

Applicability of a modified angular correction measurement method for open-wedge high tibial osteotomy

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Abstract

Purpose The purpose of this study was to evaluate the clinical potential of a new measurement technique for open-wedge high tibial osteotomy (HTO) based on the medial cortex opening (MCO) associated with the Miniaci preoperative planning technique.

Methods A retrospective review of 97 cases of valgus-producing HTO that were performed between 2008 and 2013, using the intra-operative fluoroscopic mechanical axis technique, was carried out. The Miniaci-based measurement technique was then used as a theoretical point of comparison with the intent to compare the disparity between postoperative and ideal lower extremity (LE) mechanical axis with the measured disparity between postoperative and Miniaci-based planned MCO.

Results A significant correlation was observed for the comparison of the disparity between postoperative and Miniaci-based planned MCO and the disparity between postoperative and ideal LE mechanical axis (0.53, $P = 0.001$). This would suggest that the MCO associated with the Miniaci preoperative planning technique would have resulted in a better alignment had it been the chosen method to guide the amount of osteotomy opening. No significant correlation was observed between perioperative and postoperative LE mechanical axis (n.s.), the variable on which the current technique is based, confirming the poor reliability of the fluoroscopic mechanical axis technique.

Conclusions This study suggests a more accurate and precise technique of realizing the appropriate angular correction when performing a HTO, which could lead to better clinical outcomes.

Level of evidence III.

Keywords Arthritis · High tibial osteotomy · Knee

Introduction

Current literature has demonstrated the negative impact of incorrect angular correction on functional outcomes after open-wedge high tibial osteotomy (HTO), especially under-correction [1, 2, 7–9, 11, 14–16, 22, 26–30]. Consequently, obtaining an optimal mechanical alignment is a crucial part of HTO surgeries [8]. While optimal alignment is controversial, multiples biomechanical and clinical studies show satisfactory outcomes with correction guidelines of shifting the mechanical axis to a point approximately 62.5 % of the tibial plateau width from medial to lateral, as well as a hip–knee–ankle (HKA) angle between 183° and 186° [1–3, 7, 8, 10, 27, 30].

Various methods exist for planning of operative correction. One of the most frequently cited techniques involves the perioperative use of a radio opaque cable, or long metal rod, to visualize the mechanical axis under fluoroscopy during the angular correction portion of surgery [2, 7, 16, 18, 24, 27, 30]. However, this technique has been reported to produce postoperative overcorrection, especially in cases where ligamentous laxity is present, reflecting its inherent suboptimal precision and inconsistent accuracy [17, 18, 30, 31]. Alternatively, preoperative planning can be performed with long-leg standing radiographs using the Miniaci technique [4, 7, 23, 25]. This technique yields a desired opening angle for

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the osteotomy, with calculations based on Fujisawa's assertion that optimal lower limb alignment is achieved when the mechanical axis passes through a point at 62.5 % of the tibial plateau's width, from medial to lateral, typically corresponding to the lateral tibial eminence [6–8, 10, 19, 23, 24, 27, 30]. However, perioperative assessment and application of the planned opening angle is challenging, as there is no reliable method or tool to accomplish this task [20].

An alternative angular correction measurement technique to increase precision and accuracy of postoperative open-wedge HTO corrections could be based on the linear distraction value on the medial tibial cortex, corresponding to the opening angle obtained through the Miniaci technique of preoperative planning (Fig. 1), as described by Elson et al. [8] as well as Lee et al. [21]. The medial cortical opening (MCO) measure can then be reproduced with a graduated laminar spreader applied to the posteromedial aspect of the tibial osteotomy.

This study evaluated the clinical potential for the latter measurement technique for open-wedge high tibial osteotomy (HTO), with the hypothesis that using the MCO measured on preoperative radiographs would produce a more accurate and precise angular correction than the intra-operative fluoroscopic mechanical axis measurement.

Materials and methods

A total of 110 valgus-producing HTO (104 patients), performed between 2008 and 2013, were reviewed, all of which had been carried out using the intra-operative fluoroscopic mechanical axis technique.

Out of the 110 cases, eight cases were excluded due to missing radiographic information, three cases due to revision HTO surgery, and two cases due to extreme varus deformity associated with Blount's disease. A total of 97 cases in 91 patients were retained as part of this retrospective study.

Endpoints

The primary objective was to evaluate the hypothetical reliability of the new Miniaci-based angular correction measurement technique, as to evaluate its potential use in the clinical setting. As the new technique was not relied on for the actual angular correction during surgery, postoperative results were a reflection of the current standard measurement technique under fluoroscopy, and the applied medial distraction differed from the planned distraction for most cases. The disparity between postoperative and ideal LE mechanical axis was then compared to the disparity between postoperative and Miniaci-based planned MCO to determine whether diverging from the planned MCO also meant deviating from the ideal angular correction.

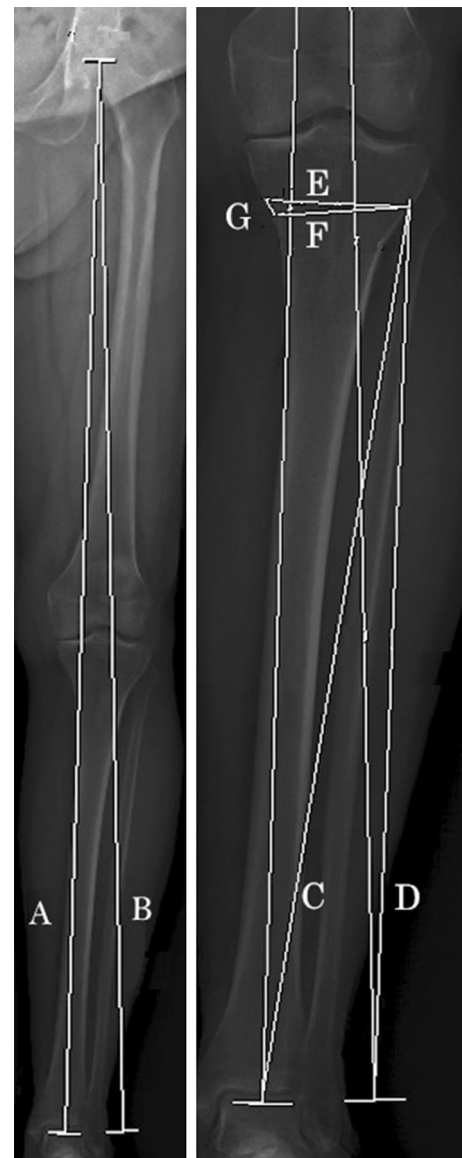


Fig. 1 Miniaci technique for preoperative planning. *A* Preoperative lower extremity mechanical axis, *B* ideal lower extremity mechanical axis, *C* and *D* lines from osteotomy hinge point to mechanical axes, forming the Miniaci angle, *E* and *F* lines from osteotomy hinge point to medial tibial cortex, reproducing the Miniaci angle, *G* medial cortical opening (MCO)

The secondary objective of the study was to evaluate the reliability of the fluoroscopic technique by correlating the intra-operative and postoperative LE mechanical axis measures.

Data collection

The retrospective review was carried out by the first author (JM) using a database of all HTO cases between 2008 and 2013 performed by a single surgeon (FL). Patients were

evaluated on a clinical and radiographic basis preoperatively, during surgery, and postoperatively.

Preoperatively, patients were evaluated clinically as well as radiographically, with three standard knee views, in addition to a standing bilateral full-leg radiograph. Compartmental osteoarthritis grade was evaluated using the modified Ahlback classification system. Whole-leg radiographs were executed using the EOS[®] X-ray imaging system (EOS[™] Imaging, Paris, France), which creates no vertical magnification and corrects for horizontal magnification. Knee arthroscopy was routinely performed prior to HTO surgery to assess cartilage, ligamentous, and meniscal status. The tibial osteotomy was performed proximal to the tibial tuberosity under fluoroscopic guidance through a longitudinal anteromedial incision. Opening of the osteotomy was determined using fluoroscopy and a metallic rod centred on the femoral head proximally and the centre of the ankle distally; opening of the osteotomy was increased until the rod was aligned with the lateral tibial eminence. The osteotomy was stabilized with a titanium plate and locking screws (Tomofix, DePuy Synthes, West Chester, PA, USA). No bone graft was used. The final alignment of the leg was assessed using the metallic rod, and the fluoroscopic image was saved. Postoperatively, patients were followed up at 6 weeks, 6, 12, and 24 months following surgery, with the same clinical and radiographic methods.

The main variables being considered were age, sex, body mass index (BMI), ligamentous laxity, severity of chondropathy, postoperative complications, as well as preoperative, perioperative, and postoperative radiographic measurements (LE mechanical axis, HKA angle, Miniaci angle, MCO according to the Miniaci angle, and lateral articular space).

Measurements were taken using the hospital's IMPAC Web1000[®] image navigator (Agfa Inc., Belgium). Preoperative and postoperative images were standing bilateral full-leg radiographs taken with the EOS[®] X-ray imaging system. Perioperative images stemmed from perioperative fluoroscopy.

The HKA angle was the angle between the mechanical axes of the femur and tibia, measured medially, the former being the line connecting the centre of the femoral head and the centre of the intercondylar notch, and the latter being the line connecting the midpoint of the tibial spines and the centre of the talar head.

The technique illustrated in Fig. 1 was used to calculate the Miniaci angle and corresponding MCO. The preoperative lower extremity mechanical axis was drawn as a line connecting the centre of the femoral head to the centre of the talar head. The ideal lower extremity mechanical axis was drawn as a line from the centre of the femoral head passing through the lateral tibial eminence and extending distally to the level of the ankle joint. The osteotomy

hinge point was then identified as the lateral tibial cortex at the level of the proximal tibiofibular joint. Two lines were drawn from the osteotomy hinge point, the first extending to the centre of the talar head and the second extending to the line representing the ideal lower extremity mechanical axis, at the same level as the centre of the talar head. The angle between these lines was the Miniaci angle. The angle was then reproduced at the level of the osteotomy by drawing two lines in the tibial metaphysis proximal to the tibial tubercle, originating from the hinge point. The MCO was measured as the distance between the two lines at their intersection with the medial cortex of the tibia.

The location of the lower extremity mechanical axis at the knee was evaluated as a percentage of total tibial plateau width, from medial to lateral, where it intersected with the tibial plateau.

The lateral articular space was measured as the smallest vertical distance between the lateral femoral condyle and lateral tibial plateau.

Based on the literature, the measurement accuracy was determined to be 1 mm for linear values and 1 degree for angular values [12, 13, 20]; however, the measurement software provided values at a precision of tenths of millimetres and degrees, and statistical analysis was executed with these exact values. The measurement accuracy selected in this study was intentionally conservative, although it does not significantly affect results nor challenge this study's conclusions. Thus, results were expressed without decimals, so as to reflect the above measurement accuracy.

Statistical analysis

Spearman's correlation coefficient was used to evaluate bivariate correlations of quantitative data. Correlation results were interpreted as inexistent (0.00), weak (0.01–0.30), moderate (0.31–0.60), strong (0.61–0.90), or perfect (0.91–1.00) [5].

Linear regression was performed to evaluate the association between postoperative mechanical axis deviation from Fujisawa's point and the following independent variables: preoperative HKA, preoperative Miniaci angle, preoperative predicted medial cortex opening, preoperative lateral articular space, perioperative mechanical axis, perioperative medial cortex distraction measure, and perioperative lateral articular space, as well as the difference between perioperative and preoperative predicted medial cortex opening. Potential collinearity was evaluated by calculating the variance inflation factor. A linear regression study was also performed to evaluate the association between postoperative HKA angle deviation from an ideal 4.5° of valgus angulation and the same independent variables as above. The ideal valgus knee angulation of 4.5° was selected because it is mean of the 3°–6° optimal valgus angulation

range cited in the literature [2, 7]. A paired *T* test was also performed to compare preoperative and perioperative lateral articular space.

Statistical significance was set as a *P* value of 0.05 or less. *P* values were determined using two-tailed tests. Statistical analysis was performed with a 95 % confidence interval, using the SPSS software, version 20.0 (SPSS Inc., Chicago, IL, USA).

Ethical approval for this study was obtained from the research ethics committee of the *Centre Hospitalier de l'Université de Montréal* (approval ID 13.299).

Results

A total of 91 patients and 97 knees were included. An overview of patient characteristics is given in Table 1.

Table 2 lists preoperative, perioperative, and postoperative radiographic measurements. A strong correlation was observed between perioperative and postoperative MCO (0.84, $P \leq 0.001$). In contrast, a poor correlation between perioperative and postoperative LE mechanical axis (n.s.) was also noted. Postoperative results revealed a slight trend towards overcorrection, as is recommended in the literature [16, 21]. The observed mean postoperative MCO was less than the perioperative value ($P = 0.001$), perhaps reflecting the effect of weight bearing with a loss of correction of 1 mm (SD 2 mm). BMI did not exert a statistically significant effect on MCO variation between the postoperative and perioperative periods.

The variation between postoperative and preoperative HKA was significantly correlated with the postoperative MCO (0.60, $P = 0.001$). A significant correlation was noted between the disparity between postoperative and ideal LE mechanical axis, in relation to the disparity between perioperative and Miniaci-based planned MCO (0.47, $P = 0.001$) (Fig. 2). A similar correlation was also observed for the disparity between postoperative and ideal HKA and the disparity between perioperative and planned MCO (0.48, $P = 0.001$). This statistically significant correlation was also present upon evaluation of the disparity between postoperative and Miniaci-based MCO, in relation to the disparity between postoperative and ideal LE mechanical axis (0.53, $P = 0.001$), as well as in relation to the disparity between postoperative and ideal HKA (0.52, $P = 0.001$).

Linear regression analysis was used to identify independent predictors of the disparity between postoperative and ideal LE mechanical axis, as well as between postoperative and ideal HKA. The disparity between postoperative and preoperative planned MCO was the unique statistically significant independent predictor, both for LE mechanical axis (0.02, $P = 0.001$) and for the HKA (0.40, $P = 0.001$). Collinearity analysis was done to rule out a potential impact on

Table 1 Patient characteristics

Number of patients	91
Number of knees	97
Gender	
Men	63 (35.1 %)
Women	34 (64.9 %)
Median age in years (range, SD)	51 (29–63, 7)
Median BMI (range, SD)	31.0 (19.1–62.2, 6.4)
Concomitant procedures	46 (47.4 %)
Meniscectomy	41
ACL reconstruction	2
Meniscectomy + ACL reconstruction	2
PLC reconstruction	1
Complications	21 (21.6 %)
Cellulitis	10
DVT	7
Haematoma	1
Inflammatory synovitis	2
Bandage allergy	1
MFTA	
Grade 0	0 (0 %)
Grade I	3 (4.1 %)
Grade II	25 (33.8 %)
Grade III	14 (18.9 %)
Grade IV	32 (42.2 %)
LFTA grade	
Grade 0	26 (35.1 %)
Grade I	21 (28.4 %)
Grade II	27 (36.5 %)
Grade III	0 (0 %)
Grade IV	0 (0 %)
PFA grade	
Grade 0	4 (5.4 %)
Grade I	17 (23.0 %)
Grade II	27 (36.5 %)
Grade III	25 (33.8 %)
Grade IV	1 (1.4 %)

BMI body mass index, *PLC* posterolateral corner, *DVT* deep vein thrombosis, *MFTA* medial femorotibial arthritis, *LFTA* lateral femorotibial arthritis, *PFA* patellofemoral arthritis

individual predictors, with no collinearity problem being detected by calculating the variance inflation factor.

An inverse correlation between Miniaci-based planned MCO and disparity between postoperative and ideal LE mechanical axis (-0.27 , $P = 0.008$) was found, suggesting a less accurate angular correction for smaller angular corrections. A similar relationship was found between Miniaci-based planned MCO and postoperative HKA angle deviation from an ideal 4.5° of valgus angulation (-0.30 , $P = 0.003$).

Table 2 Patient radiographic measures

	Mean	SD (range)
HKA (degrees)		
Preoperative	173	4 (163 to 182)
Postoperative	185	3 (172 to 190)
Preoperative Miniaci angle (degrees)	11	4 (1 to 25)
MCO (mm)		
Preoperative ideal	13	5 (2 to 34)
Perioperative	15	4 (4 to 26)
Postoperative	14	4 (4 to 24)
LE mechanical axis (%)		
Perioperative	62	6 (45 to 80)
Postoperative	69	14 (21 to 95)
Lateral articular space (mm)		
Preoperative	7	2 (4 to 13)
Perioperative	7	2 (2 to 12)
Postoperative	7	5 (2 to 54)
Disparity between postoperative and ideal HKA (degrees)	0	3 (−13 to 6)
Disparity between postoperative and ideal LE mechanical axis (%)	7	14 (−42 to 33)
Disparity between postoperative and Miniaci-based planned MCO (mm)	0.058	4 (−19 to 10)

HKA hip–knee–ankle angle, MCO medial cortex opening, LE lower extremity, SD standard deviation, mm millimetres

Discussion

The most important finding of the present study was that the described measurement technique was more precise and accurate than the standard fluoroscopy-based technique for high tibial osteotomy. This was evidenced by the significant correlation that was observed for the disparity between postoperative and Miniaci-based planned MCO and both the disparity between postoperative and ideal LE mechanical axis, as well as the disparity between postoperative and ideal HKA. In other words, the standard fluoroscopy-based technique resulted in an angular correction that was less accurate than the one that would have been theoretically produced by the Miniaci-based ideal MCO. This was further corroborated by the linear regression analysis that showed the MCO to be the only independent predictive variable for accurate angular correction.

The strong correlation observed for the postoperative MCO and the variation between postoperative and preoperative HKA suggest that using the MCO measure for HTO would be an appropriate way of directly affecting postoperative HKA.

Since the Miniaci-based technique was used as a theoretical means of comparison and was not relied on for the actual angular correction during surgery, the

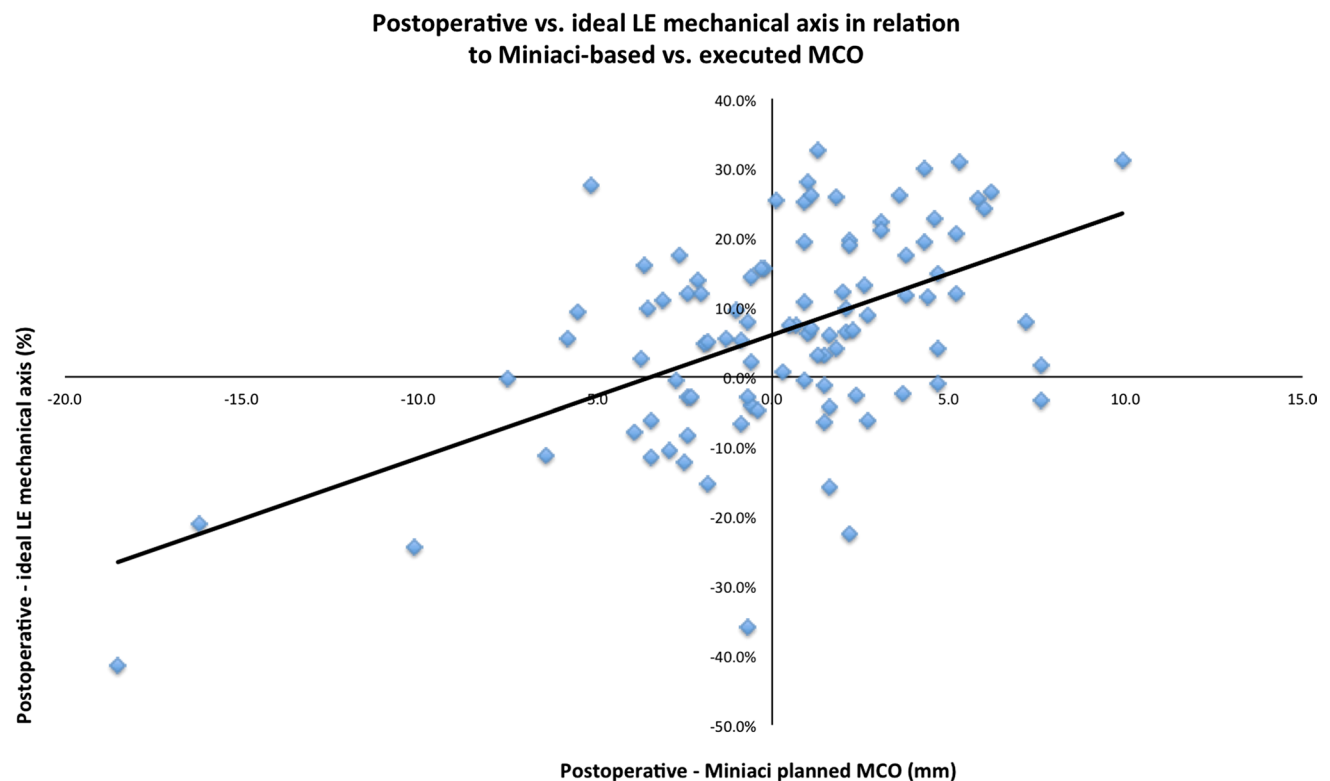


Fig. 2 As postoperative MCO diverges from the Miniaci-based planned MCO, postoperative LE mechanical axis diverges from Fujisawa's point. LE lower extremity, MCO medial cortical opening

postoperative results remain a reflection of the standard perioperative fluoroscopy technique. The data for our patient cohort nonetheless suggested adequate results with the perioperative fluoroscopy technique, as evidenced by a mean valgus angle of 5° and a mean LE mechanical axis at 69 % postoperatively. In that regard, the literature describes the ideal HTO correction goals of a valgus angle as being between 3 and 6 degrees, with a LE mechanical axis passing through Fujisawa's point at 62.5 % [2, 3, 7–10, 15, 30]. It should, however, be noted that the magnitude of the standard deviation for these criteria is an indication of this technique's lack of precision and, to a lesser extent, its lack of accuracy as demonstrated by frequent overcorrection [2, 7–9, 14, 15, 22, 27–30]. Furthermore, the results obtained in this study suggest a less accurate angular correction in cases of smaller varus deformity. These inaccuracies stem from the inherent imprecision of the technique relying on fluoroscopic visual estimation, as well as the predictable but unquantifiable effects of ligamentous laxity and weight bearing on angular correction [14, 17, 18, 30, 31].

In comparison, the technique described in this study, as well as in the studies by Elson et al. and Lee et al. [21], attempts to improve the precision and accuracy of angular correction for HTO by eliminating the fluoroscopic visual estimation of the lower extremity's mechanical axis. Surgical planning is consequently enhanced by an exact linear measure derived from high-quality radiographs on a weight-bearing patient. In contrast to Lee et al.'s paper, however, no special image processing software was necessary. The article by Elson et al. reported excellent reliability rates for the method used in this paper. In addition, our data demonstrate significantly more constant MCO values, as opposed to lower extremity mechanical axis, between the perioperative and postoperative periods, making it a more reliable variable on which to base angular correction during surgery.

The clinical relevance of this study lies in the potential for improved angular correction and, subsequently, improved clinical outcomes after valgus-producing HTO in well-selected cases of medial compartment gonarthrosis [8]. It is important to note that the planning technique described within this paper may depend on the use of radiographic equipment lacking vertical magnification, such as the EOS® X-ray imaging system, thus ensuring the measurement of valid and undistorted MCO values.

One of the study's limitations pertains to the theoretical nature of the reported results, as the angular correction technique described within this paper was not actually performed, but only served as a theoretical point of comparison. Further studies are therefore required to find the optimal surgical strategy for HTO. In order to address this need, an additional study will be performed using the

method described in this paper for preoperative planning of HTO. In addition, the risk of imprecise radiographic measures may have affected the study results, although any potential error would likely be non-systematic and therefore affect study power without introducing a bias.

Conclusions

Given that incorrect angular correction in valgus-producing HTO remains an important surgical challenge due to imprecise and inaccurate techniques, the development of more clinically reliable and exact measurement techniques is warranted. A new measurement technique, based on the Miniaci MCO, could potentially improve the accuracy and precision of angular correction and, subsequently, functional outcomes.

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Compliance with ethical standards

Conflict of interest There is no conflict of interest.

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