The Validity and Reliability of Preoperative Radiographic Canal Diameter Measurements of the Femur

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Abstract *Background:* The femoral canal is frequently measured preoperatively in cases where an intramedullary device is planned for operative fixation of a fracture. To our knowledge, a formal assessment of validity and reliability of preoperative canal measurements has not been previously performed. *Questions/Purposes:* This study aims to determine the validity and reliability of preoperative canal measurements of the femur made on plain radiographs using comparison with curved planar reformation software as the gold standard. *Methods:* Fifty-six patients were identified based on availability of anterior–posterior (AP) and lateral radiographs of the femur and computed tomography (CT) of the lower extremity. Four “raters” measured the canal diameter at its narrowest

point and the distance from the lesser trochanter to the isthmus on the AP, lateral radiograph, and CT. The width of the femoral nail on AP radiographs was also measured to determine magnification error. Curved planar reformation (CPR) was used to provide the most accurate calculation of the canal diameter. *Results:* Compared to the isthmus position determined by CPR, the measurement was most accurate on an AP and the diameter of the canal was most accurate using coronal CT, followed by AP radiographs. The measured canal diameter of the fractured femur on APs was compared to that of the used implant and varied by 1 mm. *Discussion/Conclusion:* The AP plain radiographic measurement was found to be more accurate for determination of the canal diameter compared to the lateral radiograph. These findings confirm the utility of preoperative canal measurements in predicting the feasibility of placing a specific size intramedullary implant.

Level of Evidence: Diagnostic Testing Level 4. See levels of evidence for a complete description.

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Introduction

The techniques used in intramedullary (IM) fixation have evolved significantly over the past century and the procedure has emerged as the standard of care in orthopedic surgery for the treatment of certain long bone diaphyseal fractures [1]. The femoral canal is frequently measured preoperatively in cases where an intramedullary device is planned for operative fixation of a fracture. The anatomic morphology of the femoral canal is highly variable, with some canals being too narrow to safely accept intramedullary hardware [5–7, 9]. While the width of the canal at its narrowest point is important, the validity and reliability of these measurements in the clinical setting has not been well established [5–7, 9].

The mediolateral diameter, as estimated from an anterior–posterior radiograph, has long been considered to provide an adequate level of accuracy during the preoperative planning for IM nailing of femoral diaphyseal fractures [5–7, 9]. Computed tomography (CT) has also been used to determine the width of the canal at its narrowest point, with

Fig. 1. MPR with distance pair measurement. Minimum and maximum diameters for the region of interest (*bottom panel*) are shown. The distance from the level of the isthmus to the center of the lesser trochanter is measured along a line parallel to the long axis of the femur (*top panel*).

wide variation in reported accuracy [7]. The recent implementation of digital radiography further complicates matters as magnification error can be an issue when using digital radiography without a calibration marker. Femoral diameter, as measured on a Picture Archiving and Communication

System (PACS) monitor, has been demonstrated to have a mean enlargement coefficient of $15.2\% \pm 6.0$ [3].

Curved planar reformation (CPR) served as our gold standard for determining the location and width of the femoral isthmus. CPR is a CT postprocessing technique that is more frequently used in vascular imaging, as it allows “straightening” of a tortuous three-dimensional structure, displaying it along its long axis on a single two-dimensional image. Applying this to the femoral shaft (which is slightly bowed anteriorly) allowed for canal measurements in a plane instantaneously perpendicular to the long axis of the femoral shaft. A distance pair algorithm built into the postprocessing software automatically determined the minimum canal diameter at each cross-section.

The purpose of this study was to determine the validity and reliability of current measuring techniques of femoral canal diameter in both intact femurs and in those that have undergone IM nailing. Validity was determined by comparing the measurements taken by the raters to CPR. Reliability was determined by calculating intraclass correlation coefficients.

Materials and Methods

After Institutional Review Board approval, diagnostic images of 56 femurs, from 2005 to 2011, were obtained from our hospital’s PACS system. Twenty-two of the image sets were selected from patients without a femoral fracture and/or any other pathological lesions of the femoral cortex. In this patient subpopulation, designated as “healthy”, the selected patients must have had each of the following images of the femur: an anterior–posterior (AP) X-ray, a lateral X-ray, and a coronal CT. The other 34 patients had undergone intramedullary nailing of the femur and were required to have both a preoperative AP radiograph of the fractured femur and a postoperative AP radiograph containing the implant, in order to be considered for this study. Patients included in this study were between the ages of 21 and 65,

Fig. 2. Bland–Altman plot showing the measurement bias of isthmus location, measured from the lesser trochanter on AP radiograph (a) and lateral radiograph (b).

Fig. 3. Bland–Altman plots showing the measurement bias of femoral canal diameter measurement on AP radiograph (a), AP radiograph with 300% zoom (b), CT (c), CT with 400% zoom (d), lateral radiograph (e), and lateral radiograph with 300% zoom (f).

with an equal distribution of age and gender. All radiographic images were viewed using IDX/RAD software.

In the subset of “healthy” patients, the medullary canal diameter of the femur was measured separately in each of the three imaging modalities. To evaluate validity, each measurement was compared to a gold standard, a canal diameter measurement that was obtained for each patient using curved planar reconstruction software. Isthmus measurements were taken using TeraRecon (Foster City, CA, USA) Aquarius. This was

performed using the CPR tool more commonly used in vascular imaging. Axial CT from 22 patients served as source images for CPR. A region of interest (ROI) was selected manually at each level along the femoral shaft by tracing along the interface between the endosteal surface and medullary cavity. Due to the nature of the CPR tool, this resulted in measurements in a plane that was instantaneously perpendicular to the long axis of the femur, despite the normal slightly bowed configuration of the femur. A distance pair measurement taken on each ROI

Fig. 4. Bland–Altman plot showing the measurement bias of the IM nail diameter measurement, compared to the actual implant diameter, on AP radiograph (a) and AP radiograph using 300% zoom (b).

allowed for automated acquisition of both the minimum and maximum diameters through that cross-section (Fig. 1). Notably, distance pair utilizes an algorithm built into the software that is not limited to transverse and anteroposterior measurements. The minimum diameter along the femoral shaft was designated the isthmus, and the distance from the level of the isthmus to the center of the lesser trochanter was measured along a path parallel to the long axis of the femur.

For the AP and lateral radiographs, the distance to the femoral isthmus from the middle of the lesser trochanter was the initial measurement determined by the raters, and it was at this position that the diameter of the medullary canal

diameter was measured. The isthmus position measurement was subsequently compared to the gold standard isthmus position, which was also obtained by CPR. In contrast, because the middle of the lesser trochanter is not in the same plane of section as the medullary canal of the femur on CT, raters were instructed to select the coronal section that displayed the smallest mediolateral width spanning the length of the medullary canal. All CT measurements were made while engaged in bone window.

Using the group of patients with intramedullary implants, the specific nail length was obtained to provide raters with a preset distance, one-half the length of the nail, which they used

Fig. 5. Bland–Altman plot showing measurement bias, comparing the simulated canal diameter measurement of the fractured femur, on AP radiograph (a) and AP radiograph with 300% zoom (b), to the IM nail diameter used in the surgery.

Table 1 Intraclass correlation coefficient (ICC): the inter-rater and intra-rater reliability of femoral isthmus position, measured from the greater trochanter

	Inter-rater			Intra-rater		
	ICC	LCL	UCL	ICC	LCL	UCL
AP isthmus	0.796	0.614	0.905	0.848	0.737	0.926
Lateral isthmus	0.138	0.001	0.353	0.218	0.025	0.474

LCL, UCL lower and upper 95% confidence limits

to measure from the proximal end of the nail, distally, parallel to the longitudinal axis of the femur. It was at this point that the raters measured the mediolateral diameter of the implant on the AP radiograph. The measured nail diameter was then compared to the nail diameter listed by the manufacturer for the corresponding nail and size. This served to assess validity in the measurement of a fixed, radiodense object (the IM nail), on an AP radiograph of the femur using the PACS digital radiograph imaging system at our hospital. In addition, the preoperative AP radiograph of the fractured femur, in this same group of patients, was used to provide a more accurate simulation of preoperative canal diameter measurements. Raters measured the canal diameter of the fractured femur on AP radiograph, in the same manner described above for the “healthy” femur. The simulated preoperative measurements of canal diameter in the fractured femur were then compared to the implant diameter that was used as determined from the implant record.

The group of raters consisted of four persons: a board-certified orthopedic surgeon, a board-certified radiologist, radiology resident, and a chief resident in orthopedic surgery. Each rater performed the described measurements two times, separated by a 2-week interval, such that the inter-rater and intra-rater reliability of the isthmus position, canal diameter, and implant diameter measurements could be made. The order of femur measurement and the imaging modality that was used were randomized separately for each rater and for each of the two measurement days. The intraclass correlation coefficient (ICC) was calculated according to the method of Shrout and Fleiss [8] using model (2,1) for inter-rater reliability and (3,1) for intra-rater reliability in a repeated measures design. Measurement data was transformed to normalized ranks prior to analysis to correct for non-normality [2]. Modified Bland–Altman

analyses were used to assess measurement bias versus reference measurements [4]. ICC was interpreted as follows: 0–0.2 indicates *poor* agreement, 0.3–0.4 indicates *fair* agreement, 0.5–0.6 indicates moderate agreement, 0.7–0.8 indicates *strong* agreement, and >0.8 indicates *almost perfect* agreement [8].

Results

Determining the location of the isthmus (the narrowest point of the femoral canal) is the first step in an accurate measurement of the canal diameter. If the isthmus is chosen incorrectly, the canal measurement will, in turn, be prone to error. When compared to the gold standard isthmus position obtained from CPR, the isthmus position measurement was most accurate when measured on an AP radiograph (Fig. 2). Raters showed a negative bias when measuring isthmus location on lateral radiograph (mean of −14.9 mm) and positive bias (mean of +6.37 mm) when taking the same measurement on AP radiograph. The diameter of the femoral canal at the isthmus, when compared to the gold standard CPR, coronal CT was the most accurate, followed by AP radiographs (Fig. 3). Lateral radiographs were the least accurate. The mean difference from the volumetric CT standard was +1.04 mm for coronal CT, compared to a mean difference of +2.42 mm for AP radiograph and +4.36 mm for the lateral radiograph. All differences were statistically significant ($p < 0.001$). For each of the three modalities, there was little difference between measurements taken with no zoom and those taken using maximum zoom. One standard deviation for the coronal CT and AP radiograph was ± 1.69

Table 2 Intraclass correlation coefficient (ICC): the inter-rater and intra-rater reliability of femoral canal diameter measurements in the healthy femur

	Inter-rater			Intra-rater		
	ICC	LCL	UCL	ICC	LCL	UCL
AP diameter	0.920	0.834	0.964	0.939	0.889	0.971
AP diameter 300% zoom	0.955	0.916	0.979	0.958	0.921	0.980
CT diameter	0.684	0.383	0.855	0.806	0.673	0.903
CT diameter 400% zoom	0.760	0.497	0.894	0.851	0.740	0.927
Lateral diameter	0.759	0.514	0.892	0.844	0.730	0.923
Lateral diameter 300% zoom	0.825	0.670	0.918	0.864	0.763	0.934

LCL, UCL lower and upper 95% confidence limits

Table 3 Intraclass correlation coefficient (ICC): a measure of inter-rater and intra-rater reliability of intramedullary nail diameter in the femur

	Inter-rater			Intra-rater		
	ICC	LCL	UCL	ICC	LCL	UCL
Nail diameter AP, no zoom	0.874	0.755	0.936	0.910	0.855	0.949
Nail diameter AP, 300% zoom	0.949	0.911	0.973	0.956	0.928	0.976

LCL, UCL lower and upper 95% confidence limits

and ± 1.26 mm, respectively. The actual diameter of the intramedullary nail (as obtained from the implant records) was compared to the nail diameter measurement on AP radiograph and demonstrated a mean positive bias of $+1.375$ mm (Fig. 4). There was little difference in mean bias of the nail diameter measurement taken on AP radiograph with no zoom, and the same measurement taken on AP radiograph with 300% zoom. The measured canal diameter of the fractured femur on AP radiographs was compared to the diameter of the implant that was actually used in the surgery (Fig. 5). These measurements showed less bias with no zoom (mean of 0.706 mm) than with 300% zoom (mean of 1.109 mm). Canal diameter measurements showed less bias when the implant used was 9–10 mm, compared to an implant size of 11 or 12 mm.

Inter-rater reliability (Table 1) for measurement of the distance of the femoral isthmus from the lesser trochanter of the femur on the AP radiograph showed strong agreement among raters (ICC of 0.796) and intra-rater reliability was excellent (ICC of 0.848). Measurement of the isthmus position on the lateral radiograph demonstrated poor inter-rater (ICC of 0.138) and intra-rater (ICC of 0.218) reliability. Canal diameter on AP radiograph showed the greatest inter-rater and intra-rater reliability, as compared to the measurements on CT and lateral radiograph (Table 2). Using 300% zoom on AP radiograph was slightly more reliable (inter-rater ICC of 0.955 and intra-rater ICC of 0.958), than using no zoom on AP radiograph (inter-rater ICC of 0.920 and intra-rater ICC of 0.939). Similarly, the diameter measured at the maximum zoom on CT (400%) and lateral radiograph (300%), showed greater inter-rater and intra-rater reliability when compared to each respective modality without zoom. The measurement of nail diameter, as taken at its midpoint, demonstrated excellent agreement on the AP

radiograph with 300% zoom (Table 3). Both the inter-rater (ICC of 0.949) and intra-rater (ICC of 0.956) reliability were greater than when the same measurement was taken on AP radiograph without zoom, with an inter-rater ICC of 0.874 and an intra-rater ICC of 0.910. The preoperative canal diameter measurement of the fractured femur (Table 4) was more reliable between raters (ICC of 0.909) and within the same rater (ICC of 0.920), on AP radiograph with 300% zoom, than the same canal diameter measurement on AP radiograph without zoom, which had an inter-rater ICC of 0.887 and intra-rater ICC of 0.900.

Discussion

Intramedullary fixation has become a popular treatment option for fractures of the femur. The variable anatomy and canal diameter of the femur introduces the potential for a femoral canal that cannot safely accept an intramedullary implant. The diameter of the femoral canal at the isthmus is routinely measured preoperatively at our institution to ensure appropriate implants are available and that alternative fixation strategies are discussed, if necessary. The accuracy and reliability of these measurements, however, has not been reported.

This study has several limitations. We had a relatively low number of patients and there could be a larger variability in measurements if a larger sample size was used. These findings are specific to our PACS and digital radiography system and may not be generalizable to other systems.

CPR was used to determine the location of the isthmus and the diameter of the canal at this point. The AP radiograph was found to be a more accurate and reliable image for determination of the canal diameter as compared to the lateral radiograph. Coronal CT images were more accurate

Table 4 Intraclass correlation coefficient (ICC): a measure of inter-rater and intra-rater reliability of femoral canal diameter measurements of the fractured femur

	Inter-rater			Intra-rater		
	ICC	LCL	UCL	ICC	LCL	UCL
Canal diameter AP, no zoom	0.887	0.815	0.937	0.900	0.839	0.943
Canal diameter AP, 300% zoom	0.909	0.849	0.950	0.920	0.870	0.955

LCL, UCL lower and upper 95% confidence limits

than either the AP or lateral radiographs; however, CT of the femur is not routinely performed in the setting of femoral diaphyseal fractures, as plain films are adequate for diagnosis. Interestingly, the femoral canal diameter measurement overestimated the actual canal diameter in each of the individual modalities. This could potentially be problematic if the surgeon overestimates the size of the canal and then has difficulty reaming and placing an implant that is too large for the actual canal diameter. This “overestimation” could also be related to magnification as raters found the size of the nail to be 1.375 mm greater than its actual size as confirmed by implant records. Despite magnification errors, the raters were able to estimate the canal diameter preoperatively to within 0.7 mm of the actual implant size chosen. This finding is likely due to reaming the canal prior to implant insertion, which “corrects” for the positive bias by using an implant that is a slightly larger than the pre-operative canal diameter. The mean deviation from the gold standard was +2.42 mm (± 1.26 mm) on the AP radiograph. When considering 2 standard deviations to account for a clinical scenario, the measurement of the canal diameter could range from near perfect to nearly 5 mm too large (2 SD = -0.1 to 4.94). While underestimating the canal would likely prevent attempting to place an intramedullary implant that would not fit, overestimating the canal diameter by 5 mm could be disastrous. In patients with capacious femoral canals, this will likely be of little clinical significance. However, in a patient with a borderline femoral canal (i.e., the young patient with a canal measurement of 10 mm), the surgeon should carefully consider the surgical treatment plan and have other fixation methods readily available.

The inter- and intra-rater reliability of all measurements approached “near perfect agreement” in every case, with the exception of the isthmus location on the lateral radiographs. This confirms that preoperative canal measurements on the AP radiograph is a reproducible method between raters and within the same rater.

In conclusion, preoperative femoral isthmus canal diameter measurements on the AP radiographs demonstrate a positive bias of 2.4 mm (± 1.26 mm). These measurements were found to be highly reproducible and predictive of the size of the final implant. Caution should be used when considering these measurements in patients with narrow femoral canals as the positive bias could create an implant–canal mismatch.

Disclosures

Conflict of Interest: Sayed Ali, MD, Mahin Rehman, BS, Kenneth P Walsh, BA, John R Fowler, MD, Oliver Chen, MD and John P Gaughan, PhD have declared that they have no conflict of interest. Saqib Rehman, MD is a paid consultant for Lilly and Lippincott and receives payment for lectures including service on speakers’ bureaus from Synthes, outside the 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 2008 (5).

Informed Consent: Informed consent was waived from all patients for being included in the study.

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

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