Original Article

A Morphologic Study of the Fibulas in the Thai Population: An Analysis Using Mimic 10.01 Three-Dimensional Images

Suvithayasiri S, MD[1]*, Paholpak P, MD[1]*, Tuamsuk P, MD[2], Sirichativapee W, MD[1], Wisanuyotin T, MD[1], Laupattarakasem P, MD[1], Sukhonthamarn K, MD[1], Kosuwon W, MD[1], Jeeravipoolvarn P, MD[1]

[1] Department of Orthopedics, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand

[2] Department of Anatomy, Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand

Objective: To understand the morphological details of the fibula, especially as it relates to the feasibility of retrograde intramedullary fibular nail use.

Materials and Methods: One-mm-thick slice Computed Tomography (CT) images of the left and right lower extremities of 40 patients were included in the study. Each CT image was reconstructed into a three-dimensional image using Mimic® 10.01 software. The authors measured the fibula in terms of total length, radius of curvature, fibular tip to isthmus distance, and inner diameter at the isthmus. Each parameter was analyzed and compared by sex, using the Mann-Whitney U test and the Wilcoxon sign rank test. All statistical analyses were performed in SPSS (Version 23.0, International Business Machines, Chicago, IL, USA).

Results: CT scans of 40 patients (21 female, mean age 59±15.91) were analyzed. The intraclass correlation coefficients between inter- and intra-observer were 0.743 to 0.921. The overall means and standard deviations were 342±21.2 mm for the total fibular length, 5.22±2.13 degree for radius of curvature, 87.03±14.27 mm for tip to isthmus distance, and 3.05±0.87 for isthmus inner diameter. Male participants had significant difference in measurements in terms of total fibular length as compared with female participants ($p<0.001$, male 356.25±18.84 mm, female 329.1±13.67). There was no statistically significant difference in radius of curvature, tip to isthmus distance, and isthmus inner diameter ($p=0.912$, 0.407, and 0.610, respectively). Comparison between left and right sides among participants of the same sex showed no statistically significant difference in any of the parameters in either sex ($p=0.908$ for total length, 0.583 for radius of curvature, 0.954 for tip-isthmus distance, and 0.908 for isthmus inner diameter in male participants, $p=0.970$, 0.554, 0.715, and 0.811 in female participants).

Conclusion: The retrograde fibular intramedullary nail can be safely used in the Thai population. There was no difference in regard to side or sex in terms of radius of curvature, tip to isthmus distance, and isthmus inner diameter. Appropriate pre-operative planning is necessary to achieve the safest and most adequate fixation.

Keywords: Fibula, Morphology, Anatomy, Three-dimensional, Mimic 10.01, Thai

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The fibular nail is a tool used in the fixation of lateral malleolus fracture with favorable clinical outcomes[1,2]. Compared to plating fixation, the fibular nail has several advantages such as smaller incision, less soft tissue dissection and complications, and providing adequate fixation in osteoporotic bones and cases of high-energy injury[1,3-5]. Furthermore, a cadaveric biomechanics study by Smith et al showed that the fibular nail resulted in greater torque to failure and better maintenance of the fibular construct than the plating fixation[6].

Currently, there are several fibular nailing systems on the market such as the Inyo® nail (Smith and Nephew Richards Inc., Memphis, Tenessee), the Biomet® nail (Biomet Inc., Swansea, United Kingdom), and the Acumed® fibular nail (Acumed, Portland, Oregon)[5]. Most of these are used and sold in the United States and in European countries. The size and length of fibular nails vary by company. For example, the Acumed® fibular nail comes in two

Correspondence to:

Paholpak P.

Department of Orthopaedics, Faculty of Medicine, Khon Kaen University, 123 Mittraphap Road, Mueng District, Khon Kaen 40002, Thailand.

Phone: +66-43-348398, **Fax**: +66-43-348398

Email: permpa@kku.ac.th

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diameters (3.0 mm and 3.6 mm) and three lengths (110 mm, 145 mm, and 180 mm)[1]. In terms of surgical technique, to receive the optimal benefit of intramedullary nail fixation, the proper diameter and appropriate length of nail must be carefully evaluated[7]. There have not been any reports of fibular nails being used in treating lateral malleolus fractures in Thailand. Bone morphology tends to vary according to ethnicity. For example, Caucasian populations tend to have larger average femoral antero-posterior diameters than Asian[8]. Thus, the present study was conducted to evaluate the morphology of the fibula in the Thai population and assess the possibility of using commercial fibula nails in these patients.

The aim of the present study was to evaluate morphology of the fibula bone in healthy Thai patients using three-dimensional reconstruction images rendered by MIMIC 10.01 software. The authors decided to use MIMIC 10.01 (Materialise, Belgium) to generate a 3D reconstruction image of the computed tomography (CT) scan data to improve measurement accuracy[9].

Materials and Methods

The present study was performed in the Faculty of Medicine, Khon Kaen University, Thailand. Between September 2016 and October 2017, 40 CT scans from 19 males and 21 females with normal legs were included in the present study. Subjects with leg trauma, infection, tumors, inflammatory diseases, deformity, or congenital abnormalities were excluded. The study was reviewed and approved by the Institutional Ethics Committee.

The data for leg CT scans (Brilliance iCT SP-128, Philips, USA) were obtained in DICOM format and transferred to MIMICS® 10.01 software to generate a 3D reconstruction model of the Tibia and Fibula. Each fibula was evaluated for measurement of morphological parameters.

Measurement parameters

"Total fibula length" refers to the distance between the tip of the lateral malleolus and the tip of the fibula head (Figure 1).

"Radius of curvature" refers to the radial angle of the curvature of the fibula bone. The radius of curvature was calculated from the curvature line between three points marked on fibula bone (tip of head, middle shaft, and tip of lateral malleolus) (Figure 2).

"Fibular tip to isthmus" refers to the distance between the tip of the lateral malleolus to the part of the fibula with the narrowest inner diameter (isthmus) (Figure 3).

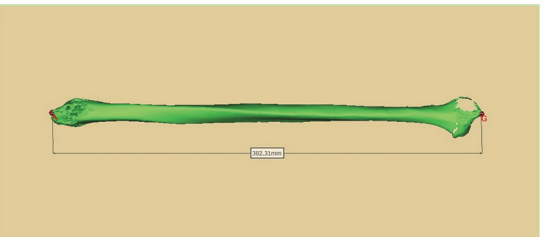

Figure 1. Demonstrated total fibula length measurement on MIMIC 10.01.

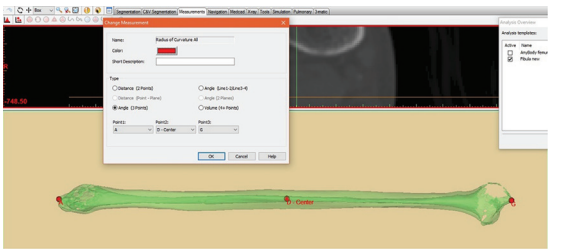

Figure 2. Showed measurement of the radius of curvature of fibula.

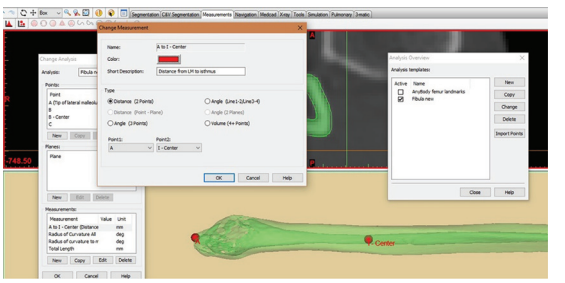

Figure 3. Demonstrated the measurement of distance between the tip of lateral malleolus and isthmus.

"Isthmus inner diameter" refers to the cross-sectional diameter at the isthmus of the fibula (Figure 4).

The authors divided the fibula into six equal parts from the tip of the lateral malleolus (point A) to the tip of the fibula head (point G) and measured the inner cross-sectional diameter at each point (point B to F) (Figure 5).

Two orthopedic surgeons (A and B, with 4 and 14 years of experience, respectively) conducted the measurements independently. All parameters were determined four times, that was, twice (at a two-week interval) by each orthopedic surgeon. The mean for each item was used as the data point. The

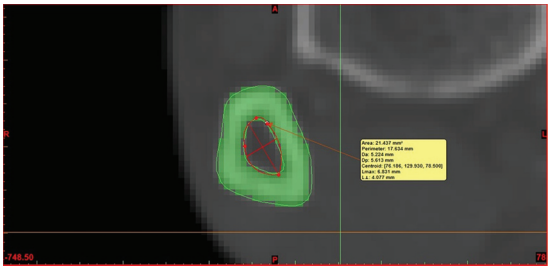

Figure 4. Demonstrated how to measure inner diameter at the isthmus point.

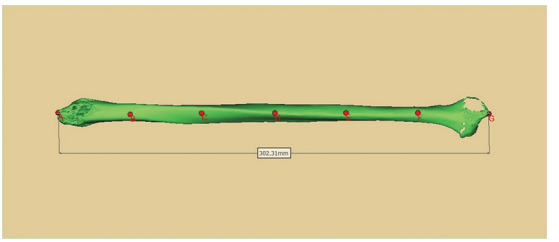

Figure 5. Showed the designated point B to F for measure inner diameter of the fibula.

intra-observer error was calculated from the first and second values determined by orthopedic surgeon A, and the inter-observer error from the values measured by both orthopedic surgeons (A and B).

Statistical analysis

The mean and standard deviation were calculated for all parameters. The Shapiro-Wilk test was used to test the normality of the data, and the nonparametric statistic was used for analysis. The Mann-Whitney U test was used to detect statistically significant difference for each parameter in subjects of different sexes. The Wilcoxon-Signed rank test was used to detect statistically significant difference for each parameter in subjects of the same sex. A p-value of less than 0.05 was considered statistically significant.

Inter-observer agreement between the two observers and intra-observer agreement for each reader were analyzed using intraclass correlation coefficients (ICCs) statistics. The ICCs values were assessed as follows, 0 to 0.2=slight agreement, 0.21 to 0.4=fair agreement, 0.41 to 0.6=moderate agreement, 0.61 to 0.8=substantial agreement, and 0.81 to 1= excellent agreement[10].

All statistical analyses were performed in SPSS (Version 23.0, International Business Machines, Chicago, IL, USA).

Table 1. Compare the fibula parameters between genders

	Male Mean±SD	Female Mean±SD	p-value
Total fibular length	356.25±18.84	329.1±13.67	<0.001*
Radius of curvature	5.18±2.03	5.26±2.25	0.912
Fibular tip to isthmus	87.85±11.99	86.29±16.17	0.407
Isthmus inner	3.04±0.98	3.06±0.76	0.610
Diameter			
B inner diameter	4.36±1.73	4.16±1.16	0.729
C inner diameter	3.91±0.93	3.89±0.81	0.923
D inner diameter	5.11±0.96	4.25±0.91	<0.001*
E inner diameter	4.2±0.95	3.16±0.69	<0.001*
F inner diameter	4.78±1.2	4.05±1.12	0.007*

SD=standard deviation

* Statistically significant difference (p<0.05)

Results

The authors analyzed 40 subjects (21 females) with a mean age of 59±15.91 years. The ICCs between the two observers showed substantial to excellent agreement in all parameters (ICCs were 0.743 to 0.921).

The isthmus inner diameter in male participants was 3.04±0.98 mm and 3.06±0.76 mm in female.

The tip to isthmus distance was 87.85±11.99 mm in male participants and 86.29±16.17 mm in female. The radius of curvature of the fibula was 5.18±2.03 degree in male participants and 5.26±2.25 in female. Table 1 shows the left and right fibular measurement parameters, as well as a statistical comparison by sex male participants, which had significantly longer total fibula length (p<0.001) and larger inner cross-sectional diameter of the proximal fibula at points D (p<0.001), E (p<0.001), and F (p=0.007). Similar results were obtained when measurements of the fibula on one side were compared by sex (Table 2).

There was no statistically significant difference in terms of fibula size between the left and right side, regardless of sex (Table 3, 4).

Discussion

Ankle fractures accounted around 9% of all fractures and were often treated by internal fixation[11-13]. Plate and screw fixation have been the standard fixation for fibula fractures since the 1960s. The plate and screw fixation has been shown to result in various dissatisfactory surgical outcomes such as wound dehiscence and wound infection,

Table 2. Comparison between two gender regarding to side

	Male:female, p-value	
	Right	Left
Total fibular length	<0.001*	<0.001*
Radius of curvature	0.520	0.573
Fibular tip to isthmus	0.503	0.728
Isthmus inner	0.503	0.936
Diameter		
B inner diameter	0.830	0.520
C inner diameter	0.936	0.768
D inner diameter	0.001*	0.057
E inner diameter	0.001*	<0.001*
F inner diameter	0.153	0.016*

* Statistically significant difference (p<0.05)

Table 3. Comparison between side in male gender

	Male, Mean±SD		p-value
	Right	Left	
Total fibular length	355.84±17.08	356.66±20.91	0.908
Radius of curvature	5.25±1.63	5.10±2.41	0.583
Fibular tip to isthmus	87.28±12.69	88.43±11.57	0.954
Isthmus inner	3.01±0.96	3.07±1.03	0.908
Diameter			
B inner diameter	4.57±2.20	4.15±1.12	0.795
C inner diameter	4±0.96	3.83±0.92	0.795
D inner diameter	5.26±0.92	4.96±1.00	0.354
E inner diameter	4.22±0.99	4.17±0.95	0.908
F inner diameter	4.71±1.38	4.84±1.01	0.840

SD=standard deviation

Table 4. Compare between sides in female gender

	Female, Mean±SD		p-value
	Right	Left	
Total fibular length	329.33±14.13	328.87±13.54	0.970
Radius of curvature	5.01±2.20	5.51±2.32	0.554
Fibular tip to isthmus	84.73±14.06	87.85±18.26	0.715
Isthmus inner	3.00±0.66	3.11±0.86	0.811
Diameter			
B inner diameter	3.99±1.32	4.34±0.967	0.642
C inner diameter	4.03±0.80	3.76±0.82	0.285
D inner diameter	4.19±0.86	4.32±0.96	0.678
E inner diameter	3.14±0.66	3.17±0.73	0.910
F inner diameter	4.04±1.09	4.07±1.18	0.890

SD=standard deviation

especially in elderly patients and patients with DM or neuropathy[14-16]. The fibular nail has been proposed as an alternative fixation device that can achieve favorable operative outcomes and less wound complications than traditional plate and screw fixation in cases of fibula fracture, especially in elderly patients and patients with high-energy ankle injury[1,2,5,7]. In Thailand, however, the author still does not use fibular nails in treating fibula fracture. Before using fibular intramedullary nails, it is necessary to ascertain whether the morphology of fibula bone in the Thai population was suitable for inserting the fibular nail. To the best of the authors knowledge, there has been no study of the fibula morphology with regard to intramedullary canal diameter, the isthmus point, and the intramedullary nailing application.

The present study demonstrated the fibula morphology with regard to various parameters. The total fibular length in the present study was comparable with the previous study of Thai fibula morphology for dental implant placement (present study: male 35.63±1.88 cm, female 32.9±1.37 cm; previous study: male 35.6±1.7 cm and female 32.7±1.8 cm)[17]. The total fibular length was significant longer in male participants than in female. This can be explained by the average height of males being greater than females. The authors found that the fibula in the Thai population had a radius of curvature of five degrees and did not differ by gender or side. The isthmus point of the fibula was at 87.85±11.99 mm above the tip of lateral malleolus in male participants and 86.29±16.17 mm in female. The tip of the lateral malleolus-isthmus distance was not significantly different between sexes or sides. The inner diameter of the isthmus point was around 3 mm in both sexes and there was also no significant difference by side.

The Acumed® fibular nail comes in two diameters (3.0 mm and 3.6 mm) and three lengths (110 mm, 145 mm, and 180 mm). Before insertion of the nail, the intramedullary canal must be reamed by the 3.1 mm (for 3.0 mm nail) and 3.7 mm (for 3.6 mm nail) reamer at diaphysis. The isthmus cross sectional inner diameter in the present study was slightly smaller than even for the 3.0 mm nail reamer. If an Acumed® fibular nail is being used, the process of intramedullary reaming should be carefully performed by hand to prevent bone breakage. In cases of fibula fracture

within 8.5 cm from the tip of the lateral malleolus, the proximal locking screw of the intramedullary nail is not required, as the nail will fit at the isthmus point. If the fracture is farther than 8.7 cm from the tip of lateral malleolus, the proximal locking screw should be inserted in order to prevent proximal migration of the nail[1].

The advantages of the present study were: (a) it is the first study to evaluate fibula morphology to evaluate the possibility of using an intramedullary nail, and (b) measurements were conducted using MIMIC 10.01 software. The present study was limited because it only looked at the measurement, thus, could not confirm the possibility of inserting the fibula intramedullary nail into the fibulae of Thai patients. Further cadaveric study needs to be conducted.

Conclusion

The Acumed® fibular nail can be inserted into the fibulae of Thai patients. The 3.0 mm nail is the most suitable nail size for the majority of the Thai population. The most crucial step is intramedullary canal reaming with the 3.1 mm diameter reamer to avoid fibula bone breakage. The proximal locking screw is not necessary if the fibula fracture happened within 8.5 cm above the tip of the lateral malleolus. The present study results could be used to support the decision to use fibula intramedullary nails when treating fibula fracture in Thai patients.

What is already known on this topic?

The fibular nail is one of the tools used in the fixation lateral malleolus fracture. The fibular nail has comparable biomechanics strength as plate and screws, and has several advantages such as smaller incision, less soft tissue dissection and complications, and providing adequate fixation in osteoporotic bones and cases of high-energy injury. There have not been any reports of fibular nails being used in treating lateral malleolus fractures in Thailand.

What this study adds?

This study added the information of Thai fibular morphology and confirmed that the fibular nail can be inserted into the fibulae of Thai patients. The 3.0 mm diameter nail is the most appropriate size for Thai population. The proximal locking screw is not necessary if the fibula fracture happened within 8.5 cm above the tip of the lateral malleolus.

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Conflicts of interest

The authors declare no conflict of interest.

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