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Léo-Pôhl Bardot, Grégoire Micicoi, Henri Favreau, Petr Zeman, Raghbir Khakha, et al.. Global varus malalignment increase from double-leg to single-leg stance due to intra-articular changes.. *Knee Surgery, Sports Traumatology, Arthroscopy*, 2021, 30 (2), pp.715-720. 10.1007/s00167-021-06446-6 . hal-03553775

HAL Id: hal-03553775

<https://hal.science/hal-03553775v1>

Submitted on 14 Apr 2022

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Global varus malalignment increase from double-leg to single-leg stance due to intra-articular changes

Léo-Pôhl Bardot^{1,2} · Grégoire Micicoi^{2,3} · Henri Favreau⁴ · Petr Zeman¹ · Raghbir Khakha^{2,5} · Matthieu Ehlinger⁴ · Matthieu Ollivier^{1,2}

Abstract

Purpose Preoperatively planned correction for tibial osteotomy surgery is usually based on weightbearing long-leg Xrays, while the surgery is performed in a supine non-weightbearing position. The purpose of this study was to assess the differences in lower limb alignment in three different weightbearing conditions: supine position, double-leg (DL) stance and single-leg (SL) stance prior to performing a medial opening wedge high tibial osteotomy (MOWHTO) for varus malalignment. The hypothesis of this study was that progressive limb-loading would lead to an increased preoperative varus deformity.

Material and methods This retrospective study included 89 patients (96 knees) with isolated medial knee osteoarthritis (Ahlbäck grade I or II) and significant metaphyseal tibial vara ($>6^\circ$). The differences between supine position, DL stance and SL stance were analysed for the hip-knee-ankle angle (HKA), lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), weight-bearing line ratio (WBL) and joint line convergence angle (JLCA).

Results From a supine position to DL stance, the HKA angle slightly increased from $175.5^\circ \pm 1.1^\circ$ to $176.3^\circ \pm 1.1^\circ$ and JLCA changed from $2.0^\circ \pm 0.3^\circ$ to $1.8^\circ \pm 0.3^\circ$ without a statistically significant difference. From DL to SL stances, the HKA angle decreased from $176.3^\circ \pm 1.1^\circ$ to $174.4^\circ \pm 1.1^\circ$ ($p < 0.05$) and the JLCA increased from $1.8^\circ \pm 0.3^\circ$ to $2.6^\circ \pm 0.3^\circ$ ($p < 0.05$). A significant correlation was found between Δ HKA and Δ JLCA between the DL and the SL stances ($R^2 = 0.46$; $p = 0.01$). **Conclusion** Varus malalignment increases with weight-bearing loading from double-leg to single-leg stances with an associated JLCA increase. Thus, single-leg stance radiographs may be useful to correct preoperative planning considering patient-specific changes in JLCA.

Level of clinical evidence III, retrospective comparative study.

Keywords Knee · Osteotomy · Weight-bearing · Genu varum · Weight-bearing radiographs · Joint line convergence

Introduction

Studying the mechanical axis of the lower limb in the most accurate way is a topical subject, particularly because of the important development of medial opening-wedge high tibial osteotomy (MOWHTO). Indeed, the technique for correcting the alignment of the lower limbs is based on the surgeon's ability to reproduce the correction planned in the preoperative period [2, 4, 20, 23]. Despite the numerous techniques used and developed [1, 5, 11, 15, 26], discrepancies between preoperatively planned and achieved postoperative alignments are observed, due to the inability to factor in soft tissue laxity on standard radiographs [9–11]. Whilst the bone morphology does not vary, the joint line convergence angle (JLCA) which represents intra-articular deformity

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and peripheral ligament tension, can vary depending on the loads placed through the joint. The increase in JLCA needs to be factored as part of the pre-operative plan due to the recognised overcorrection after MOWHTO [6, 12, 17, 18]. The differences between preoperative planned correction and postoperative corrected alignment may be explained by the influence of weight-bearing positions on soft tissue laxity. Lee et al. [13] claimed that soft tissue laxity defined by Δ JLCA was correlated with coronal correction error after osteotomy and a larger JLCA had been observed with single-leg stance weight-bearing position measurements compared to double-leg stance weight bearing [25].

Only a few studies have reported the impact of weight-bearing status on the global lower limb alignment [7, 19, 21, 22, 24].

Medial opening wedge high tibial osteotomy preoperative planning is usually performed on a radiograph taken in DL standing with the surgery being performed in non-weightbearing conditions. It can be assumed that the chosen degree of correction, if it is based on the global lower limb alignment, may differ due to the stance conditions of preoperative radiograph.

This study was intended to assess varus malalignment changes by increasing weight-bearing conditions and to assess the soft tissue laxity influence on these alignment changes from the variations of the JLCA.

The purpose of this study was to assess the differences of lower-limb global malalignment according to three different weight-bearing conditions: supine position, double-leg (DL) stance and single-leg (SL) stance prior to MOWHTO. The hypothesis of this study was that progressive limb-loading would lead to an increased pre-operative varus deformity.

Material and methods

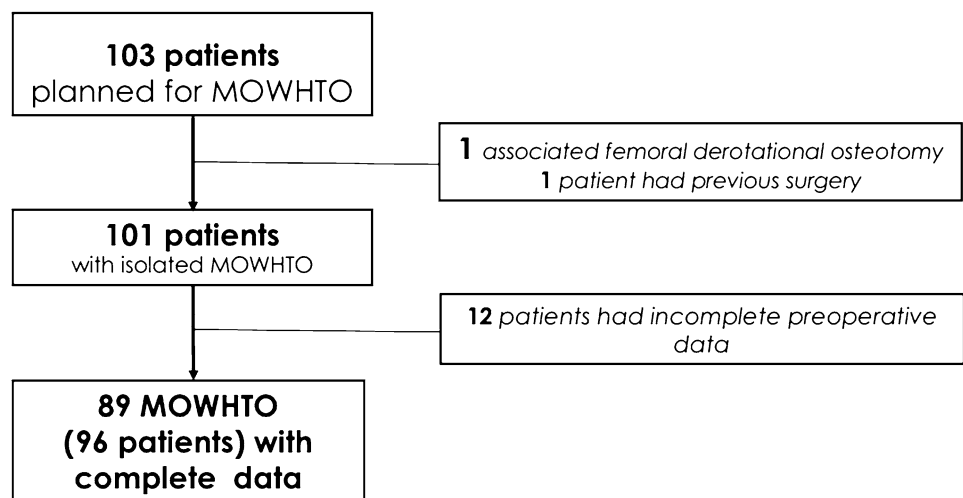
This multicentre retrospective study included patients who underwent medial opening wedge high tibial osteotomy for varus osteoarthritis between February 2015 and September 2019. Indications for surgery included patients with isolated medial knee osteoarthritis (Ahlbäck grade I or II), with significant metaphyseal tibial vara (Medial proximal tibial angle (MPTA) $< 84^\circ$), a stable knee in sagittal and coronal plane and the failure of all medical treatments. There were 110 MOWHTOs suitable for analysis from this period of time. Patients with complete datasets for the three different weight-bearing conditions were included in this study.

Exclusion criteria included those who had previous knee surgery and those who had symptomatic excessive torsional malalignment of the femur. Twelve patients had incomplete data, one had previous surgery and another patient was excluded due to an associated femoral derotational osteotomy. Finally, 89 patients (96 knees) met the inclusion criteria (Fig. 1).

Radiographic measurements

Only preoperative radiographs taken not later than three months before MOWHTO were used in this study. A single independent examiner (orthopaedic senior resident) carried out all measurements and evaluation on PEEKMED (Braga, Portugal), a semi-automated pre-operative planning software for orthopedic surgery. The radiographs for all three positions: supine, DL stance and SL stance were taken on the same day. Before acquiring each radiograph, the limb was positioned to achieve a true antero-posterior image in a forward knee position, with the patella centred on the femoral condyles. The patients were requested to maintain knee extension to get identical knee angles in all

Fig. 1 Study flow chart. *MOWHTO* medial opening wedge high tibial osteotomy



three positions. Of note, the images used for analysis in the supine positions were acquired from the scanogram of pre-operative CT scan for all patients. Every effort was taken to maintain the optimum knee positions for equal comparison. The hip–knee–ankle angle (HKA), medial proximal tibial angle (MPTA), lateral distal femoral angle (LDFA), weight-bearing line (WBL) and joint line convergence angle (JLCA) were measured for each image (Fig. 2).

The HKA angle was defined by the lines connecting the centre of the femoral head, the knee and the ankle, respectively. It was measured at the medial side, with an angle less than 180° corresponding to a varus alignment. The MPTA was defined as the medial angle formed between the line of the mechanical tibial axis and a line tangent to the joint surface of the proximal tibial plateau. The LDFA defined as the lateral angle formed between the mechanical axis line of the femur and a line tangent to the articular surface of the distal femur.

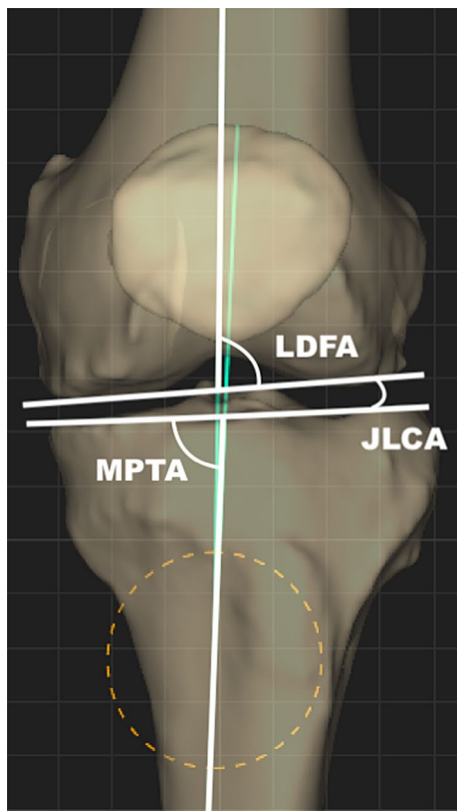


Fig. 2 Illustrations of the anatomical measurements. The lateral distal femoral angle (LDFA) was defined as the lateral angle between the femoral axis and the tangent to the femoral condyles. The medial proximal tibial angle (MPTA) was defined as the medial angle between the tibial anatomic axis and the joint line of the proximal tibia. The joint line convergence angle (JLCA) was defined as the angle between the tangent to the subchondral plates of the femoral condyle and the tibial plateau (Figure from Micicoi et al. [14])

The WBL was defined as a line starting from the centre of the femoral head to the centre of the ankle. The WBL ratio was calculated as a ratio between the tibial width and the width of the tibial intersection of the WBL (measured from the medial side, with the medial tibial edge at 0% and the lateral tibial edge at 100%). The JLCA was defined as the angle between the tangential lines of the most distal part of the femoral condyles and the subchondral plate of the tibial plateau. HKA angle and JLCA absolute differences between two weight-bearing conditions: supine and/or standing in DL and/or SL stances were expressed as Δ HKA and Δ JLCA.

The study obtained institutional review board approval from our institution.

Statistical analysis

Means and standard deviations (SDs) were determined for each of the measurements made for the population. Normal (Gaussian) distributions were determined. Univariate analysis was performed using t-tests to estimate changes in double and single or supine standings angles. An a priori power analysis was performed to determine the sample size using the 2-sided hypothesis test at an alpha level of 0.05 and a power of 0.8. Multiple linear regression models were developed to establish the determinants for each of the variables. For each model, variables with a p value less than 0.1 were kept in the final model. A trained statistician performed statistical analysis using SPSS software (Version 22; SPSS Inc, Chicago, IL, USA). All calculations were based on two-tailed tests.

Results

The MPTA was unchanged between supine position, DL stance and SL stance ($86.5^\circ \pm 0.84$; $86.2^\circ \pm 0.84$ and $86.4^\circ \pm 0.84$, respectively; $p = 0.97$) as well as the LDFA ($87.8^\circ \pm 0.53$; $88.0^\circ \pm 0.53$ and $88.8^\circ \pm 0.53$, respectively; $p = 0.37$).

Supine vs. DL stance

The results did not find any significant difference between supine position and DL stance for HKA [Δ HKA = 0.77° ($- 3.2^\circ$ to 5.2°); $p = 0.6$], neither for WBL ratio (Δ WBL = 2.2% ; $p = 0.78$) nor JLCA (Δ JLCA = 0.2° ; $p = 0.82$) (Table 1). From supine position to DL stance, the HKA angle slightly increased from $175.5^\circ \pm 1.05$ to $176.3^\circ \pm 1.05$. The WBL ratio changed from $35.2\% \pm 5.5$ to $33\% \pm 5.5$ and the JLCA from $2.0^\circ \pm 0.3$ to $1.8^\circ \pm 0.3$. None of these modifications were significantly different.

Table 1 Comparison of HKA, JLCA and WBL ratio between three weight-bearing conditions

| Weight-bearing condition | Supine position | Double-leg Stance | Single Leg Stance |
|----------------------------|-------------------------------|-------------------------------|--------------------------------|
| HKA ^a | 175.5° ± 1.05 (173.4°–177.6°) | 176.3° ± 1.05 (174.2°–178.4°) | 174.4° ± 1.05 (172.3°–176.45°) |
| <i>p</i> value | | <i>p</i> = 0.6 | <i>p</i> < 0.04 |
| JLCA ^a | 2.00° ± 0.31 (1.36°–2.62°) | 1.80° ± 0.31 (1.26°–2.52°) | 2.59° ± 0.31 (1.86°–3.12°) |
| <i>p</i> value | | <i>p</i> = 0.82 | <i>p</i> = 0.04 |
| WBL ^a ratio (%) | 35% ± 5.5 (24–46) | 33% ± 5.5 (22–44) | 27% ± 5.5 (16–38) |
| <i>p</i> value | | <i>p</i> = 0.78 | <i>p</i> = 0.47 |

Values are means ± standard deviations values with 95% confidence level in parentheses Values < 0.05 are displayed in bold

^aHKA hip–knee–ankle angle, JLCA joint line convergence angle, WBL weight-bearing line

DL vs SL stance

From DL to SL stances, we found a significant difference for HKA (Δ HKA = 1.92° [-0.4° – 5.2°]; *p* = 0.04) and JLCA (Δ JLCA = 0.8°; *p* = 0.04). Thus, the HKA angle decreased from 176.3° ± 1.05 to 174.4° ± 1.05 and the JLCA increased from 1.8° ± 0.31 to 2.59° ± 0.31.

However, we did not find any significant difference for the WBL ratio (Δ WBL = 5.5%; *p* = 0.47) which decreased from 33% ± 5.5 to 27.4% ± 5.5.

A significant correlation was found between Δ HKA and Δ JLCA between the DL and the SL stances (R^2 = 0.46; *p* = 0.01).

Discussion

The main finding of this study is that varus malalignment is accentuated from double-leg stance to single-leg stance, resulting from an associated JLCA increase between these two weight-bearing conditions. Our study has demonstrated the increase in global varus alignment (corresponding to the HKA angle decrease) when going from a double-leg stance to a single-leg stance (Fig. 3). The published literature agrees with these findings.

Specogna et al. [22] described an increase of global varus alignment with increased loading and described the SL stance as most representative of dynamic joint loading. Wang et al. [24] also demonstrated that global alignment varus increased by 2.1° in SL than in DL stance, which is comparable to our results.

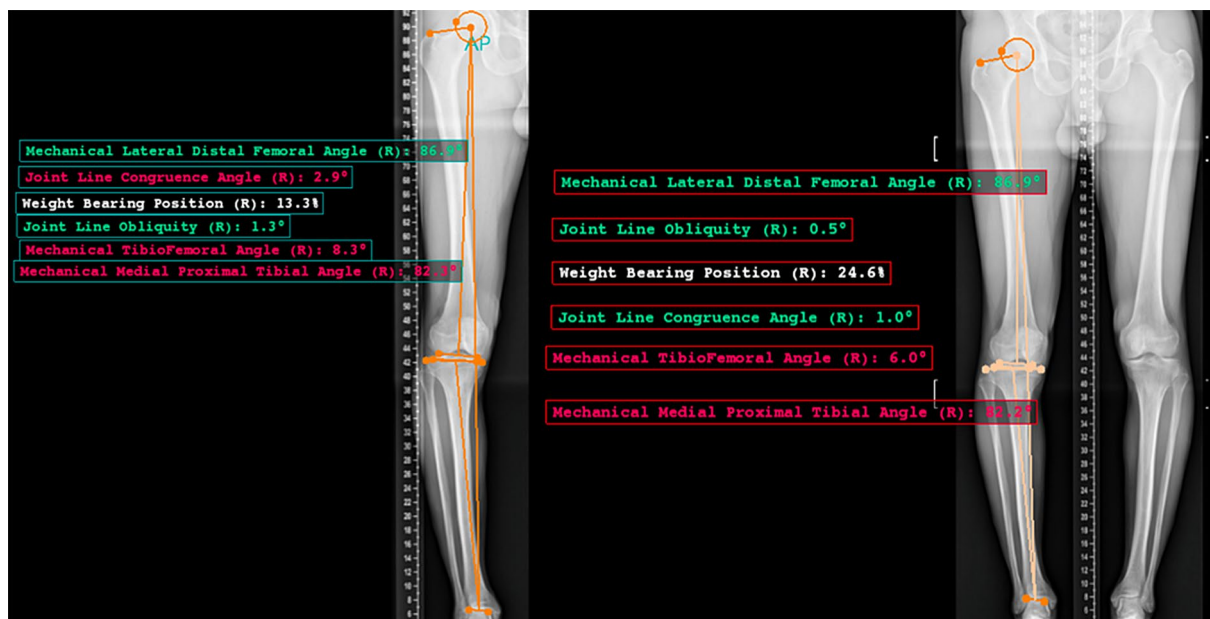


Fig. 3 Example of comparison between SL and DL stance. In this case, on SL stance the HKA (hip–knee–ankle angle) was 2,3° more varus and the JLCA (joint line convergence angle) was 1,9° higher

Our study did not find any significant difference in HKA angle when going from a supine to a double leg stance position, which is contrary to previous published studies. Paternostre et al. [19] found in his study a difference of 2° between non weight-bearing and weight-bearing conditions in 46% of the patients studied. Wang et al. [24] also found the DL stance to be 1.4° more varus than in the supine position. One explanation for this may be due to the differences in population selection. The present study included patients with mild to moderate knee OA (K-L stage I or II), compared to the studies mentioned which only included patients with severe knee OA (76% of K-L stage III or IV for Wang et al. and 89% for Paternostre et al.). The degree of OA may account for the magnitude in change of HKA angle and JLCA. More recently, Jud et al. [7] found a significant difference of 1° for HKA angle between supine position and DL stance, however no detail was provided regarding grade of knee arthritis in their cohort. The key finding in this study is the significant difference in JLCA when performing preoperative analysis of the long leg alignment views between DL and SL stances. These changes from DL to SL stance may be due to the residual laxity of the lateral soft tissues because the preoperative value and changes of JLCA depend on the lateral laxity and intra-articular deformation [14]. Yazdanpanah et al. [25] similarly reported an increase of 0.42° of JLCA between this DL and SL stances. In our study, the changes were of a greater magnitude, with an average increase of 0.8°. Wang et al. [24] also suggested that HKA angle differences might be caused by the effect of lateral soft tissue laxity and changes in the JLCA.

Contrary to So et al. [21] who found a 1.8° JLCA difference between supine and DL stance and Jud et al. [7] who found a 1° difference, we were not able to find any significant difference in our study. The present study found a significant correlation between Δ HKA angle and Δ JLCA, with a strong correlation coefficient suggesting that increased changes in JLCA will be associated with increasing differences in HKA angle between DL and SL stance. It may, therefore, be assumed that SL stance radiographs are useful for estimating the soft tissue correction in cases of higher preoperative JLCA or higher estimated JLCA changes.

There are some limitations to our study. The use of a scanogram for the measurement of the supine lower limb parameters requires careful positioning of the patient with the patella pointing forwards. The images do not guarantee neutral rotation or complete extension, which are necessary for measurement of angular values [3]. Recently, Jud et al. demonstrated that an average 10° of internal rotation or 20° external rotation in combination with 15° flexion is needed to alter the mechanical leg axis measurements relevantly by more than 3° [8]. Other authors find that scanograms have a reasonable accuracy for measuring

lower limb axis [16]. A second limitation is the absence of patients with severe knee OA. In our population of patients, all those included were found to have mild to moderate OA on radiographic parameters. It may be interesting in future studies to include arthroscopy as part of the procedure and confirm the grade of osteoarthritis.

This study highlights the linear correlation between Δ HKA angle and Δ JLCA when switching from a DL to a SL stance. In light of these findings and those seen in similar studies, it is clear that the modification of the HKA mechanical axis during patient loading is intimately linked to the grade of osteoarthritis. Medial knee arthritis will increase JLCA value due to substantial intra-articular wear and/or lateral soft tissue laxity, ultimately HKA angle value will be impacted by JLCA modification. Our study demonstrates the various problems that a surgeon may encounter when applying JLCA measurement in the SL stance position in planning for a MOWHTO. The significant difference between DL and SL positions should lead surgeons to use SL measurements sparingly, at the risk of overestimating their patients' bone deformity if surgeons plan an osteotomy based only on the HKA angle. However, SL measurements appear to be useful in estimating lateral laxity by applying a varus stress to the knee. This may be helpful in planning and anticipating postoperative discrepancies. Most surgeons agree with the goal of correction angle to position the weight-bearing axis slightly lateral to the centre of the knee. However, if the degree of correction varied depending on the patient stance, the extent for overcorrection can be difficult to anticipate. In those patients with an elevated joint convergence angle, single-leg stance may help to define the expected soft tissue correction after osteotomy or the intra-articular correction performed in the tibia.

Conclusion

Varus malalignment increases with weightbearing loading from double-leg to single-leg stances with an associated JLCA increase. Thus, single-leg stance radiographs may be useful to correct preoperative planning considering patient-specific changes in JLCA.

Author contributions MO designed the protocol and performed statistical analysis. LB and HF collected the Data. LB wrote the initial draft and perform edition for the different version of the manuscript. GM, RK, ME and MO corrected the different versions of the draft. All the authors approved the submitted version.

Funding No funding was needed for this study.

Compliance with ethical standards

Conflict of interest LB, GM, RK have nothing to disclose. MO is educational consultant for Stryker, AO-Recon and Newclip-Technics. ME is educational consultant for Amplitude, Groupe Lépine and Newclip-Technics.

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

Informed consent NA.

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