A New Preoperative Planning Technique Can Reduce Radiation Exposure During the Performance of Medial Opening-Wedge High Tibial Osteotomy

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Abstract *Background:* Medial opening-wedge high tibial osteotomy (HTO) is one of the most common and effective HTO techniques, in which the proximal tibia is cut medially, leaving an intact lateral hinge of bone that can be opened to a variable amount for the desired correction, but the technical complications of lateral cortex fracture and intra-articular fracture are well described. The lateral bone hinge for medial opening-wedge HTO is crucial. If the hinge is too small, the tibia can fracture and become unstable, requiring further fixation. If the hinge is too large, the osteotomy can propagate into the joint as an intra-articular fracture when opening the osteotomy. *Purpose:* We propose a new technique that utilizes digital preoperative templating to improve the accuracy of the cut. Preoperative digital templating may allow the surgeon to reproducibly obtain a lateral bone hinge of 10 mm, while also reducing radiation exposure relative to the traditional fluoroscopically assisted technique. *Methods:* Ten cadaver extremities from five cadavers were matched into pairs and randomized into two groups: those with and without preoperative templating. The templating protocol measures the distance between two points on the medial and lateral cortices, and 20 mm is subtracted to determine the depth of the saw cut (10 mm for the hinge and another 10 mm because the proximal tibia is oval in shape).

The control method was done by making the cut using fluoroscopy with tactile feedback. Postoperative computed tomography scans were obtained of all legs to measure the width of the lateral bone hinge. Intraoperative fluoroscopy used during both techniques and the numbers of fluoroscopy shots were recorded. *Results:* We found neither the treatment group with preoperative planning nor the control group with the conventional technique had bone hinge widths that were different from the ideal 10 mm. The average hinge widths for the treatment and control groups were 11.2 and 11.5 mm, respectively. However, the treatment group was exposed to significantly less intraoperative fluoroscopy during the osteotomy cut. The average total number of fluoroscopy shots was 2.2 in the treatment group versus 6.3 for the control group. *Conclusions:* This new preoperative planning technique achieves similar accuracy of the lateral bone hinge when compared to current methods but exposes the patient, surgeon, and staff to significantly less intraoperative radiation.

Keywords high tibial osteotomy · bone hinge · preoperative planning · knee

Introduction

Medial opening-wedge high tibial osteotomy (HTO) is one of the most common and effective HTO techniques, in which the proximal tibia is cut medially, leaving an intact lateral hinge of bone that can be opened to a variable amount for the desired alignment and fixed with a plate to stabilize that correction [1, 5, 10, 13, 17, 20, 27, 30]. Two well-described technical complications of medial opening wedge HTO are lateral cortex fractures and intra-articular fractures [11, 15]. The literature reports rates of lateral cortex fractures ranging from 0.3 to 34% [11] and a rate of intra-articular fractures of 7% [15].

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In order to prevent lateral cortex fractures intraoperatively, it is critical to maintain an appropriately sized lateral bone bridge or hinge. Kolb et al. [20], who adapted their surgical technique from that of Staubli et al. [29], recommend leaving a 1-cm (10-mm) lateral hinge to prevent fracture. In addition, other studies also suggest that leaving a 10-mm lateral hinge often minimizes the risk of intra-articular fracture [7, 25]. In the description by Staubli et al., Kirschner wires are advanced to the lateral cortex and measured in order to determine the width of the tibia; 10 mm is then subtracted in order to leave a hinge of appropriate length [29].

Traditionally, the width of the lateral bone hinge is visually confirmed with the assistance of intraoperative fluoroscopy. Intraoperative fluoroscopy has been shown to increase radiation exposure of patients, physicians, and operating room staff [23, 24, 26, 28]. One study showed that orthopedic surgeons have a fivefold greater cancer incidence compared to physicians in other specialties and radiation-exposed non-physicians, though it was indicated that the physicians in this study did not consistently utilize radiation protection [22]. Studies that looked at female orthopedic surgeons specifically have also found that they have higher-than-expected cancer prevalence compared to both the general female population [8] and physicians in other specialties [9].

This study proposes a new technique for preoperative X-ray templating to determine the saw-cut depth for opening wedge HTO. Using cadaveric specimens, we sought to determine whether preoperative digital templating is as effective at obtaining a 10-mm lateral bone hinge as fluoroscopically assisted surgery with free-hand technique. Additionally, we sought to compare differences in radiation exposure between these two techniques. We hypothesized that preoperative digital templating would allow the surgeon to more reproducibly obtain a lateral bone hinge of 10 mm while also reducing radiation exposure relative to fluoroscopically assisted measurements.

Materials and Methods

Five pairs of cadaveric human knees were procured for a total of ten knees from the Anatomy Gifts Registry. A power analysis was performed to determine sample size. Assuming that the mean difference from a 10-mm lateral hinge in one group was 0.25 mm and the mean difference from the other group was 0.75 mm, we calculated that five specimens in each group would be required in order to achieve a power of 89%. Analysis of the final results will be performed using an independent samples *t* test.

Age of the cadaveric specimens ranged from 68 to 76 years, with a mean age of 70.6 years. Six male and four female cadavers were tested in this study. The donors' medical histories were reviewed to ensure no prior history of cancer or fracture of the ipsilateral knee, femur, tibia, or fibula. One knee in each pair was randomly selected into either the control or treatment group, and its matched pair was assigned to the other group.

Fig. 1. Preoperative X-ray and CT scan. **a** Line measured on X-ray from 5 cm below the joint line medially to 1.5 cm below the joint line laterally on a single specimen (total length = 72.9 mm). **b** The same line measured is 63.1 mm on CT scan (10 mm less than on X-ray) due to the fact that the tibia is somewhat oval in shape at this level. Saw cut in red is 53.0 mm. Image shows single specimen as an example.

The control group underwent HTO using the traditional technique without preoperative planning, instead relying upon intraoperative fluoroscopy to make an osteotomy cut with a 10-mm lateral bone bridge. Fluoroscopy was used during the saw cut to confirm the depth of the cut, as needed. The experimental group underwent HTO using a nearly identical surgical technique, except that the length of the intended osteotomy was determined preoperatively using digital templating. Fluoroscopy was used for guidewire

Fig. 2. Postoperative CT scan with measurements: A perpendicular line from the osteotomy cut to the farthest lateral cortex (using the axial cut that demonstrates the most lateral extent of the bone cut) is the lateral hinge (12.4 mm in this case).

placement, but cut depth was based on the preoperative templating and fluoroscopy was not used during the saw cut.

Preoperative Digital Templating: Determining Length of Osteotomy Cut

All preoperative planning was done on standard X-ray. Anteroposterior (AP) X-rays of all the specimens in the preoperative templating treatment group were obtained prior to any procedure. The AP X-rays were retrieved on the institutional picture archive and communication system (PACS). The lengths of lines (X) were recorded beginning on the medial cortex 5 cm below the joint line, just proximal to the pes anserinus [18], to the lateral tibial cortex 1.5 cm below the lateral joint line meant to simulate the normal starting position and trajectory of a medial opening-wedge HTO. Twenty millimeters were subtracted from the length of this line ($X - 20$) to account for the intended lateral bone bridge (10 mm) as well as the shape of the tibia in the axial plane (additional 10 mm) (Fig. 1).

Surgical Technique

All knees underwent the HTO procedure by a single surgeon experienced in this technique (RGM). A longitudinal incision was made, and the superficial medial collateral ligament was divided horizontally at the superior aspect of the pes anserinus, just above the gracilis tendon, at 5 cm below

the joint line. A Hohmann retractor was placed behind the posteromedial tibia to protect the neurovascular bundle [21].

The knee was then extended and rotated so that the patella was located directly anteriorly toward the ceiling in a neutral position. Fluoroscopy was then used to assist in placing a Kirschner wire from 5 cm below the medial joint line advancing to the lateral tibial cortex 1.5 cm below the lateral joint line. The wire's position was compared to the preoperative planning X-ray for confirmation, using bony landmarks to assure accurate position in the fluoroscopy image compared to the X-ray.

For specimens in the control group that had not received prior preoperative planning, there were no measurements done prior to the cut. The osteotomy was performed in both the control and the treatment groups with an oscillating saw beginning at the posteromedial aspect of the tibia and advancing parallel to the adjacent Kirschner wire. The cut extended toward 1.5 cm below the lateral joint line.

In the control group, the surgeon continued the cut until he felt the lateral cortex based on tactile feedback, and intraoperative fluoroscopy was used intermittently during the procedure to obtain visual confirmation of the length and direction of the cut.

In the experimental group, we marked the length of the osteotomy cut, as determined via preoperative templating, on a sawblade with a marking pen and used intraoperative fluoroscopy to confirm the direction of the cut using the wire. However, after this initial determination of the cut's direction, no further imaging or intraoperative fluoroscopy was used to aid in completing the osteotomy. The cut was made by placing the saw on top of the wire and sliding along the wire as it cut the bone. The width of the Zimmer oscillating sawblade used was approximately 1 mm.

In all cases, the decision was made to not open the cut as would occur in a living patient due to the risk of fracture of the brittle cadaver bone. As well, the goal of the study was to assess cut accuracy, not any measurement relating to angular correction. Moreover, the cut was made oblique anteriorly to avoid the tibial tubercle. After the osteotomy, all knees underwent computed tomography (CT) imaging postoperatively with reconstructions in the axial, coronal, and sagittal planes. We used the axial CT images to measure the lateral cortex hinge. The primary purpose of the CT scan was to illustrate that the tibia is not as wide in reality as it appears on the X-ray and this must be taken into account when planning the saw-cut depth. Though another option to determine saw-cut depth is to place a wire under fluoroscopic guidance and measure the wire, the tibia is oval in shape, and if the wire is oblique, the distance can be

Table 1 Interrater reliability

Interrater reliability				
	<i>N</i>	Rating 1	Lower 95% CI	Upper 95% CI
ICC(2,1)	9	0.695	0.086	0.923
	<i>N</i>	Rating 2	Lower 95% CI	Upper 95% CI
ICC(2,1)	9	0.641	0.048	0.904

Table 2 Intrarater reliability

Intrarater reliability				
ICC(3,1)	<i>N</i>	Rating 1	Lower 95% CI	Upper 95% CI
	9	0.981	0.92	0.996
ICC(3,1)	<i>N</i>	Rating 2	Lower 95% CI	Upper 95% CI
	9	0.653	0.036	0.91

under- or overestimated, leading to potential intra-articular propagation of the osteotomy or fracture of the lateral hinge, respectively.

Determining the Length of the Lateral Bone Hinge Using Postoperative CT

In our review of the current literature, we found no appropriate method for measuring the width of the lateral bone hinge. CT (0.6-mm cuts) was chosen to measure the width of the lateral bone hinge in order to account for the 3-dimensional structure of the bone not appreciable on radiographs. Sizing markers were used for calibration, as shown in Fig. 1.

Plain radiographs, rather than a coronal reformatted image, were used to take measurements because CT scans are not routinely obtained for preoperative planning. CT scan was used for this study both to demonstrate how the practical width of the tibia is overestimated on plain radiographs and also to measure the hinge in our specimens after the osteotomy was created. To determine the lateral cortical hinge, the image demonstrating the osteotomy cut in the axial plane with the furthest lateral evidence of the bone cut where both the anterior and posterior cortices were violated was found. On the same image, a line was drawn between the violated anterior and posterior cortices, which represented the furthest extent of the cut line. A second perpendicular line from the osteotomy cut was then extended to the most prominent portion of the lateral cortex, and the distance of this line was recorded as the lateral hinge width. This number was compared to the intended lateral bone

bridge length of 10 mm to determine the accuracy and precision of the cut (Fig. 2).

Measurements were performed by two independent surgeons. In cases where there was a large discrepancy between the two surgeons, a third surgeon also performed the measurement. Values from the control and experimental groups were compared to see which group more closely approximated the intended 10-mm lateral bone bridge. One month after the original measurements, the CT images were again randomized and the two original surgeons repeated their measurements to determine inter- and intrarater reliability of the measurement technique.

Statistical Methods

Differences in raters' scores from the objective ideal of 10 mm were evaluated using the Wilcoxon signed rank test. The raters' raw scores were also compared to the objective 10 mm using a 1-sample *t* test. The Mann-Whitney *U* test was used to see if there was a significant difference between the measurements in the treatment and control groups. To compare the number of fluoroscopy shots between treatment and control groups, the Mann-Whitney *U* test was used for both types of shots (with pin before cut and for the osteotomy cut).

To assess interrater reliability, two-way random, absolute agreement, single-measures intraclass correlation coefficient (ICC) was performed to assess the degree to which surgeons' measurements agreed. To assess intrarater reliability, two-way mixed, consistency, single-measures ICC assuming the rater as a fixed effect was used to assess the degree that the surgeons were consistent in their measurements across

Table 3 Lateral cortex bone bridge width measurements^a

Specimen	Measurement 1 (mm)		Measurement 2 (mm)	
	Rater 1	Rater 2	Rater 1	Rater 2
Left 1	19.8	10.8	21.0	20.7
Right 1	7.9	8.0	11.2	9.5
Left 2	13.3	13.6	13.0	13.6
Right 2	13.3	14.1	13.3	11.6
Left 3	10.8	10.7	10.4	11.6
Right 3	13.0	13.0	13.7	11.6
Left 4	10.7	10.8	10.9	11.8
Right 4	10.8	10.4	10.2	9.5
Left 5	10.8	11.3	9.6	9.2
Right 5	11.5	11.6	11.1	11.0

^a Specimen "Left 1" was excluded from the analysis because posterior cortex cut was inadequate

Table 4 Comparison between treatment and control group for rater 1

	Number	Mean	Standard deviation	Lower 95% CL	Upper 95% CL	<i>p</i> value
Difference from 10 mm						
Treatment	5	1.22	1.06	− 0.19	3.19	0.313
Control	4	1.50	2.24	− 1.56	4.00	0.125
Raw rating						
Treatment	5	11.22	2.24	8.44	14.00	0.063
Control	4	11.50	1.06	9.81	13.19	0.125

*Mann-Whitney *U* test comparing between treatment and control, $p = 0.90$ for difference between 10 mm

specimens. All analyses were conducted using the “irr” package in *R* (version 3.2.1 2015–06-18) and SAS version 9.3 (SAS Inc., Cary, NC, USA).

Results

Following CT scan analysis, we observed that one of the control specimens had a poor quality osteotomy that did not fully violate the posterior cortex throughout the length of the osteotomy. Due to this technical error, we decided to remove this specimen from the results analysis, yielding a sample of four controls and five treatments. We found the interrater reliability to be moderate with intraclass correlation coefficients ICC(2,1) of 0.70 (95% CI, 0.09–0.92) and 0.64 (95% CI, 0.05–0.90) [12] (Table 1). We found more variability in intrarater reliability using the same four control group measurements. Rater 1 had good intrarater reliability with an ICC(3,1) of 0.98 (95% CI, 0.92–0.996). Rater 2 had moderate intrarater reliability 0.65 (95% CI, 0.04–0.91) (Table 2). When comparing the treatment and control groups, only rater 1’s first set of measurements was used, as there was moderate-to-good agreement in inter- and intrareliability.

Neither the treatment group with preoperative planning ($p = 0.31$) nor the control group using the conventional technique ($p = 0.13$) had bone hinge widths that were significantly different from the ideal 10 mm (Tables 3 and 4). In addition, there were no significant differences found between the measurements in the treatment and control groups and 10 mm using the 1 sample *t* test ($p = 0.06$ for the treatment group and $p = 0.13$ for the control group). Furthermore, the Mann-Whitney *U* test showed no significant difference between the treatment and

control groups ($p = 0.90$). The average hinge widths for the treatment and control groups were 11.2 (95% CI, 10.4–12.1 mm) and 11.5 mm (95% CI, 11.0–12.0 mm), respectively.

The number of intraoperative fluoroscopy shots that were used in the new technique with preoperative planning was significantly fewer than the number of shots used in the traditional technique ($p = 0.03$). The average number of shots for the treatment group was 2.2 (95% CI, 0.8–3.6) versus 6.3 in the control group (95% CI, 4.8–7.7) ($p = 0.03$) (Table 5). We dichotomized the surgery further into two separate phases that utilize fluoroscopy: (1) during Kirschner wire insertion and (2) while performing the osteotomy cut. There is no significant difference between the average number of shots used in the treatment and control groups when inserting the pin: 2.2 (95% CI, 0.8–3.6) shots in the treatment group and 3.5 (95% CI, 2.5–4.5) in the control group ($p = 0.13$). During the cut, no fluoroscopy was used when performing the osteotomy with preoperative planning, and an average of 2.8 (95% CI, 1.3–4.2) shots were used when performing the osteotomy in the control group ($p = 0.01$).

Discussion

Our study explores whether the use of preoperative digital templating will allow the surgeon to reproducibly obtain a lateral bone hinge of 10 mm, while also reducing radiation exposure relative to the traditional fluoroscopically assisted technique. The study’s findings suggest that neither the treatment nor control specimens had bone widths that were significantly different from the goal of 10 mm, indicating

Table 5 Comparison of number of fluoroscopy shots between treatment and control groups using the Wilcoxon rank sum test

Number of fluoroscopy shots	Number	Mean	Standard Deviation	Minimum	Maximum	<i>p</i> value
With pin before cut	9	2.78	1.48	1	5	0.1299
Treatment	5	2.20	1.64	1	5	
Control	4	3.50	1.00	3	5	
For osteotomy cut	9	1.22	1.72	0	4	0.0104
Treatment	5	0.00	0.00	0	0	
Control	4	2.75	1.50	1	4	
Total	9	4.00	2.60	1	7	0.0327
Treatment	5	2.20	1.64	1	5	
Control	4	6.25	1.50	4	7	

that both techniques have comparable cut accuracy. Though the techniques yielded comparable results with regard to the bone hinge width, the surgical technique with preoperative planning was found to use less intraoperative fluoroscopy.

Our study has some limitations. Though the study demonstrates a way to reduce radiation exposure for the patients, surgeons, and staff, an inherent limitation relates to its clinical importance. In particular, the clinical relevance of a difference of four fluoroscopy shots between the treatment and control groups can be debated. However, any reduction in fluoroscopy is clinically relevant, given that radiation exposure is cumulative over one's lifetime and the operating room staff is frequently exposed. In addition, the interobserver reliability of the lateral hinge measurement was moderate, and the results must be interpreted in light of this.

Preoperative digital templating was found to use an overall average of 4.1 fluoroscopic shots fewer than the traditional technique. This would be equivalent to approximately 13.67 μGy (micrograys) of radiation exposure at about 30 cm from the large c-arm utilized in the procedure [2]. Literature reports that at approximately 20 to 30 cm from the central beam of a large c-arm, scattered radiation exposure is approximately 200 $\mu\text{Gy}/\text{min}$ [2]. Though this is less than a typical CT scan, which delivers about 32,620 μGy of radiation, radiation exposure is cumulative, and any exposure during a surgery presents a risk to the surgeon and patient [14].

The control group utilized more fluoroscopy because the surgeon is reliant upon X-ray guidance to terminate the osteotomy at the appropriate point. Furthermore, X-ray images are not always accurate and may miss cuts that do not violate both cortices, which occurred with one of the specimens in our control group. With preoperative planning, the surgeon can perform the osteotomy in a single step without taking additional radiographic images and can focus on making an accurate cut of both cortices.

Given the well documented cumulative exposure of radiation and its associated risks [8, 9, 16, 19] that orthopedic surgeons experience throughout their careers, this recommended templating technique is another method to reduce radiation exposure for surgeons, patients, and staff. The osteotomies in this study were performed by an experienced attending surgeon. The decrease in radiation may be even greater for less-experienced surgeons, who may take more fluoroscopic images when making the cut [3, 4, 6, 19]. The technique with preoperative planning removes some of the subjectivity of tactile feedback that is required when performing the osteotomy in the traditional fluoroscopically guided manner and allows for the osteotomy to be performed with a single, uninterrupted saw cut.

This study describes a new technique for preoperative planning for HTO. Both the new technique and the traditional technique yield similar lateral bone hinge widths that do not differ significantly from the 10-mm ideal. However, preoperative planning significantly reduced the number of fluoroscopy shots used during the procedure. This technique makes a complex operation less difficult, which may be especially beneficial for less-experienced surgeons.

Compliance with Ethical Standards

Conflict of Interest: Elad Spitzer, MD, Joseph J. Ruzbarsky, MD, John B. Doyle, BA, Kaitlyn L. Yin, BA, declare they have no conflict of interest. Robert G. Marx, MD, MSc, FRCS, reports receiving research funding from DePuy Synthes to support this work, as well as book royalties from Springer and Demos Health and Deputy and Associate Editorships at Journal of Bone and Joint Surgery outside this work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013.

Informed Consent: N/A

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

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