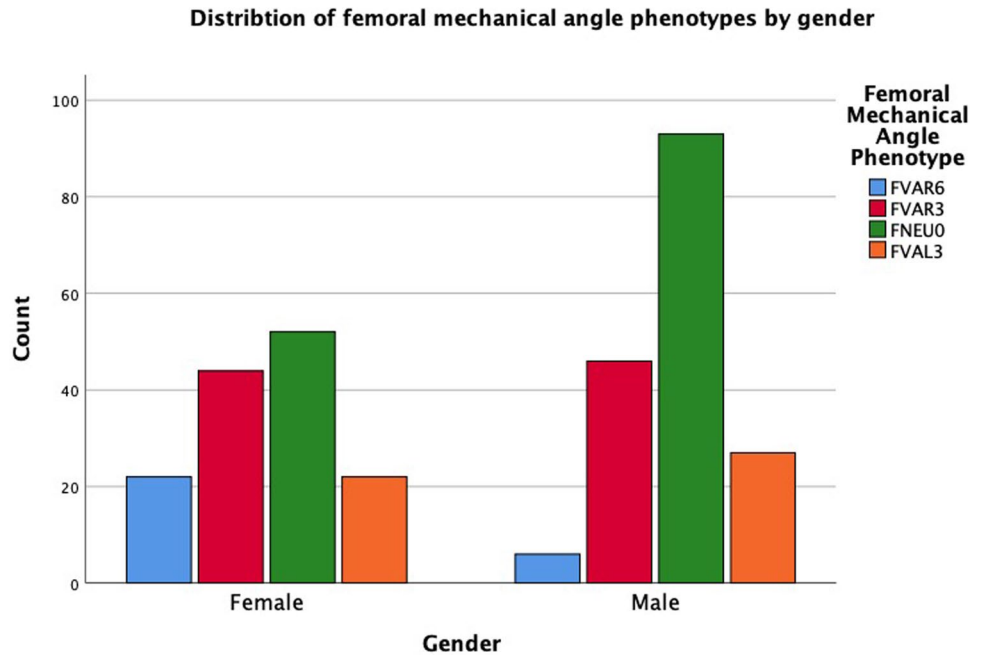
Fig. 3 Bar chart showing distribution of tibial phenotypes according to groups



tibia, such as Blount’s disease. However, in varus knee OA, the tibia does not seem to be the major contributing factor [9]. In both Caucasian and Asian populations, the mean MPTA values between OA patients and non-arthritic controls were reported to be similar [6, 7]. In this study, the tibial alignment was comparable between the two groups although there was more neutral tibia found in the HTO group. This could be a result of compensation in the proximal tibia to the higher degree of distal femoral varus in the

HTO group. While this phenomenon has not been reported to date, compensation of the ipsilateral femur for tibia vara has been demonstrated in non-arthritic patients with neutral knee alignment [20]. The most common knee phenotype in this study was a neutral femur and a 3° varus tibia. This likely represents the prevalence of constitutional varus in our study population. Bellemans et al. reported that important contributors to constitutional varus were the MPTA and mL DFA, contributing 40.8% and 29.4%, respectively [2]. In

Fig. 4 Bar chart showing distribution of femoral mechanical angle (FMA) phenotypes by gender



this study, no difference was found in the nwJLCA between the two groups. There could be several reasons for our finding. First, the measurement methods were employed without weight-bearing conditions. Next, it is assumed that patients being planned for HTO had lower grades of OA and hence less intra-articular deformities. Moreover, constitutional varus does not affect joint line orientation unlike advanced medial knee OA, which causes greater joint line obliquity, thus affecting the JLCA [26].

This study is the first to compare alignment parameters between varus non-arthritic knees and varus OA knees planned for HTO. The wide range of FMA and TMA reported in this study population alludes to a wide variability in knee phenotypes in both osteoarthritic and non-osteoarthritic patients, which is consistent with previous studies that evaluated knee phenotypes [14, 24]. Hirschmann et al. showed a great variability among knee phenotypes in non-arthritic patients [13–15, 21]. These differences are important for osteotomy planning as the aim of realignment surgery is to restore function by restoring anatomy. This study is of clinical relevance because it shows that osteoarthritic knees being planned for HTO had more varus alignment due to a higher degree of femoral varus as compared to native non-arthritic knees. The discerning Orthopaedic Surgeon must understand that tibial varus could be the normal morphotype and femoral varus could be pathological in the patient presenting with varus knee OA. Therefore, preoperative planning should include consideration for a distal femoral osteotomy or a double level osteotomy to avoid excessive joint line obliquity in striving towards the concept of a patient-specific osteotomy, or kinematic osteotomy.

The findings of this study must be interpreted in light of its limitations too. First, a large part of this study is based on review of CT imaging from two different sources and therefore has inherent biases due to its retrospective nature. This is especially so for the control group which had patients undergoing CT scan for a variety of reasons. This could have a confounding effect on our results. Next, this study focused purely on image-based assessment of the alignment parameters with no clinical outcomes evaluated in patients who underwent HTO. While the study reports statistically significant difference in alignment parameters between the groups, there is no affirmation that this would translate to clinical significance.

Conclusion

Patients undergoing HTO for medial knee OA have more femoral varus compared to non-arthritic controls while tibial morphology was similar. This will be an important consideration in pre-operating planning for realignment osteotomy in patients presenting with medial knee OA and warrants further investigation.

Author contributions HRBAR, AF, SL and MO performed data extraction, HRBAR and MO designed the protocol and performed statistical analysis. HRBAR and GM wrote the initial draft. HRBAR, GM, MTH, AR, SL and MO edited the different versions of the draft. All authors approved the submitted and final version of the manuscript.

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Compliance with ethical standards

Conflict of interest HRBAR, GM, RSK, ME, AF and SI have nothing to disclose. MO is an educational consultant for Stryker.

Ethical approval The local ethics committee approved our study protocol prior to investigation.

Informed consent A waiver of consent was obtained for this study as only deidentified data was used.

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