

High reliability in digital planning of medial opening wedge high tibial osteotomy, using Miniaci's method

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Abstract

Purpose Pre-operative planning is essential in high tibial osteotomy (HTO). Miniaci's method employs Mikulicz's weight-bearing line and is advantageous because the point of mechanical loading is related to the known degenerative condition of the knee. Miniaci's geometrical method has been modified for an opening wedge and described for use with a digital picture archiving and communications system viewer. Reliability for this method was hypothesised to be equivalent to published reliability for landmark-based commercial software and independent of observer experience.

Methods Twenty-four patients awaiting HTO had standardised long-leg radiographs. Mikulicz's weight-bearing line was projected through the lateral compartment of the knee at Fujisawa's point. The correction angle was generated at the hinge point subtending the current and proposed ankle centres. The opening wedge was plotted to measure an opening distance. Observations were recorded twice by three observers. Agreement was reported as intraclass correlation coefficients with 95 % confidence intervals.

Results Intra-rater agreement was excellent for the correction angle (0.965–0.985) and opening distance (0.928–0.980). If no set hinge point was used, then the inter-rater reliability was 0.986 for the correction angle and 0.984 for the opening distance. There was no discernible

pattern demonstrating improved reliability from the experienced observer.

Conclusions Reliability is comparable to commercially based landmark software and independent of observer experience. This makes such geometrical pre-operative planning accessible to surgeons who perform HTO with insufficient frequency to justify the investment in commercial software.

Level of evidence Diagnostic study, Level II.

Keywords High tibial osteotomy · Knee osteotomy · Opening wedge · Reliability · Digital radiographic annotation · Pre-operative planning

Introduction

High tibial osteotomy (HTO) is a pre-arthroplasty procedure to reduce pain and prolong function in the arthritic knee. Realignment into valgus preserves the failing knee joint with successful short and midterm results [2, 8, 20, 34]. Correction of the weight-bearing axis to a predetermined point is the mechanical aim of the procedure [4]. Under- or overcorrection leads to early failure [7], hence careful pre-operative planning is now mandatory.

The reliability of landmark-based digital planning software such as The HTO Pro[®] (Fowler Kennedy Sport medicine clinic, Ontario, Canada) [33], AutoCAD[®] (Autodesk Inc, San Rafael, CA, USA) [31], mediCAD[®] (Hectec GmbH, Germany) [29] and PreOPlan[®] (Siemens, Germany/Synthes, Switzerland) [29] is known to be high, but this software is not readily accessible to all surgeons wishing to perform HTO. Here, the user selects anatomical points which are allocated Cartesian coordinates [3] in a theoretical layer over the radiograph. The software

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calculates *pre-defined* angles and distances from the geometry of these coordinates.

Digital radiographic images are universally available in modern hospitals using the picture archiving and communications system (PACS). This is delivered through various similar software portals which allow annotation of radiographic images. In the PACS annotation method, the geometry is defined *whilst selecting* the anatomical points, but the geometrical calculations are performed with allocated Cartesian coordinates. The hypothesis that PACS portals will have a similar reliability to landmark-based software is therefore supported by the comparable mathematics [3].

Miniaci et al. [24] proposed a geometric method to generate a pre-operative correction angle for HTO. This method has been applied and recently validated with excellent reliability [21]. However, the method described by Lee et al. [21] requires both a PACS viewer with *additional graphics software* to manipulate images. The method described in this paper generates planning variables with just a PACS viewer. This is a simpler method that makes pre-operative planning for HTO accessible for all surgeons who perform HTO.

The purpose of this study is to describe how Miniaci's method is modified in application for opening wedge HTO using digital images. The hypothesis is that reliability using Miniaci's method with PACS software is equivalent to the reliability of landmark-based HTO planning software. A secondary hypothesis is that the reliability of observations will not be influenced by the experience of the observer.

Materials and methods

Twenty-four patients awaiting high tibial osteotomy were included in this study. All had medial compartment arthritis with varus alignment.

Obtaining long-leg radiographs

Long-leg weight-bearing radiographs were obtained for each patient. Four overlapping 35 × 43 cm cassettes were placed behind the patient who stood with full weight through both legs. The radiograph beam was centred at the level of the knee, a distance of 2.7 m from the patient, for a single exposure with beam settings in the range 150–200 mAs and 85–90 kV. In obese patients, abdominal soft tissues were manually elevated to allow beam penetration around the hip. A 25-mm reference ball was included for calibration. The images were digitally stitched using Carestream CR 975 version 4.60. (Carestream Health Inc., Rochester, New York).

Radiographic annotation (modified from Miniaci [24])

The method described by Miniaci has been modified for opening wedge osteotomy and for application to digital images viewed using a PACS system. The long-leg radiographs were viewed and annotated using the PACS software Centricity Enterprise Web 2006, version 3.0.10. (GE Medical systems, Barrington, Illinois). This portal allows on-screen annotation with tools that can record distances and angles. These parameters were recorded to one decimal place. This process concludes with the generation of both a *correction angle* and *opening distance* to guide the subsequent HTO surgery.

1. All measurements were calibrated against the projected size of the 25-mm marker ball. The width of the tibial plateau was measured just below the joint line, keeping the pixels in a horizontal unbroken pixel line and adjusting to exclude marginal osteophyte formations (Fig. 1). A line from the centre of the femoral head to the centre of the talar dome was projected as the pre-operative weight-bearing or Mikulicz line. The point where this line intersected the tibial plateau was called the Mikulicz point and recorded as a percentage of the tibial width (from medial to lateral) (Fig. 1). Both the *tibial width* and the *Mikulicz point (%)* were recorded as pre-operative variables.
2. Fujisawa's point [9] was calculated as 62.5 % of the recorded tibial width from medial to lateral, typically projecting Fujisawa's point just lateral to the lateral tibial eminence. A marking line was commenced from the medial edge of the tibial plateau, maintained with horizontal unbroken pixels and carried to the calculated Fujisawa's point. Typically, the mark's displayed distance did not match the calculated distance exactly and the mark was overcorrected by the next pixel beyond the Fujisawa's point. An additional line was projected from the centre of the femoral head, passing through the now-marked Fujisawa point and extrapolated to the level of the talar dome as the post-operative ankle centre (Fig. 2).
3. The hinge point on the lateral tibial cortex was then selected (Fig. 3). In the first round of observation, this point was selected at the individual discretion of the each observer. This process was later considered to be too vague. In the second round of observations, the instruction was revised; the hinge point was positioned below the subchondral sclerosis of the lateral tibial plateau by 18 mm in male patients and 15 mm in female patients [26]. The distance of this hinge point below the lateral joint line (vertical unbroken pixel line) was recorded as the *hinge point*.
4. Next, an angle was annotated with the apex at the selected hinge point. This angle subtending lines from

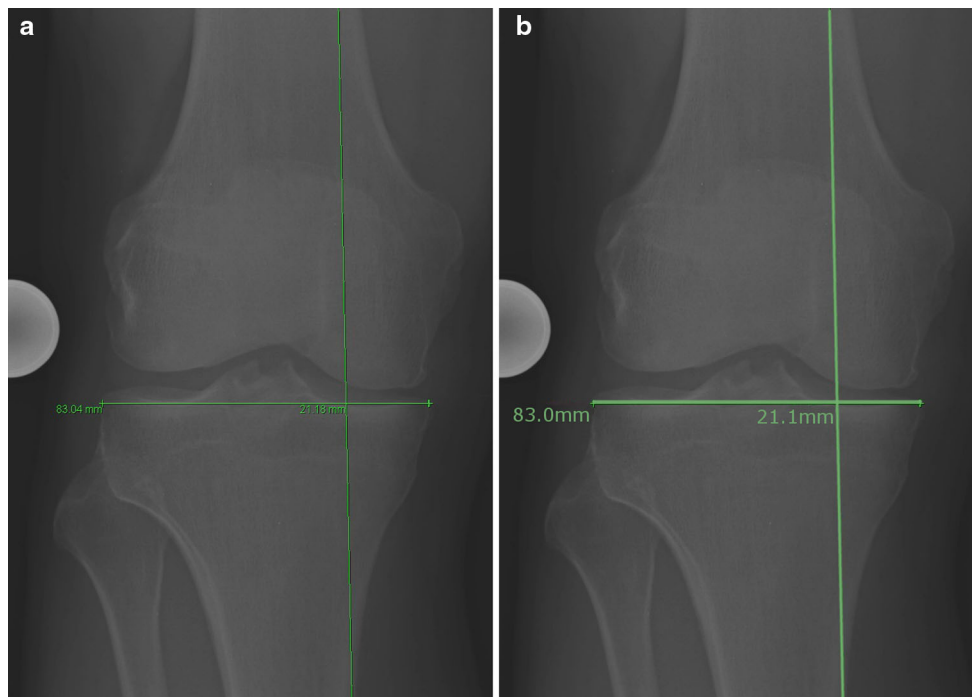


Fig. 1 The tibial width was measured with marginal osteophyte excluded. The pre-operative weight-bearing line (dropped from the femoral head centre to the ankle centre) transects this at the Mikulicz point, recorded as a percentage of the tibial width (medial to lateral)

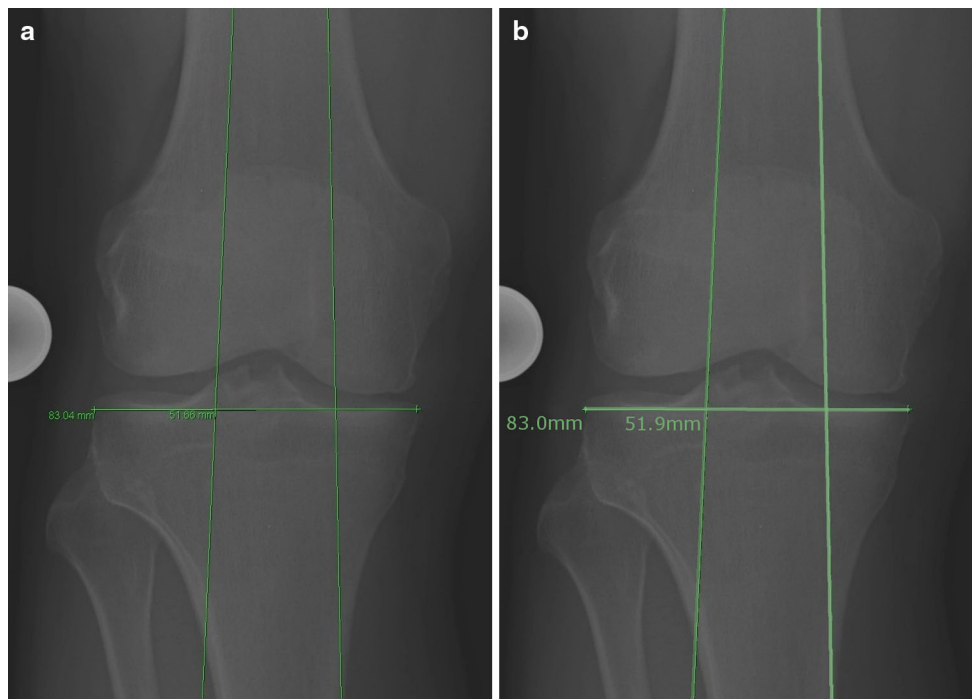


Fig. 2 Fujisawa's point was marked at 62.5 % of the tibial width (medial to lateral). A projected new Mikulicz line was drawn from the femoral head centre, passing through the marked Fujisawa's point and extrapolated down to the level of the ankle

the hinge point to pre-operative ankle centre and hinge point to post-operative ankle centre was recorded as the *correction angle* (Fig. 4).

5. The opening wedge was then annotated using the angle tool centred at the hinge point. The osteotomy plane in the proximal tibia typically arises above the pes

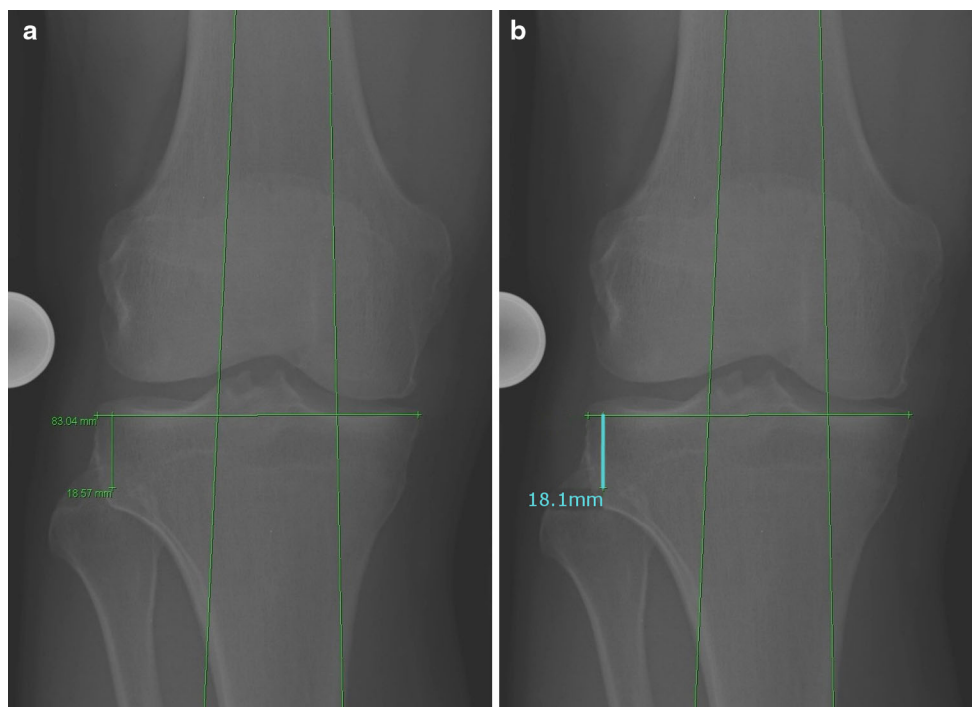


Fig. 3 The hinge point on the lateral cortex was selected and recorded

anserinus and projects towards the fibula head [10]. We have observed the obliquity of this plane to be 110° from a vertical line. Therefore, the proximal osteotomy cut was consistently projected at an angle of 110° from a vertical line passing above the hinge point (Fig. 5).

6. The proximal arm of the angle tool was then swung distally to the amplitude of the previously calculated correction angle, with both lines extrapolated beyond the medial cortex (Fig. 6). The distance between the lines at the points of intersection with the medial cortex was recorded as the *opening distance*.

Reliability assessment

This process of radiographic annotation was performed by one experienced observer (MJD) and two less experienced observers (DWE and TGP) for each of the 24 radiographs in the study. The following parameters were recorded: *tibial width*, *Mikulicz point*, *hinge point*, *correction angle* and *opening distance*. A second round of observations was performed after a delay of more than 1 month to generate both inter-rater and intra-rater reliability data.

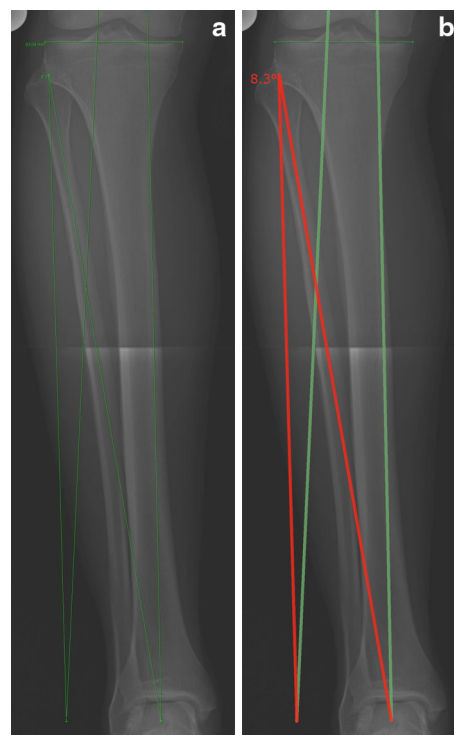


Fig. 4 The correction angle (*red lines*, in this case, 8.3°) intersects *lines* from the hinge point to pre-operative ankle centre and the hinge point to post-operative ankle centre

Ethics

Pre-operative planning is routine practice. The activity of this study was equivalent to an audit of practice and so ethical approval was not sought. All patients gave their informed consent to participate.

Statistical analysis

Variables were compared for absolute agreement using the intraclass correlation coefficient (ICC). The two-way mixed effects model was employed where people effects are random and measures effects are fixed [23, 30]. Ninety-

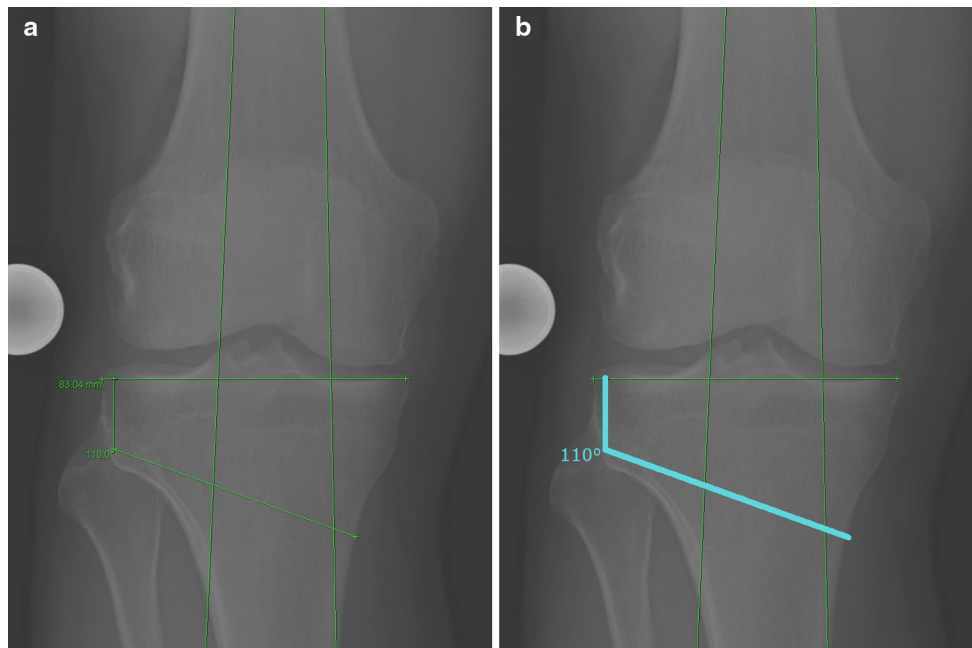


Fig. 5 The proximal osteotomy cut was projected 110° from the *vertical pixel line*

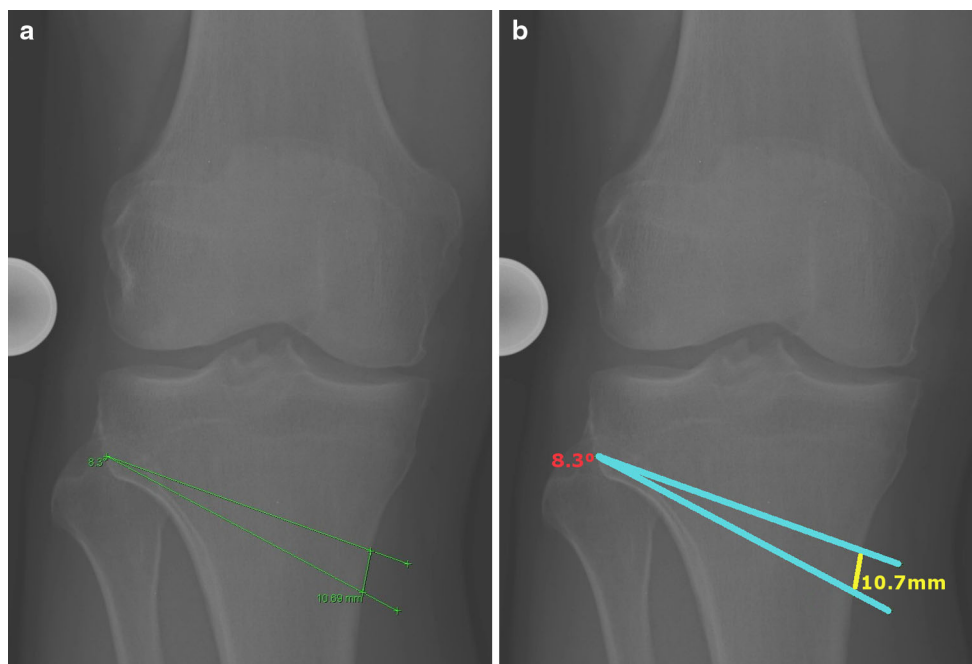


Fig. 6 The proximal arm of the angle tool was then swung distally to the magnitude of the previously calculated correction angle (in this case, 8.3°) and extrapolated beyond the medial cortex. The distance

between the intersections of these lines with the medial cortex was recorded as the opening distance (in this case, 10.7 mm)

five percent confidence intervals were reported. The software used for statistical processing was Statistical Package for Social Sciences version 20 (SPSS Inc., Chicago, Illinois).

Results

Descriptive statistics

The tibial width was recorded with a narrow range of means 80.8 mm to 82.7 mm as was the Mikulicz point; 21.0–23.6 %. A wider range of mean hinge points was observed in the first round of observation; 16.2–21.7 mm. The protocol for hinge point selection was subsequently adjusted for the second round of observation and the range narrowed accordingly, 17.5–18.3 mm. Narrow ranges were reported for the correction angle means (9.2°–9.7°) and opening distance means (12.1–12.6 mm).

Intra-rater reliability

Reported values in parentheses are ICC for intra-rater reliability, comparing each observer. In addition, the effect of observer experience was explored. Excellent agreement was found for the measured distances: tibial width (0.985–0.992) and Mikulicz point (0.981–0.990) which was independent of experience (inexperienced observers within the 95 % confidence interval yielded from the experienced observer). Agreement for the hinge point was poor (0.071–0.582) which reflects the adjustment to the protocol for hinge point selection. The experienced observer demonstrated the highest reliability (0.582) in placing the hinge point, whilst taking into account the comments above. Agreement was again excellent for the correction angle (0.965–0.985) with the higher reliability reported by less experienced observers. An inexperienced observer had the best reliability (0.980) in reporting the opening distance, but the other was worse (0.928) than the experienced observer (0.950). There was no evidence of a consistent pattern demonstrating improved reliability from the experienced observer.

Inter-rater reliability

Reported values in parentheses are ICC for inter-rater reliability comparing both rounds of observation. Reliability remained similar for tibial width (0.983 to 0.979) and Mikulicz point (0.984 to 0.983). Reliability improved for the hinge point (0.574 to 0.705) as a result of tightening the protocol for hinge point selection. Following this adjustment, there was a small reduction for the correction angle (0.986 to 0.980) and a larger reduction in the opening distance (0.984 to 0.952).

Discussion

The most important finding of the present study was excellent reliability rates for the simple and cheap method which is described. This method uses a single package of computer software (PACS viewer) but does not use computer navigation technology. It is known that computer-based measurements upon digital radiographs are more accurate than manual measurements on hard copy radiographs [11, 31]. There is some evidence [1, 6, 15] that computer navigation enhances the accuracy of correction, but this technology is expensive and not available for all surgeons.

This cheap modified Miniaci method, applied using a PACS portal, has yielded high inter-rater reliability values. Without a set hinge point, the correction angle ICC was 0.986 and opening distance ICC was 0.984. This is comparable to the high agreement reported [29] for PreOPlan[®] software (correction angle ICC = 0.993 and opening distance ICC = 0.979) and mediCAD[®] software (correction angle ICC = 0.995 and opening distance ICC = 0.969). When assessing the reliability of TheHTO Pro[®] software, comparable figures are reported [33] with a mechanical axis angle ICC of 0.98 and a mechanical axis deviation ICC of 0.97. AutoCAD[®] software is reported [31] to have ICC for inter-rater reliability from 0.839 to 0.995 for several different lower limb measurements. The figures we report in this study are therefore comparable to other landmark-based software programs which are commercially available. The hypothesis that equivalent reliability can be achieved with this modified Miniaci technique has been confirmed. In addition, the results of this paper are comparable to that of Lee et al. [21] with similar ICC values (Table 1). The method described here avoids the transfer and manipulation of digital images with further graphics software. This makes geometrical pre-operative planning accessible to surgeons who perform HTO but with insufficient frequency to justify the investment in commercial software or computerised navigation for this purpose.

Table 1 Comparison between papers which validate the digital application of Miniaci's method for pre-operative HTO planning

Reliability	Parameter	Paper	
		Elson et al.	Lee et al.
Inter-rater	Correction angle	0.980–0.986	0.956–0.979
	Opening distance	0.952–0.984	0.968–0.985
Intra-rater	Correction angle	0.965–0.985	0.980–0.992
	Opening distance	0.928–0.980	0.971–0.994

Elson et al. refer to this manuscript compared to Lee et al. [21]. Reported values are intra-class correlation coefficients

This study found narrow measurement ranges for the tibial width and Mikulicz points. An interim analysis identified a wider range for the hinge point and highlighted a potential inaccuracy. Systematic error was hypothesised as the cause because a less experienced observer had consistently selected a hinge point 5 mm lower than the two other observers. In response, the protocol was modified and subsequently the precision between observers improved for the hinge point. Whilst this protocol modification was intended to improve accuracy, it had the paradoxical effect of reducing end point precision for both the correction angle and opening distance. This finding that increasing accuracy at one stage failed to improve end point precision is initially counterintuitive. However, it may be explained if the selection of hinge point is not critical to the accuracy of correction angle and opening distances. The recommendation to drop the hinge point a set distance [26] below the lateral tibial plateau may be too prescriptive in individuals of varying sizes. In a separate cadaveric study, lateral cortex fractures were avoided when opening wedges were directed towards ‘safe zone’ hinges between the tip and circumferential line of the fibula head [10]. The findings from this study would suggest that aiming for a hinge point within such a zone may be a better approach than using a set distance.

In this study, the third author was an experienced consultant who has performed over 150 HTO procedures. The effect of this experience was explored, but there was no evidence of a consistent pattern demonstrating improved reliability. This confirms the second hypothesis that the reliability of Miniaci’s method is independent of experience, once the technique has been understood. Observer reliability is independent of experience for knee arthritis [27], but is dependent upon experience in Perthes disease [35] and templating hip arthroplasty [28] which suggests that the anatomical region being considered is an important factor.

This study is limited by the sample size ($n = 24$) and the use of only three observers. However, other authors exploring reliability in pre-operative planning have used the same sample size [15, 21] and just three observers [29]. Of benefit, we report both intra-rater and inter-rater reliability rates, where some other papers report only inter-rater reliability.

Historically, bony configurations were measured with calipers [22] and osteotomy corrections were judged by eye [32], later John Insall advised against this practice [14]. The early application of radiographs for HTO planning was restricted to short knee films [17], but later Harris recognised the benefit of long-leg weight-bearing films [12]. Pre-operative planning became increasingly important because the degree of correction influenced HTO longevity [7]. Planning methods have been described using the anatomical [5, 7, 18, 19] or mechanical [13, 16, 25] axes. Alternatively, planning methods that employ Mikulicz’s weight-

bearing line are advantageous because the surgeon can appreciate the point of mechanical loading in relation to the known degenerative condition of the knee. Miniaci’s method of planning was selected for this reason. Miniaci’s original description [24] is a lateral closing wedge osteotomy, geometrically planned using the weight-bearing line of Mikulicz. However, the principle of an angle generated at the hinge point subtending the current and proposed ankle centres is readily applicable to an opening wedge osteotomy [26]. Likewise, a new projected hip centre can be employed when planning a distal femoral osteotomy, although not investigated in this manuscript.

Pre-operative planning is essential to obtain good results in HTO [7]. This method is described with particular attention to the detail of radiograph annotation. No apology is offered, because this detail is necessary for readers to reproduce correction angles and opening distances. It is acknowledged that even the most meticulous pre-operative planning cannot exclude but merely limit the errors made during the procedure. The adage ‘measure with a microscope, mark with a chalk, cut with an axe’ is especially true when considered in the context of HTO. It highlights the importance of attempting accuracy at the outset in order to limit errors and obtain good results. This approach can be applied to routine clinical work.

Conclusion

In summary, we describe a modification of Miniaci’s method of planning prior to HTO surgery. The description detail is sufficient to be reproducible for all surgeons with access to a PACS viewer and requires no additional software. Inter-rater reliability is excellent and comparable to commercially available landmark-based planning software. Reproducibility is independent of the surgeon’s experience.

Conflict of interest No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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