

Radiographic Study of the Fifth Metatarsal for Optimal Intramedullary Screw Fixation of Jones Fracture

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Abstract

Background: Jones fractures occur in the relatively avascular metadiaphyseal junction of the fifth metatarsal (MT), which predisposes these fractures to delayed union and nonunion. Operative treatment with intramedullary (IM) screw fixation is recommended in certain cases. Incorrect screw selection can lead to refractures, nonunion, and cortical blowout fractures. A better understanding of the anatomy of the fifth MT could aid in preoperative planning, guide screw size selection, and minimize complications.

Methods: We retrospectively identified foot computed tomographic (CT) scans of 119 patients that met inclusion criteria. Using interactive 3-dimensional (3-D) models, the following measurements were calculated: MT length, “straight segment length” (distance from the base of the MT to the shaft curvature), and canal diameter.

Results: The diaphysis had a lateroplantar curvature where the medullary canal began to taper. The average straight segment length was 52 mm, and corresponded to 68% of the overall length of the MT from its proximal end. The medullary canal cross-section was elliptical rather than circular, with widest width in the sagittal plane and narrowest in coronal plane. The average coronal canal diameter at the isthmus was 5.0 mm. A coronal diameter greater than 4.5 mm at the isthmus was present in 81% of males and 74% of females.

Conclusion: To our knowledge, this is the first anatomic description of the fifth metatarsal based on 3-D imaging. Excessive screw length could be avoided by keeping screw length less than 68% of the length of the fifth metatarsal. A greater than 4.5 mm diameter screw might be needed to provide adequate fixation for most study patients since the isthmus of the medullary canal for most were greater than 4.5 mm.

Clinical Relevance: Our results provide an improved understanding of the fifth metatarsal anatomy to guide screw diameter and length selection to maximize screw fixation and minimize complications.

Keywords: Jones fracture, proximal fifth metatarsal fracture, anatomy, radiographic study, intramedullary screw fixation, complication

Fracture of the proximal fifth metatarsal is a common injury, and its treatment is largely determined by the anatomic location of the fracture. Zone 1 includes the proximal cancellous tuberosity with an abundant blood supply, and fractures in this region reliably heal with nonoperative treatment.² Zone 2 represents the metadiaphyseal region and is the location of the fracture first described by Sir Robert Jones in 1902.⁸ This region has a relatively poor blood supply and as a result is at increased risk of delayed union or nonunion.^{2,4} Zone 3 represents the proximal diaphysis and fractures in this region are commonly diaphyseal stress fractures.

Operative indications are not universally agreed on, however there is evidence to support intramedullary compression screw fixation in specific subsets of patients. These include acute zone 2 fractures in the competitive athlete and

zone 2 fractures with delayed union or nonunion in the general population.^{1,3,9,13} In addition, a zone 3 fracture with clinical and radiographic evidence of delayed union or nonunion is an indication for operative treatment.^{14,17}

While intramedullary screw fixation of proximal fifth metatarsal fractures generally achieves favorable results, there are known complications. In previous studies, many of these complications have been attributed to improper

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selection of screw length and diameter. Delayed union, non-union and refracture have been associated with inadequate screw diameter and biomechanical studies have shown increased screw pullout strength with larger diameter screws.^{6,10,18} On the other hand, use of a large diameter screw in a relatively narrow medullary canal can result in iatrogenic longitudinal fractures.¹⁰

The challenge in choosing an appropriate screw length is related to the characteristic lateroplantar shaft curvature of the fifth metatarsal. Early descriptions of the intramedullary screw fixation technique recommended use of the longest screw that fits into the medullary canal.³ However, use of a screw with excessive length has been shown to cause straightening of the bone and resultant lateral cortical gapping at the fracture site, which increases risk of delayed union and nonunion.^{7,10} In addition, excessive screw length can result in perforation of the medial cortex.⁹

While a complete understanding of the fifth metatarsal anatomy is critical in proper selection of an intramedullary screw, no study has fully defined its dimensions and the location of the shaft curvature or bow. Some previous biomechanical studies have measured canal diameters with plain radiographs. These studies reported on small numbers of cadavers and measured the canal diameter at only one point along the length of each specimen.^{10,11} The most comprehensive description of the fifth metatarsal anatomy was a cadaver study that involved sectioning 20 specimens and making canal diameter measurements at 3 locations (proximal, middle, and distal).⁵ No study has used 3-dimensional (3-D) imaging to define the anatomy nor identified the location along the length of the fifth metatarsal at which the lateroplantar curvature occurs.

In this study, we present a detailed anatomic description of the fifth metatarsal based on 3-D computed tomography (CT) and plain radiographs. The average sagittal and coronal canal diameters as well as the average length of the fifth metatarsal and the average distance from the tip of the tuberosity to the origin of the curvature were determined. This information could be used to guide selection of screw diameter and length, in order to obtain rigid endosteal thread purchase while minimizing intraoperative and post-operative complications such as cortical perforation, blow-out fractures, and lateral fracture site distraction during screw insertion and refractures.

Materials and Methods

After appropriate institutional review board approval, consecutive foot CT scans obtained at our institution between 2006 and 2013 were reviewed. CT scans of patients were excluded if they had prior surgery or injury to the fifth metatarsal, Charcot arthropathy, or any midfoot or forefoot fractures, dislocations or deformity that disrupted the normal relationship of the fifth metatarsal with the foot. Scans

of 119 patients met inclusion criteria and were utilized for this study. The indication for the foot CT scans in all 119 patients was for evaluation of hindfoot fractures. All scans included the entire fifth metatarsal. Seventy-four of the study patients had non-weight-bearing, adequate digital plain radiographs of the ipsilateral foot and were analyzed. The mean age of our study population was 44 ± 16 years. Seventy-three patients were male (age 41 ± 15) and 46 were female (age 49 ± 15). The mean age of the 74 patients with adequate plain radiographs of the ipsilateral foot was 44 ± 16 years.

Each of the CT scans of our study cohort was exported from picture archiving and communication system (PACS, GE Healthcare, Barrington, IL) to the VitreaCore Version: 6.5.3046.1 Software (ViTAL, A Toshiba Medical Systems Group Company, Minnetonka, MN). Interactive 3-D models were rendered from the 2-dimensional (2-D) CT cross-sectional images. These 3-D models were studied to better characterize the morphology and the curvature of the metatarsal, and determine average medullary canal diameter of the fifth metatarsal. The plantar surface (soft tissue) of each foot was used as a reference line to determine the coronal and sagittal planes of the fifth metatarsal. The plantar surface corresponded to the coronal plane and the sagittal plane perpendicular to it. The 3-D models were cross-referenced to the 2-D axial, reformatted coronal, and sagittal images. Measurements were performed on the cross referenced 2-D axial, coronal, and sagittal images and confirmed using the 3-D models to ensure that appropriate points were being measured. Two senior orthopaedic surgery residents performed all measurements using the protocol created and reviewed by a fellowship trained orthopaedic foot and ankle surgeon.

These 3-D models were also viewed in a transparent mode, which allowed for detailed evaluation and mapping of the medullary canal (Figure 1). The medullary canal was isolated and analyzed independently (Figure 1). Furthermore, cross-sectional reconstructions in the plane orthogonal to the longitudinal axis of the fifth metatarsal were created to measure the dimensions of the medullary canal.

The length of the bone was measured. The origin of the shaft curvature (referred to as “bow” or “curvature” for the remainder of this article) was determined in the coronal and sagittal views by drawing parallel lines along inner cortices from the proximal to distal shaft. The origin of the curvature was noted to correspond to the point where the parallel lines come in contact with the medullary bone cortex. The distance separating each set of parallel lines was the same as the maximum canal diameter for the metatarsal. The goal of this study was to determine the effective contact point of the shaft curvature when the maximum diameter screw is used. When a smaller diameter is used, the effective contact point was noted to be more distal by only a few millimeters.



Figure 1. CT scan interactive 3D model rendering of the foot showing the characteristic lateroplantar curvature of the fifth metatarsal: viewed in normal mode (A), viewed in transparent mode with enhancement of the medullary canal (B), and isolated fifth metatarsal viewed in the transparent mode (C).

In the coronal plane, the origin of the shaft bow was found to correspond to the point where the parallel line intersects the distal inner medial cortex (Figure 2). Conversely, in the sagittal plane, the origin of the curvature was found to correspond to the point where the parallel line intersects the distal inner dorsal cortex (Figure 2). The distance from the tip of the MT base to the bow (referred to as the “straight segment length” for remainder of this article) was then measured both in the coronal and sagittal planes. The location of the shaft curvature was also verified using the 3-D interactive models. The coronal and sagittal medullary canal diameters at the bow and 40 mm from the tip the base of the metatarsal were measured using the cross referenced 2-D imaging as shown in Figure 2. The 40 mm distance was chosen because a Jones fracture, as described by Sir Robert Jones, occurs approximately three-fourths of an inch (approximately 19 mm) from the base.⁸ Relative to the base of the fifth metatarsal, 40 mm is twice the distance from where Jones fracture occurs. As such, intramedullary screw fixation of a Jones fracture with a 40 mm screw length that has an optimal width should provide adequate compression at the fracture site, as all the screw threads (typically 16 mm) should engage the bone distal to the fracture site.

Similar measurements as described above were performed on the available plain radiographs. These measurements were performed on the anteroposterior (AP), oblique, and lateral views of the foot (Figure 3). The metatarsal length, the bow length, and corresponding medullary canal diameters at the curvature and 40 mm were measured.

Statistical Analysis

Statistical analysis was performed using Stata 10 Statistical Software (StataCorp, College Station, TX). Unpaired Student's *t* tests with an alpha level of .05 were performed to assess differences in CT scan measurements between males and females and differences in measurement between CT scans and plain radiographs. Pearson's product-moment correlation coefficient was calculated to assess correlation between CT scan and plain radiographic measurements.

Results

Measurements for the study cohorts are shown in Table 1. The mean straight segment length for the study cohort was 51.9 ± 4.4 mm (range, 43-68). The average ratio of the

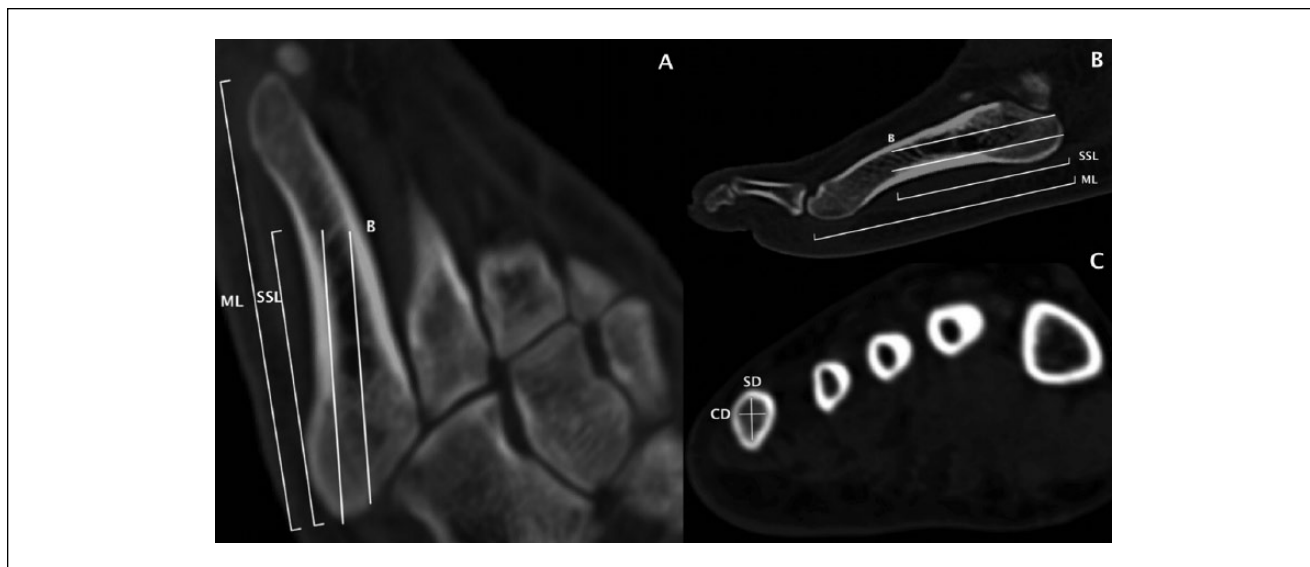


Figure 2. Cross referenced 2D CT scan of the fifth metatarsal showing how measurements were performed in the coronal (A), sagittal (B), and axial (C) planes. B, bow; CD, coronal diameter; ML, metatarsal length; SD, sagittal diameter; SSL, length from tip to bow (straight segment length).

straight segment length to metatarsal length was 0.68 (68%; range, 57-76%). The isthmus of the medullary canal of the fifth metatarsal was at the bow. The cross section of the medullary canal was elliptical rather than circular, with the widest diameter in the sagittal plane and narrowest in the coronal plane. The mean coronal diameter at the bow and at 40 mm from the tip was 5.0 ± 0.9 and 5.1 ± 0.8 mm, respectively. The mean sagittal diameter at the bow and at 40 mm from the tip was 6.7 ± 1.0 and 7.0 ± 1.1 mm, respectively.

Subgroup Analysis

Age. The mean age of male patients ($n = 73$) was 41 years and of female patients ($n = 46$) was 49 years. There was no correlation between age and straight segment length ($r = -.080$) or age and canal diameter ($r = -.010$), as shown, respectively, in Figures 4 and 5.

Gender. Gender-specific measurements for the study cohort are shown in Table 2. The straight segment length for males was significantly longer compared to females, 53.3 ± 4.3 mm versus 49.7 ± 3.0 ($P < .001$); however, the ratio of straight segment length to MT length remained constant, 68.3% versus 68.4% ($P = .796$). Male cohorts also had significantly wider coronal canal diameter compared to female cohorts both at the curvature and at 40 mm from the tip, 5.2 ± 0.9 mm versus 4.8 ± 0.7 mm ($P = .011$) and 5.3 ± 0.9 mm versus 4.8 ± 0.7 mm ($P = .001$), respectively.

Among males, 81% and 82% of patients had a coronal canal diameter greater than 4.5 mm at the bow and at 40 mm, respectively. Among females these values were 74%

and 74%, respectively (Table 3). The difference for both genders in our study group was not statistically significant ($P = .301$).

CT Scans Versus Plain Radiographs

When CT scan measurements were compared to plain radiographs, it was noted that the plain radiographs overestimated the measurements. Table 4 provides a detailed comparison of CT scan to plain radiograph measurements. The canal diameter measurements at bow and at 40 mm on the lateral view plain radiographs, compared to sagittal CT measurement, were significantly higher ($P = .033$ and $P = .001$, respectively). However, there was no significant difference in our study cohort between canal diameter measurement at bow and at 40 mm for AP view plain radiographs compared to coronal CT measurement ($P = .472$ and $P = .137$, respectively). The AP radiographs were found to most accurately approximate the CT scan measurements. The correlation coefficient (r) of the AP straight segment length compared to CT straight segment length was .534 (Figure 6). The correlation coefficient (r) of the AP diameter compared to CT coronal diameter at the bow was .716 (Figure 7).

Discussion

Our study defined the specific anatomy of the fifth metatarsal based on CT scan data from 119 patients. The fifth metatarsal diaphysis had a lateroplantar curvature. The medullary canal tapered from proximal to distal with the isthmus at the



Figure 3. Plain radiographs of the fifth metatarsal showing how measurements were performed in the anteroposterior (A), oblique (B), and lateral (C) views. B, bow; ML, metatarsal length; SSL, length from tip to bow (straight segment length).

origin of the curvature. The medullary canal cross-section was not circular, but rather elliptical. It was wider in the sagittal plane than in the coronal plane. In our study population, the average metatarsal length was 76 mm and the average length from the tip of the base of the fifth metatarsal to the origin of the curvature (straight segment length) was 52 mm. On average, the straight segment of the fifth metatarsal constituted approximately 68% of the overall length of the metatarsal.

There is a dearth of literature describing the anatomy of the fifth metatarsal. In the one prior relevant study, Ebraheim et al studied 20 cadaveric fifth metatarsal specimens and measured medullary diameter directly with calipers.⁵ Interestingly, this study stated that the mediolateral diameter at each location was greater than the dorsoplantar diameter. This is contrary to our findings in which the sagittal diameter was greater than the coronal diameter at all points along the length of the metatarsal. The apparent

Table I. Summary Data of CT Measurements.

	Mean	SD	95% CI	Range
Overall length (mm)	76.0	5.6	75.0-77.0	59.0-93.0
Straight segment length (mm) ^a	51.9	4.4	51.1-52.8	43.0-68.0
Ratio of straight segment length to overall length (%)	68.4	3.4	67.8-69.0	56.6-76.0
Canal diameter at 40 mm proximal (mm) ^a				
Coronal	5.1	0.8	5.0-5.3	3.0-7.5
Sagittal	7.0	1.1	6.8-7.2	4.0-10.5
Canal diameter at bow (mm)				
Coronal	5.0	0.9	4.9-5.2	3.1-8.0
Sagittal	6.7	1.0	6.5-6.9	4.0-9.3

^aMeasurement made with respect to proximal tip of fifth metatarsal.

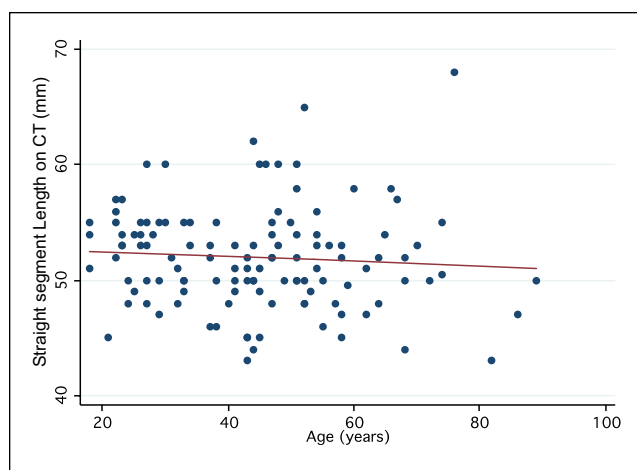


Figure 4. A graph showing that there was no correlation between age and CT scan straight segment length ($r = -.080$).

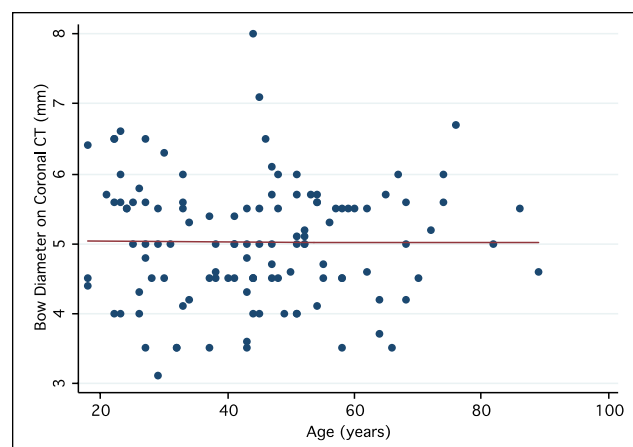


Figure 5. A graph showing that there was no correlation between age and CT scan canal diameter ($r = -.010$).

reversal of this relationship can likely be explained by the methodology used in the prior study. In that study, the fifth metatarsals were evaluated in isolation from the rest of the cadaveric foot. It is likely that the usual anatomic orientation of the metatarsal was not recreated during measurements. Therefore, the presumed mediolateral and dorsoplantar axes did not correspond to the anatomic coronal and sagittal planes. This would also explain why the study did not identify a plantar curvature on their presumed lateral projection radiographs. Their finding is contrary to the previously reported plantar lateral curvature,⁷ that was confirmed by our study. In addition, this study did not attempt to identify the longitudinal location of the curvature, which is equally, if not more important than medullary canal diameter in operative planning.

The typical Jones fracture occurs about 19 mm distal to the proximal tip of the fifth metatarsal.⁸ Intramedullary placement of a 40 mm partially threaded screw will allow the screw threads (at distal 16 mm of the screw) to be

distal to the fracture site with about 5 mm margin for error. In addition, a 40 mm screw would end proximal to the curvature in all 119 patients included in our cohort. Therefore, a 40 mm screw is a safe screw length that may eliminate concerns of lateral cortical fracture gapping and medial cortical perforation. However, patient specific pre-operative templating may allow for a longer screw length in patients with longer fifth metatarsals. Based on our findings, a screw length that is less than 68% of the length of the fifth metatarsal will avoid engaging the shaft curvature in most patients. While location of curvature was not accurately determined on radiographs ($r = .567$), the AP and oblique radiograph measurements of full metatarsal length did correlate well with 3D imaging ($r = .800, .810$). The location of curvature can be estimated by subtracting 10% (specific for our institution, but institution dependent) of radiographic measured length (average magnification error for study patients despite automatic magnification correction) and calculating 68% of the

Table 2. Gender-Specific CT Measurement Data.

	Male (n = 73)	Female (n = 46)	P Value
Overall length (mm)	78.1 ± 5.2 (67-93)	72.7 ± 4.6 (59-82)	<.001
Straight segment length (mm) ^a	53.3 ± 4.6 (43-68)	49.7 ± 3.0 (43-56)	<.001
Ratio of straight segment length to overall length (%)	68.3 ± 3.8 (57-76)	68.4 ± 2.7 (60-76)	.796
Canal diameter at 40 mm proximal ^a			
Coronal	5.3 ± 0.9 (3-7.5)	4.8 ± 0.7 (3.5-6)	.001
Sagittal	7.4 ± 1.1 (4-10.5)	6.5 ± 0.7 (4.5-8)	<.001
Canal diameter at bow			
Coronal	5.2 ± 0.9 (3.1-8)	4.8 ± 0.7 (3.5-6)	.011
Sagittal	7.0 ± 1.1 (4-9.3)	6.2 ± 0.7 (4.8-7.4)	<.001

^aMeasurement made with respect to proximal tip of fifth metatarsal.

Table 3. Percentage of CT Coronal Diameter Greater Than 4.5 mm.

	Male (%)	Female (%)	P Value
Diameter at 40 mm from tip ^a	82	74	.3005
Diameter at the bow	81	74	.3915

^aMeasurement made with respect to proximal tip of fifth metatarsal.

resulting value. This can be used as an upper limit for screw length.

While we recommend that screw length should end proximal to the bow of the fifth metatarsal to avoid complications, it is necessary to select larger screw diameters than have been historically used to gain rigid fracture fixation and stability. Screw diameters of 4.0 and 4.5 mm are the most commonly reported in the literature.^{7,12,15,16,18} However, based on our data this screw diameter will likely be inadequate to achieve endosteal fixation. Among males in our cohort, 82% had a coronal diameter (which was the narrowest diameter) greater than 4.5 mm when measured at 40 mm distal to proximal tip. In addition, 81% of patients had a coronal diameter greater than 4.5 mm at the isthmic bow. In females these values were 74% and 74%, respectively.

The necessity for larger screw diameters may initially seem at odds with the previously published literature. A biomechanical study by Horst et al comparing the torque resistance of a 5-mm versus 6.5 mm intramedullary screw found that there was no significant difference. However, the 5 mm screws were on average 10-mm longer than the 6.5 mm to achieve similar fixation.⁷ The 5 mm screws with the longer length engaged the curvature and subsequently caused lateral fracture site distraction while the 6.5 mm screws achieved fixation proximal to the curvature. Another biomechanical study by Shah et al did not find that increasing screw diameter from 4.5 mm to 5.5 mm increased fixation rigidity in a fifth metatarsal fracture cadaver model.¹⁵

However, the authors stated that fixation was achieved by engaging the medial cortex at the curvature. There was no information stating whether or not lateral cortical fracture gapping occurred.

Our data suggest that screw diameter greater than 4.5 mm will be necessary for most patients. However, it is more difficult to recommend the optimal screw diameter that will achieve stable fixation while avoiding longitudinal cortical blowout fractures. In a cadaveric study by Orr et al, fifth metatarsals that were radiographically templated and found to have a medullary canal diameter of 4.0 to 4.5 mm received a 5.0 mm diameter intramedullary screw. Conversely, fifth metatarsals that had canal diameters greater than 4.5-mm canal diameter received a 6.0 mm diameter screw. There were no cases of canal blowout or longitudinal fracture using this protocol.¹¹ We recommend individual preoperative templating, with particular reliance on the AP projection, which best approximates the coronal medullary diameter and had the greatest correlation to 3D imaging ($r = .753$; Figure 7). Furthermore, we believe it is prudent to predrill and tap the medullary canal prior to insertion of the screw, to minimize canal hoop stress.

All images used for this study were non-weight-bearing. As such, one can assume that the orientation of the fifth metatarsal would change slightly with weight-bearing. However, the overall dimension and morphology of the bone would remain unchanged. In clinical practice, non-weight-bearing radiographs are used preoperatively to evaluate and intraoperatively for fixation of Jones fracture.

A “high and inside” starting point that is just medial to the tip of the base has been described to maximize screw length prior to engaging the shaft curvature. However, we found the tip of the base to be the most reproducible reference point. Thus, all length measurements were made in reference to the tip of the base of the fifth metatarsal. Therefore, it should be noted that using this particular reference as a starting point may not provide the most collinear screw trajectory.

Table 4. Comparison of CT and Radiograph Measurements.

	Mean (mm)	Correlation Coefficient (<i>r</i>) (CT vs Radiograph)	P Value (CT vs Radiograph)
Straight segment length ^a			
CT	52.4	—	—
AP radiograph	57.4	.567	<.001
Oblique radiograph	58.5	.539	<.001
Lateral radiograph	55.7	.512	<.001
Coronal canal diameter at 40 mm proximal ^a			
Coronal CT	5.2	—	—
AP radiograph	5.5	.770	.137
Sagittal canal diameter at 40 mm proximal ^a			
Sagittal CT	7.0	—	—
Lateral radiograph	7.9	.675	.001
Coronal canal diameter at bow			
Coronal CT	5.1	—	—
AP radiograph	5.3	.753	.472
Sagittal canal diameter at bow			
Sagittal CT	6.8	—	—
Lateral radiograph	7.3	.549	.033

^aMeasurement made with respect to proximal tip of fifth metatarsal.

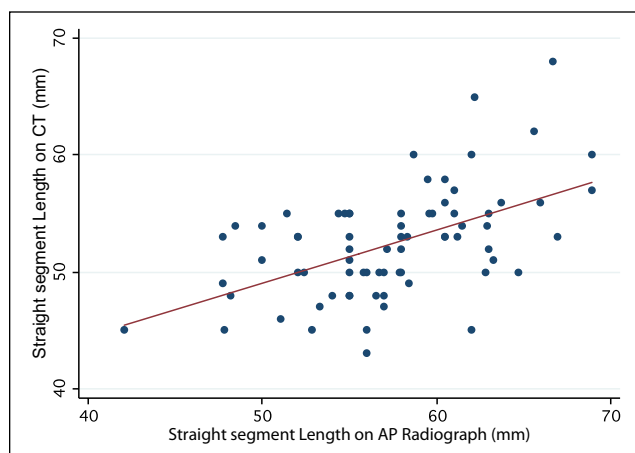


Figure 6. A graph showing that there was a correlation between plain radiographs AP view bow length and CT scan straight segment length ($r = .534$).

Another limitation of this study is the fact that it is a radiographic study. The findings of this study will need to be validated in clinical practice. The principles outlined above will need to be applied in the clinical setting and studied to determine if they indeed lead to improved fracture fixation stability and decreased complications. Despite the detailed study and analysis of the anatomy of the fifth metatarsal of a large number of patients using 3D imaging, each patient is unique and screw sizes should be determined based on each patient's preoperative imaging.

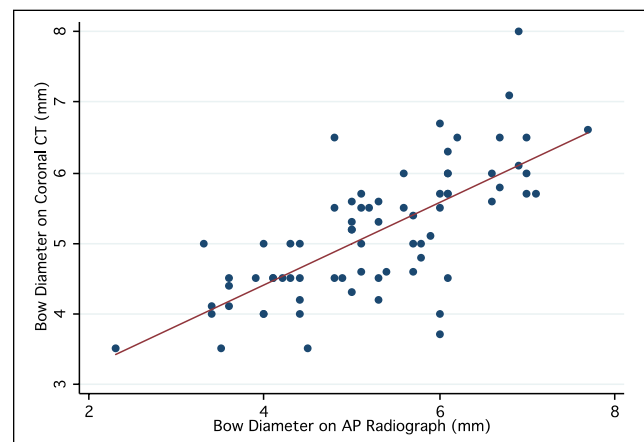


Figure 7. A graph showing that there was a correlation between plain radiograph AP diameter canal and CT scan coronal diameter ($r = .716$).

In conclusion, this study defined the normal anatomy of the fifth metatarsal. Measurements were made with each metatarsal in their normal anatomic position with respect to the foot. The results should help guide intramedullary screw diameter and length selection for the treatment of Jones fractures. A 40 mm screw in length should reliably end proximal to the curvature of the metatarsal and prevent complications related to implant insertion. A 4.5 mm diameter screw would be undersized for most patients.

Additional data related to this research can be obtained by sending a request to the corresponding author.

Declaration of Conflicting Interests

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