ANTHROPOMETRIC STUDY OF ADULT TIBIA BONE FOR PRE-OPERATIVE DETERMINATION OF LENGTH OF INTRAMEDULLARY NAIL

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ABSTRACT

Background: The tibia is the bone that is mostly fractured in the body. Surgical fixation of tibia fractures with intramedullary (IM) nail is a common procedure around the world.
Objective: This study discusses pre-operative determination of intramedullary nail length to be inserted for a fractured tibia based on anthropometric measurements of dry tibia bones.
Design: This was a prospective descriptive study.
Methods: The study involved measurement of length and other parts of adult dry tibia bones. Data of patients that had tibia fracture fixation with intramedullary interlocking nails using SIgn ®nails were also retrieved. All measurements and data obtained were recorded and analyzed using STATA version 13 (StataCorp, Texas. USA).
Results: The Maximum Tibia Length (MTL) of 44 adult tibia bones ranged from 35.2cm to 43.6cm with an average of 39.9 ± 2.2cm. The Bicondylar Tibial Width (BTW) ranged from 68.9mm to 80.4mm with an average of 75.1 ± 3.4mm. Tibia length (cm) can be estimated using the equation "12.6 + 3.7*{Bicondylar Tibial width (cm)} ± 3cm". The distance of the Tibial plateau to the tubercle (TTD) ranged from 2.66cm to 3.53cm with an average of 3.03 ± 0. 23cm. The Medial Malleolus Height (MMH) ranged from 1.20cm to 1.86cm with an average of 1.51 ± 0. 17cm. Part of the tibia bone that is usually occupied by inserted nail is MTL – (TTD + MMH). Average TTD + MMH = 4.5 ± 0.4cm. Length of intramedullary nail = MTL – 4.5cm. The average length of intramedullary nail used in our centre was 34.7 ± 2.7cm. The difference between the average tibia length and IM nail inserted was 5cm, which is closed to the findings in this study (i.e length of intramedullary nail for a tibia = maximum length of the tibia – 4.5cm).
Conclusion: Pre-operative determination of intramedullary nail length for the tibia can be derived using: "Length of the tibia (from the knee joint to the tip of medial malleolus) minus 4.5cm" (for tibia tubercle as the entry point); "Length of the tibia (from the knee joint to the tip of medial malleolus) minus 1.5cm" (for entry point just below the tibia plateau; The diameter of the nail to be inserted can be estimated along with the length of the IM nail using: Diameter of nail (mm) = {7.2 + 0.007* length of the nail (mm)} ± 1.5 mm. This study also showed that tibia length can be estimated from the equation "12.6 + {3.7*Bicondylar tibial width (cm)} ± 3cm". This is useful in forensic medicine or when the contralateral limb is not available for use in a patient who is to undergo IM tibia nailing.

Key words: Tibia fracture, Pre-operative determination, Intramedullary nail, Tibia bone fixation, Africans, Anthropometry, Tibia, Interlocking nail

INTRODUCTION

The tibia is the weight bearing bone in the leg. It is medially located and consists of the expanded upper metaphyseal region, the shaft (diaphysis) and a much smaller lower distal metaphyseal region (1-3). It articulates with the femoral condyles and head of fibula proximally and in the distal end, the talus and the distal part of the fibula (1). It is an important structure in the body whose function is basically for locomotion and weight support. It is the bone that is mostly fractured in the body (2,4-7). It also has the highest incidence of open fractures (2,8). Its anatomy is responsible for it being the most fractured bone and more so, the high incidence of open fracture (2). The entire anteromedial part of shaft of the tibia is subcutaneous (2). The bone is, therefore, easily injured when exposed to trauma, as the soft tissue cover is minimal. Trauma remains the major aetiological factor for tibia fractures (4,6,7).

Surgical fixations of fractures (tibial fractures inclusive), are common procedures performed by orthopaedic surgeons around the world. Intramedullary nailing, either locking or non-locking, is one of the procedures that is usually employed for fracture fixation. The possibility of using intramedullary nailing in some types of open fractures encountered in the tibia fractures has helped in early fracture stabilization which enhances early recovery and promotes healing (9,10). Pre-operative planning is necessary in the preparation for the intramedullary nailing procedure.

It involves having an idea of the likely length of the intramedullary nail that would be inserted at the surgery. Different methods had been proposed, but none is 100% accurate. This study aimed to provide a reliable method to estimate the tibia length from its palpable part(s). It also aimed to provide a method that would help in the pre-operative determination of the length of intramedullary nail that most likely would fit a given tibia length.

MATERIALS AND METHODS

This was a descriptive study that involved measurement and documentation of parts of dry tibia bones and retrieving data of patients that had tibia fracture fixation with intramedullary interlocking nails using SIGN® nails. Ethical approval was obtained from the Lagos University Teaching Hospital's Health Research Ethics Committee (LUTH HREC) before the commencement of the study.

Measurement of dry bones: The tibia bones measured were from the museum of the Department of Anatomy, College of Medicine, University of Lagos. A total of 44 tibia bones with completely closed epiphyseal plates, which indicated that they were adult bones were measured after all deformed bones were excluded. The tibia bones were sorted into laterality which resulted in 21 right and 23 left tibia bones. Each of the bone was given an alphanumerical identity and labeled. The tibia bones with right laterality were labeled from R1 to R21 while those of the left laterality were labeled L1 to L23. The Maximum Tibia Length (MTL) of each tibia bone was measured using the osteometric board and measurement obtained documented. The Bicondylar Tibial width (BTW), the distance between Tibial plateau and Tibial tubercle (TTD), the Medial Malleolar Height (MMH) and Medial Malleolar Breadth (MMB) were also measured using both manual and digital vernier caliper calibrated to the nearest 0.01 mm and documented. The Maximum Tibia Length (MTL) is the vertical distance from the most superior part of the tibia to the most inferior point of the medial malleolus (11, 12) (Figure 1). The Bicondylar Tibial Width (BTW) is the maximum transverse distance (coronal measurement) from the lateral side of the lateral condyle to the medial side of the medial condyle (12) (Figure 2). The distance between tibial plateau and tibial tubercle (TTD) is the vertical distance between the tibial plateau and the tibial tubercle (Figure 3). The medial malleolar height is the vertical height from the tip of the medial malleolus to the tibial plafond (13) (Figure 4). The Medial Malleolus Breadth (MMB) is defined as the anteroposterior length of the medial malleolus (13) (Figure 5).

Figure 1
Measuring the Maximum Tibial Length (MTL)

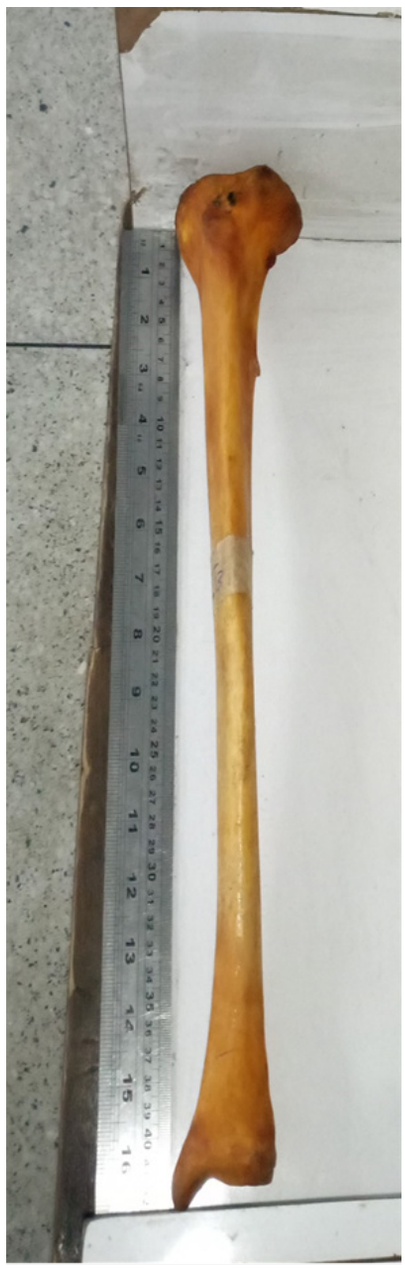
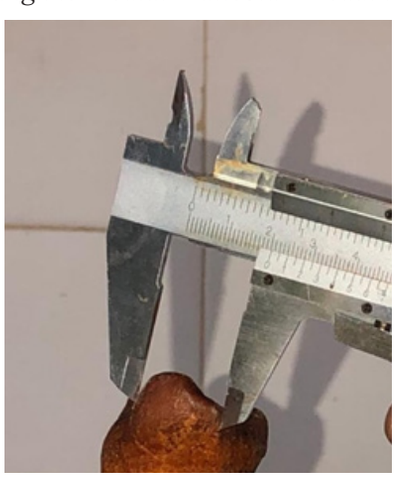


Figure 2
Measuring the Bicondylar Tibia Width (BTW)

Figure 3
Measuring the Tibial Plateau –Tibial Tubercle distance (TTD)

Figure 4
Measuring the Medial Malleolar Height (MMH)

Figure 5
Measuring the Medial Malleolar Breadth (MMB)



The intramedullary nail data: The theatre records and patients' case notes were used to retrieve data on tibia fractures that were treated with intramedullary interlocking nail from January 2009 to December 2018. Data obtained included clinical types of fracture, laterality of fractures with diameter and length of the intramedullary nails used. These data were retrieved and documented.

All measurements and data obtained were recorded and analyzed using STATA version 13 (StataCorp, Texas. USA). Mean and standard deviation were computed. Linear regression analysis was conducted and regression equation formulated for the prediction of the maximum length of the tibia from the other measured parameters of the bone. Statistical significances in all cases were set at $P < 0.05$.

RESULTS

The Maximum Tibia Length (MTL) ranged from 35.2cm to 43.6cm (Average 39.9 ± 2.2cm). The MTL of tibia with right laterality ranged from 35.2cm to 43.6cm (average - 39.6 ± 2.4 cm) while those of left laterality ranged from 35.5cm to 43cm (average 40.2 ± 2.1 cm) (Table 1). Fifty nine percent of the MTL measured were between 39.0cm to 41.9cm (Table 2).

Table 1
Parameters measured on dry tibia bones

Parameters	Sides	Min. value (cm)	Max. value (cm)	Mean ± SD (cm)
MTL	Right	35.2	43.6	39.58 ± 2.43
	Left	35.5	43	40.2 ± 2.07
BTW	Right	6.89	8.04	7.46 ± 3.03
	Left	6.95	7.97	7.55 ± 3.7
TTD	Right	2.66	3.50	3.08 ± 0.26
	Left	2.73	3.22	2.96 ± 0.18
MMH	Right	1.21	1.86	1.54 ± 0.2
	Left	1.34	1.69	1.48 ± 0.12
MMB	Right	1.97	2.67	2.38 ± 0.19
	Left	1.74	2.74	2.4 ± 0.22

Table 2
Frequency of the tibia lengths measured

Range	Frequency (right)	Frequency (left)	Total	(%)
35.0 – 35.9	4	2	6	13.6
36.0 – 36.9	0	0	0	0
37.0 – 37.9	2	1	3	6.8
38.0 – 38.9	0	3	3	6.8
39.0 – 39.9	2	2	4	9.2
40.0 – 40.9	7	4	11	25
41.0 – 41.9	3	8	11	25
42.0 – 42.9	2	1	3	6.8
43.0 – 43.9	1	2	3	6.8
Total	21	23	44	100

The Bicondylar Tibial width (BTW) ranged from 68.9mm to 80.4mm with an average of 75.1 ± 3.4mm. (Right side ranged from 68.9 mm to 80.4mm, average 74.6 ± 3.0 mm; Left side ranged from 69.5mm to 79.7mm, average 75.5 ± 3.7mm).

The distance of the tibial plateau to the tubercle (TTD) ranged from 26.61mm to 35.03mm with a mean of 30.3 ± 2.3mm. On the right side, TTD ranged from 26.61mm to 35.03mm with an average of 30.8 ±

2.6mm while it ranged from 27.34mm to 32.21mm on the left with an average of 29.6 ± 1.8mm.

The Medial Malleolus Height (MMH) ranged from 12.08mm to 18.6mm with an average of 15.1 ± 1.7mm. On the right side, the MMB ranged from 12.08mm to 18.6mm with an average of 15.4 ± 2.0mm while on the left the MMB ranged from 13.44mm to 16.93mm with an average of 14.8 ± 1.2mm.

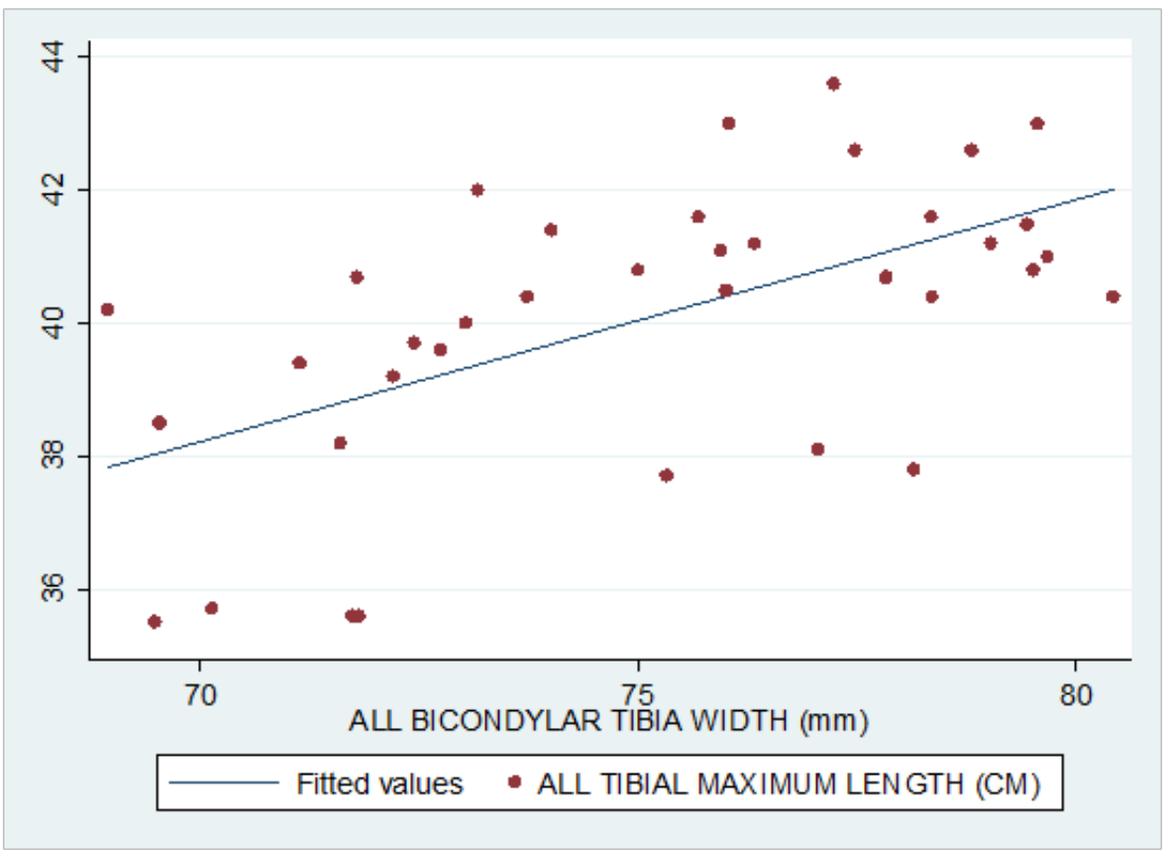
The Medial Malleolus Breadth (MMB) of all the tibia bones analyzed ranged from 17.36mm to 27.41mm with an average of 23.9 ± 2.1mm. On the right side, the MMB ranged from 19.72mm to 26.68mm with an average of 23.8 ± 1.9mm while on the left the MMB ranged from 17.36mm to 27.41mm with an average of 24.0 ± 2.3mm (Table 1).

Linear regression analysis of the Maximum Tibia Length (MTL) and other measured parts of the tibia were done. None of the regression analysis of MTL and other parameters for tibia with right laterality was significant. The regression analysis of MTL and both BTW and MMB were significant (p = 0.0014 and p = 0.0240 respectively) for measurements with left laterality. However, for all tibia bones measured, only the linear regression of the MTL and BTW was statistically significant (P value = 0.0002) (Figure 6 – Scatter plot diagram). A formula to estimate Tibia length from bicondylar tibia width (BTW) was generated to be:

Tibia Length (cm) = {12.6 + 3.7*Bicondylar Tibial width (cm)} ± 3cm.

Figure 6

Scatter plot for maximum tibial length and bicondylar tibia width



A total of 126 interlocking intramedullary nails were inserted in 118 patients during the period analyzed. The average age of patients was 38.0 ± 13.1 years. Based on laterality, 61 cases involved the left tibia and 65 on the right. The average length of intramedullary nail used in all the patients was 34.7 ± 2.7cm (Left: 34.6 ± 2.8cm; Right: 34.9 ± 2.6cm) but ranged from 28cm to 40cm with the nail lengths of 34cm and 36cm accounting for 58% of all the nails used. (Appropriate IM nail lengths were used for the surgeries) (Table 3). The average diameter of the intramedullary nail was 9.3 ± 0.8mm (Left - 9.3 ± 0.7mm; Right - 9.3 ± 0.8mm) but size 9mm nails accounted for 50% of the entire intramedullary nails used (Table 4). The screws used for locking the intramedullary nails ranged from 30mm to 65mm. Linear regression analysis of the diameter of the nail used and the length of nail inserted was statistically significant (P =0.0150). It generated an equation to estimate nail length as:

Diameter of the nail inserted (mm) = {7.2 + 0.007* length of the nail inserted (mm)} ± 1.5 mm

Table 3
Frequency of intramedullary nails lengths inserted

Length of IM nail used	Frequency	(%)
280	5	3.97
300	4	3.17
320	20	15.87
340	38	30.16
360	35	27.78
380	18	14.29
400	6	4.76
Total	126	100

Table 4
Frequency of intramedullary nails diameter inserted

Diameter of the intramedullary nail	Frequency	(%)
8	15	11.90
9	63	50.00
10	41	32.54
11	7	5.56
Total	126	100

The difference between the average of the MTL (39.9 cm) and the average length of the IM nails (34.7cm) inserted is 5cm. When this 5cm was subtracted from the maximum tibia length of each bone, it was discovered that the lengths of tibia bones (39.0cm to 41.9cm) with highest frequency (59%), correspond with the most frequent (58%) length of nails (340mm and 360mm) that were inserted.

(i) The range of the MTL with highest frequency (59%) was 39.0cm to 41.9cm.

(ii) Subtracting the difference between the average MTL and the average length of the IM Nail inserted (5cm) from the range 39.0 cm to 41.9cm. 39.0cm – 5cm = 34 cm; 41.9cm – 5cm = 36.9cm

The length of nails that were most frequently (58%) used were 340mm (34cm) and 360mm (36cm). This, therefore, showed that the most frequent length of tibia bone corresponded with the most frequent intramedullary nail that were inserted with similar frequency (59% and 58% respectively).

DISCUSSION

This study revealed the average length of adult tibia bone of a southwestern Nigerian to be 39.9 ± 2.2cm with length that ranged from 35.2cm to 43.6cm. This average length is similar to the findings reported by Ugochukwu *et al.* (12) in a study done on tibia bones from Ebonyi, Enugu and Cross river states. They documented mean maximum length of the right tibia to be 40.30 ± 4.32cm while that of the left tibia was 40.80 ± 3.91cm. Mandela *et al.* (14) in a study that worked on tibia bones of adult Kenyans documented an average length of 38.2 ±2.75cm while Naidoo *et al.* (3) who analyzed tibia from southern Africans documented average tibia length of 382.51mm (38.25cm) in males and 367.09mm (36.70cm) in females. However, reports from Indian continent revealed maximum tibia lengths which were slightly less than those across Africa. Attada *et al*. (15) documented average maximum tibial length of 37.50 ± 3.03cm for right tibia and 37.05 ± 3.12cm for left tibia among southern Indians while Bokariya *et al*. (16) documented average maximum length of 37.13 ± 2.32cm for left tibia and 37.94 ± 1.89cm for right tibia among central Indians. It is therefore important to have a proper documentation of the tibial length of a particular region such that appropriate sizes of implants can be made available for patients in that region. The tibia length has a high correlation with height (17). Height and statures are well known to differ around the world (18). Regions where more individuals have small stature will therefore require more quantity of shorter intramedullary nails than those in other regions with taller individuals. This therefore, reiterates that the need to ensure that appropriate size of implants is made available in different regions of the world.

The minimum tibia length was 35.2 cm (approximately 35cm) while the longest tibia was 43.6cm (approximately 44cm). It, therefore, means that for most adults in Nigeria, the likelihood of using an intramedullary nail length of above 44cm is quite slim and very few, if any, of such nail length should be provided. The nail lengths that were mostly inserted in this study were those between 320mm (32cm) and 380mm (38cm) with nail lengths of 340mm (34cm) and 360mm (36cm) the most frequently used (58%). The average length of the tibia in this study was 39.9 ± 2.2cm. The Maximum Tibia Length (MTL) measured was from the highest point of the tibia to the most inferior point of the medial malleolus. The insertion point of the nail is usually distal to the highest point of the tibia. The tibial tubercle is the insertion point for most of the nails used in this study. Neyret *et al.* (19) documented that the distance between the tibia plateau and tibia tubercle (TTD) was 28 ± 5mm. This was similar to the value noted in our study, which was 30.3 ± 2.3mm.The MTL also included the length of the medial malleolus. The tibia plafond, which is the lowest limit for the intramedullary nail, is proximal to the tip of medial malleolus. This vertical height of the medial malleolus was included in the measurement of the MTL. The vertical height of the medial malleolus (MMH) measured in our study was 15.14 ± 1.65mm. Mandela *et al.* (14), working on adult Kenyan tibia

bones, documented the vertical length of medial malleolus to be 14.19 ± 1.89mm which was similar to the finding in our study but Labronici *et al.* (20) stated that the distance between the tip of the malleolus and the medullary canal was average of 55mm with a standard deviation on 10mm. These two parts (TTD and MMH) of the tibia are not usually covered by the IM nail when used in the tibia (especially IM nails whose entry point is at the tibial tubercle) (Figure 7).

Figure 7

Image showing IM nail in situ and parts of the tibia bone not occupied by the IM nail (painted orange)

The nail length (for IM nail whose entry is at the tibial tubercle) = MTL – (TTD and MMH) while the nail length for IM nail whose entry is proximal to the tibial tubercle) = MTL – MMH. Therefore, pre-operative length of intramedullary nail (for tibial intramedullary nail whose entry is Tibial tubercle) = Maximum Tibial Length – (TTD and MMH)
TTD and MMH = 3.0 + 1.5 = 4.5cm.
The pre-operative length of intramedullary nail (for tibial intramedullary nail whose entry is Tibial tubercle) = Maximum Tibial Length – 4.5cm

However, for IM nails whose entry point is above the tibial tuberosity, only the MMH will be subtracted from the maximum tibial length (the only part that would not be occupied by the nail will be the length of the medial malleolus. MMH = 1.5cm

Thus, the pre-operative length of intramedullary nail (for tibial intramedullary nail whose entry is above tibial tuberosity) = Maximum Tibial Length – 1.5cm.

The above (the pre-operative length of intramedullary nail (for tibial intramedullary nail whose entry is above tibial tuberosity) = Maximum Tibial Length – 1.5cm) is similar to the formula documented by Venkateswaran *et al.* (21) for pre-operative method for determining tibial nail lengths where they stated that subtracting 2cm from maximum tibial length will give accurate IM nail lengths.

The summation of both TTD (average) and MMH (average) will give approximately 5cm. It is therefore not surprising that the difference of the average maximum tibial length (39.9cm) and the average length of IM nail inserted (34.7 cm) was 5cm. This 5cm represents the parts of the bone that the intramedullary nail will not occupy (the part of the bone above the tibial tubercle and the length of the medial malleolus). Furthermore, it is not also surprising that the most frequent MTL (39.0cm to 41.9cm for which when 5cm is subtracted, became 34cm and 36.9cm) and most frequent IM nail length (340mm and 360mm) corresponded with similar frequency values (59% and 58% respectively). It therefore, suggests strongly that more proportions of 340mm and 360mm intramedullary nails (compare to other nail length sizes) that should be made available for patients in Nigeria. This study also generated equation that can be used to estimate the maximum tibial length as:
Maximum tibia length = {12.6 + 3.7* Bicondylar tibial width (cm)} ± 3cm

Clinically, it is easier to measure the bicondylar tibia width. Its use in clinical setting could be limited as the contralateral limbs can be measured to estimate the length of one of the limb except in conditions where the contralateral limb is deformed, amputated or atrophic, and thus such limb cannot be used to estimate the injured tibia length being prepared for surgery. However, it would be useful in forensic medicine, where only part of the bone way be available to estimate the length of the tibia. The equation can also be used to confirm the length of the tibia obtained from other methods used to estimate the tibia length as none of these methods is error-proof. Coren *et al.* (22) , in a study that compared four methods of estimating the length of tibial nail length noted that none of the methods gave accurate length of nails used, the best option was which was "tibial tubercle-medial malleolar distance" was incorrect in 29%. Combining methods to determine the pre-operative determination of IM nail length size would be of great benefit to the orthopaedic surgeons.

The largest possible nail diameter should be inserted for stable biomechanics. Larger diameter nails provides significant reduction of movement at fracture site with well enhanced stiffness of the bone – implant construct (23). Eighty two percent of the nail diameter used were sizes 9mm and 10mm and these two sizes worked well with our patients (these nails are solid, not hollow). None of our patients received a nail diameter above 11mm. Though, it is ideal to have all sizes of IM nails available, IM nail diameter of 9mm and 10mm would likely serve an average built southern Nigerians.

In this study, an equation from the linear regression of the diameter of the intramedullary nail and the length of the intramedullary was derived. The estimated diameter of the IM for a particular length of IM nail is given as:

Diameter of IM nail (mm) = {7.2 + 0.007* length of IM nail (mm)} ± 1.5 mm. It therefore means that the likely diameter of the nail that would be inserted can be estimated along with the length of the IM nail during the pre-op planning**.**

CONCLUSION

Pre-operative determination of intramedullary nail length for the tibia can be derived using:

(i) Length of the tibia (from the knee joint to the tip of medial malleolus) minus 5cm" (for tibia tubercle as the entry point).

(ii) Length of the tibia (from the knee joint to the tip of medial malleolus) minus 1.5cm" (for entry point just below the tibia plateau.

(iii) The diameter of the IM nail that would be inserted can be estimated along with the length of the IM nail during the pre-op planning by using Diameter of IM nail (mm) = {7.2 + 0.007* length of IM nail (mm)} ± 1.5 mm

This study also showed that tibia length can be estimated from the equation "12.6 + {3.7*Bicondylar Tibial width (cm)} ± 3cm". This would be useful when the contralateral limb is not available to estimate the tibial length or in forensic medicine.

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