ORIGINAL ARTICLE

Evaluation of Arm Length as a New Upper Limb Anthropometric Method for Preoperative Estimation of Tibial Intramedullary Nail Length

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Abstract

Aim and objective: To assess the use of arm length (AL) for the estimation of tibial nail length preoperatively and compare its accuracy to various established upper and lower limb anthropometric parameters.

Material and methods: This prospective study of 54 patients assessed upper limb parameters as a possible alternative for intraoperatively measured tibial nail length. The anthropometric parameters measured independently by two observers were AL, olecranon to fifth metacarpal head (OMD), tibial tuberosity to medial malleolus (TT-MM), tibial tuberosity to medial malleolus minus 20 mm (TT-MM-20 mm) and knee joint line to medial malleolus minus 40 mm (KJL-MM-40) and compared to final nail size used intraoperatively. Two observers were used. Bland-Altman plots were constructed to assess the limits of agreement to intraoperative estimates of optimum nail length. A repeatability assessment was also assessed by both observers.

Results: None of the anthropometric parameters showed limits of agreement within $\pm$10 mm of nail length. AL showed the least average difference and best limits of agreement among all the anthropometric parameters. Among the lower limb parameters, the KJL-MM showed the least average difference but poorer limits of agreement to nail length. The OMD measurement showed a greater average difference than the AL indicating it is a poorer upper limb parameter for predicting nail length.

Conclusion: AL as measured between the angle of the acromion to the lateral epicondyle can be used as a preoperative upper limb anthropometric estimate of nail length to one nail size of the optimum length. Further studies with a larger sample size may reduce the confidence intervals and help justify its wider use.

Keywords: Anthropometry, Arm, Intramedullary nailing, Prospective study, Tibia.

Strategies in Trauma and Limb Reconstruction (2021): 10.5005/jp-journals-10080-1520

Introduction

Tibial nail length can be determined preoperatively or intraoperatively. Intraoperative assessment is considered to be the most accurate method but is associated with an increase in surgical time, inaccuracy if not performed by an expert or if faulty methods of measurement are used.[1]

Conventionally, anthropometric methods are used to calculate nail length preoperatively and prevent unwarranted complications related to size and availability. The tibial tuberosity to medial malleolus (TT-MM) is considered the most accurate lower limb anthropometric parameter.[2] Other commonly used measurements include the distance between tibial tuberosity to ankle joint line (TT-AJL), knee joint line to ankle joint (KJL-AJL) and knee joint line to medial malleolus (KJL-MM). These measurements use anatomical landmarks on the contralateral side, that is, normal limb.

In bilateral fractures of the tibia, or when there is obesity or congenital or acquired malformations of the lower limb, the methods above or radiological preoperative assessment is not possible. In these instances, upper limb parameters may be used to determine preoperative nail length. The only upper limb parameter published is the olecranon to fifth metacarpal head (OMD) distance, which is, although not very accurate, the current solution.[3]

Arm length (AL), as measured between the angle of the acromion to the lateral epicondyle, to determine the tibial nail length preoperatively has not yet been explored.[4] We conducted this study to explore the use of AL as an alternative upper limb anthropometric parameter to OMD for the preoperative determination of tibial nail length.

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How to cite this article: Sharma A, Sinha S, Gupta S, *et al.* Evaluation of Arm Length as a New Upper Limb Anthropometric Method for Preoperative Estimation of Tibial Intramedullary Nail Length. Strategies Trauma Limb Reconstr 2021;16(1):20–26.

Source of support: Nil

Conflict of interest: None

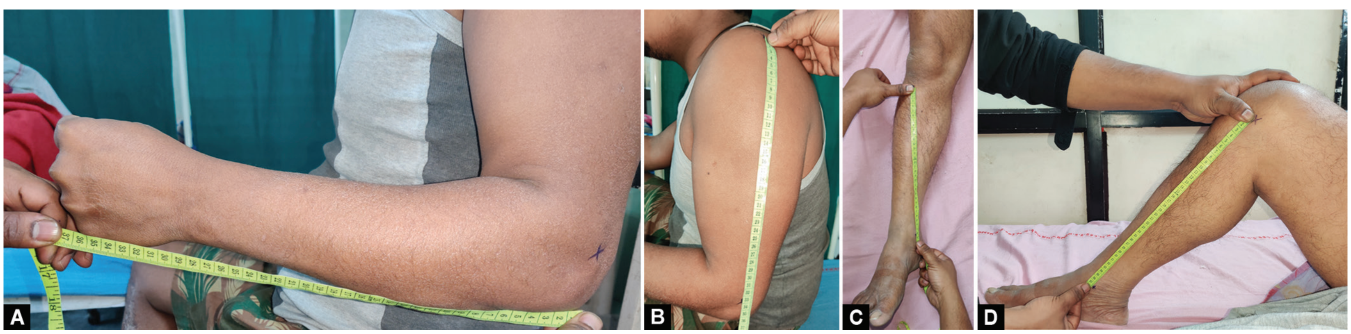
Materials and Methods

The study was a prospective study conducted in a tertiary care institute from October 2017 to October 2019. A total of 54 patients were included. Approval from the Institution's Ethics Committee and due consent from each patient were obtained. Adult patients with tibial shaft fractures presenting to the emergency department who were scheduled to have treatment by intramedullary nailing were included in the study. Excluded were patients with bilateral tibial fractures, patients with any congenital or acquired bony deformity involving the normal upper or lower limb that may have altered surface landmarks used for the anthropometric measurement, and patients who were to have their fractures managed conservatively. Preoperative measurements of four anthropometric parameters were done using the contralateral normal limb for both upper and lower limb parameters[1,4-6] (Table 1 and Fig. 1).

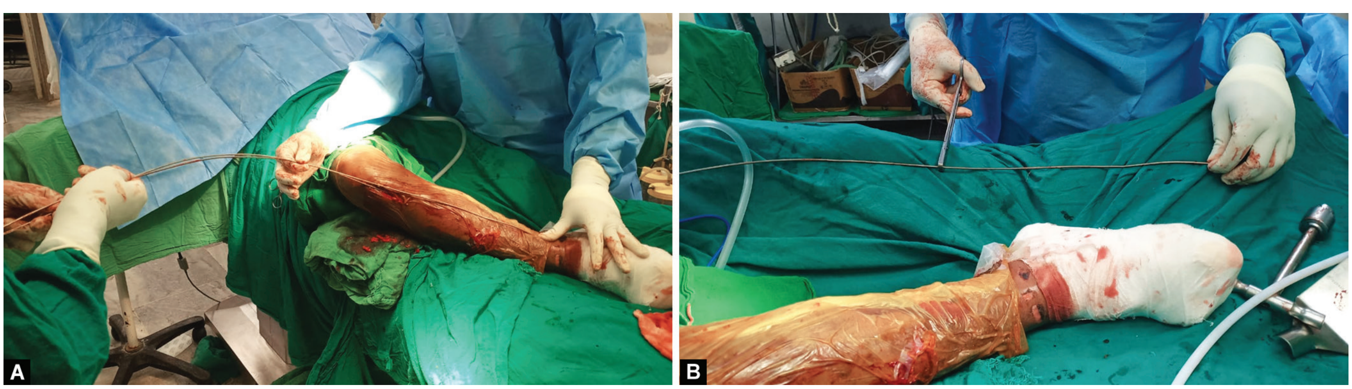
The intraoperative guidewire measurement technique was used to determine the optimum nail length to be inserted (Fig. 2). All available nail sizes were arranged to be available at the surgery. Postoperative calibrated plain radiographs were done and were assessed for the appropriateness of the nail length chosen. The optimal nail length was considered as nail lying 5-10 mm below the proximal tibial articular surface and between 10 mm and 20 mm proximal to the distal articular surface in plain radiographs.[1,5,6] All anthropometric measurements were recorded by two independent observers and recorded. One surgeon performed all procedures and recorded the intraoperative measurements. A comparison of the anthropometric data collected for each patient was made to the nail size using the BlandAltman method for the assessment of the agreement.

Table 1: Anthropometric measurement used and its relevant landmarks

Anthropometric parameters used for the assessment of preoperative tibial nail length		
Sl. No.	*Parameter*	*Method of determination*
1	Olecranon to fifth metacarpal (OMD)	Measuring the distance from the olecranon tip to head of little finger metacarpal elbow and metacarpophalangeal joints flexed to 90 and the wrist held in neutral[5]
2	Arm length (AL)	Angle of acromion to the lateral epicondyle[4]
3	Tibial tuberosity to medial malleolus (TT-MM)	Distance between the most prominent points on the tibial tuberosity and medial malleolus[6]
4	Knee joint line to medial malleolus – minus 20 mm (KJL-MM-20)	Medial knee joint line, joint line 3 cm medial to the medial edge of the patellar tendon to the most prominent point on the medial malleolus. Twenty millimetres was subtracted from the absolute value[1]
5	Nail length	Optimal nail length as nail lying 5–10 mm below the proximal tibial articular surface and between 10 mm and 20 mm proximal to the distal articular surface in plain radiographs[1,5,6]



Figs 1A to D: (**A**) Method of measuring olecranon to fifth metacarpal head distance (OMD); (**B**) Method of measuring arm length (AL) ; (**C**) Method of measuring tibial tuberosity to medial malleolus distance (TT-MM); (**D**) Method of measuring knee joint line to medial malleolus distance



Figs 2A and B: (**A**) Using the guidewire method to calculate intraoperative nail size, two guidewires of equal length taken; (**B**) Difference in guide-wire outside nail marked and measurement taken

The mean and standard deviation of age, nail length, and the anthropometric measurements of AL, OMD, TT-MM, its derivative TT-MM-20 and KJL-MM-40 were calculated.[1,3] Statistical analysis was done using SPSS version 25.

Bland-Altman plots were constructed to assess the limits of agreement. The agreement was set as anthropometric measurement within ±10 mm of intraoperative nail length. A Bland-Altman plot between the anthropometric parameter showing best agreement to nail length was used to assess the repeatability of the measurement using data from the two observers.

Results

The mean age of the patients was 35.62 ± 11.08 years, and 46 (85.2%) subjects were male. The most frequently used nail size was 320 mm in 27 (50%) patients followed by 340 mm in 14 (25.9%) patients. The average nail size used was 331.0 ± 20.51 mm (Table 2).

Of the 54 patients, there were three patients who had a suboptimal length of nail inserted from the analysis of postoperative radiographs. These were included in the final analysis. This proportion (5.5%) of error in the study using the intraoperative guidewire technique corroborates with an error of 6% mentioned in the literature.[7]

The least average difference (smallest bias) and narrowest limits of agreement were seen using AL. This produced an average difference of −1.3 mm and similar limits of agreements (−28.4 to 25.8 for observer 1 and −25.7 to 23.1 for observer 2). When using anthropometric measurements in the lower limb, the KJL-MM showed the least difference with an average of −12.9 (−40.3 to 14.5) for observer 1 and −13.6 (−41.1 to 14) for observer 2. Other measured anthropometric parameters showed larger average differences and wider limits of agreements (Table 3). Bland-Altman plots were made for each anthropometric parameter against nail length for each observer separately (Figs 3 and 4). On performing a repeatability assessment using the BlandAltman method for AL as measured by observer 1 and observer 2, the study found a low average difference indicating that the results are repeatable (mean difference—0.02; limits of agreement—19.04 to 19.01) (Table 4, Fig. 5).

Table 2: Demographic and descriptive data of the study

Sex	*Number*	*Percent*
Male	46	85.2
Female	8	14.8
Total	54	100
Characteristic	*Mean ± SD (N = 54)*	
Age	35.62 ± 11.08	
Arm length (AL)	331.61 ± 16.41	
Olecranon to fifth metacarpal base (OMD)	340.85 ± 21.59	
Tibial tuberosity to medial malleolus (TT-MM)	347.98 ± 21.22	
Knee joint line to medial malleolus minus 40 mm (KJL-MM-40)	343.51 ± 22.95	
Nail length	330.37 ± 20.46	
Nail length frequency	*Number*	*Percent*
280 mm	2	3.7
300 mm	2	3.7
320 mm	27	50
340 mm	14	25.9
360 mm	7	13
380 mm	2	3.7
Total	54	100

Discussion

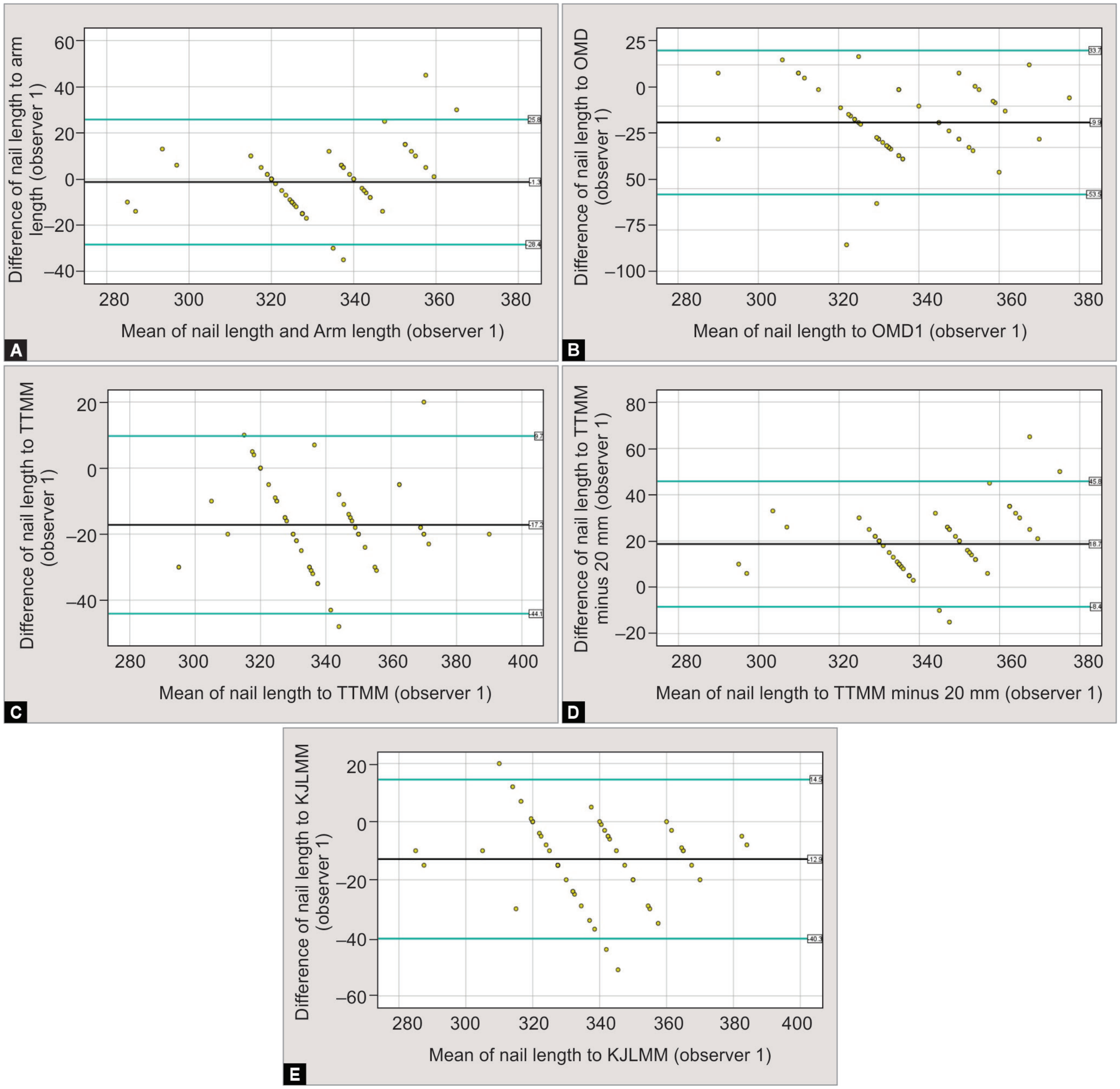
There is no consensus regarding the best parameter to be used for predicting tibial nail length. A deviation from normal of the contralateral side by any congenital or acquired deformity negates the use of lower limb parameters. Measuring the OMD, height and weight has been proposed to circumvent this limitation.[3,5,7,8]

The most predictive of the anthropometric parameters in the literature has been the TT-MM distance.[2,3,5,6] Venkateshwaran et al. and Galbraith et al. did not recommend using TT-MM distance as a preoperative parameter to estimate tibial nail length, and this study reaches a similar conclusion; both the TT-MM and its derivative of TT-MM−20 mm had a large average difference and wide limits of agreement to nail length for both sets of observations.[1,7] This poor agreement might result from the tibial tuberosity being large and ill-defined from which using one point to measure the distance may vary for each reading. Another possible cause of poor agreement is the variation of the method of measuring TT-MM. This study has taken a direct measurement from the tibial tuberosity to medial malleolus as between prominent bony landmarks.[5] Another method is calculating the vertical distance using a ruler as described by Lottes.[9] The direct measurement, although larger in value to the vertical distance, is more accurate for predicting the nail length.[5,6]

The KJL-MM distance was calculated by Isaac et al. to be 69% accurate if 33 mm was subtracted from the value.[3] Venkateshwaran et al. calculated that the KJL-MM-40 had a corelation coefficient of 0.976.[1] Galbraith et al. were only able to calculate 50% of nail length using this parameter.[7] The results of this study show that, among all the lower limb parameters measured, KJLMM had the least average

Table 3: Average difference and limits of agreement of the anthropometric measurement to nail length for each observer

	Observer 1		*Observer 2*	
Anthropometric measurement to nail length	*Average difference*	*Limits of agreement*	*Average difference*	*Limits of agreement*
Arm length (AL)	−1.3	−28.4 to 25.8	−1.3	−25.7 to 23.1
Olecranon to fifth metatarsal base (OMD)	−9.9	−53.5 to 33.7	−11.3	−52.3 to 29.8
Tibial tuberosity to medial malleolus (TT-MM)	−17.2	−44.1 to 9.7	−18.1	−43.7 to 7.5
Tibial tuberosity to medial malleolus minus 20 mm (TT-MM−20 mm)	18.7	−8.4 to 45.8	18.7	−5.7 to 43.1
Knee joint line to medial malleolus (KJL-MM)	−12.9	−40.3 to 14.5	−13.6	−41.1 to 14.0



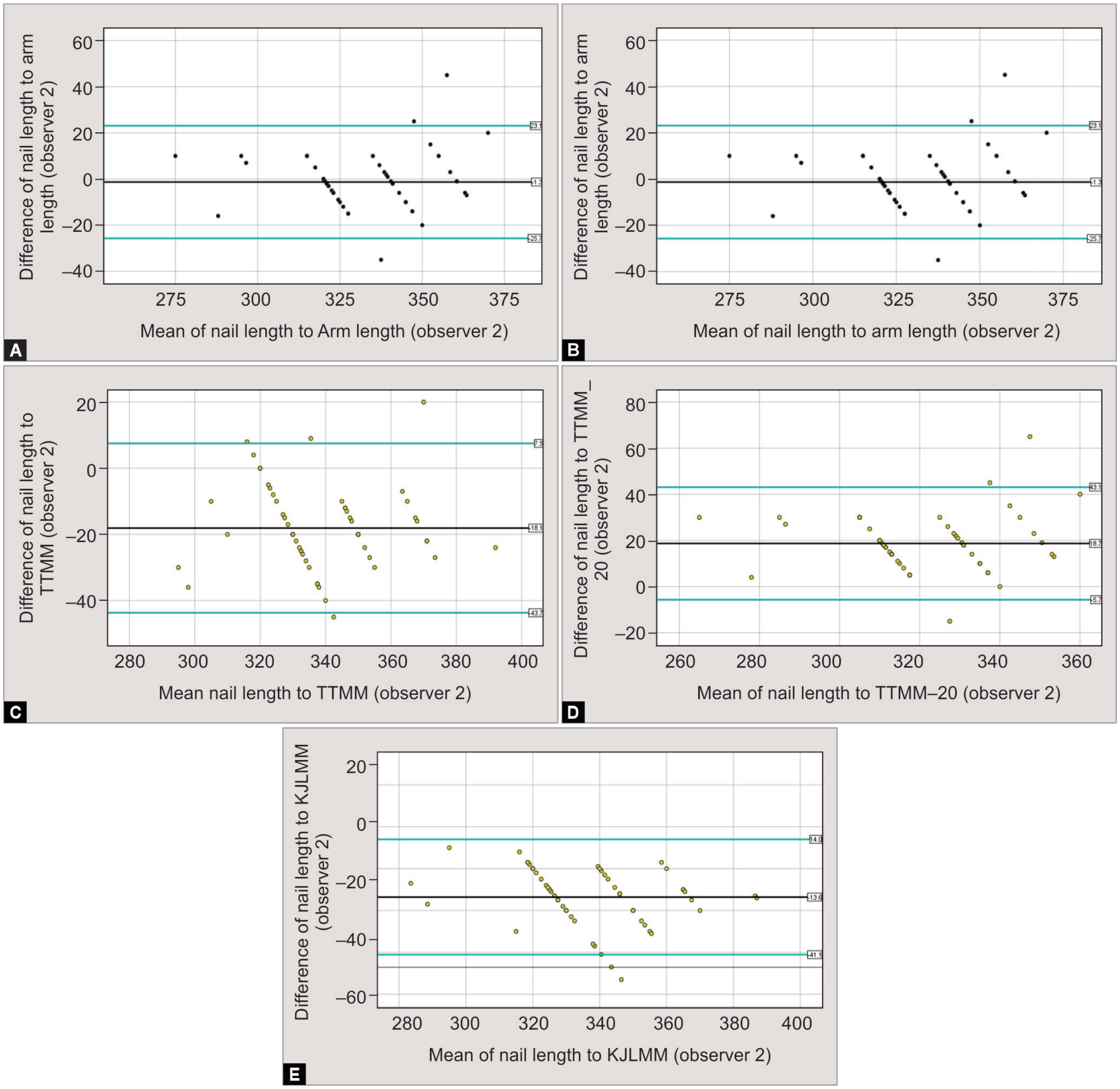
Figs 3A to E: (A) Bland Altman plot of nail length to arm lengths by observer 1; **(B)** Bland Altman plot of nail length to olecranon to fifth metacarpal base by observer 1; **(C)** Bland Altman plot of nail length to tibial tuberosity to medial malleolus by observer 1; **(D)** Bland Altman plot of nail length to tibial tuberosity to medial malleolus minus 20 mm by observer 1; **(E)** Bland Altman plot of nail length to knee joint line to medial malleolus by observer 1

difference to nail length but had wide limits of agreement for both observers. This reduces its usability on a case-by-case basis.

Isaac et al. did not recommend OMD for anthropometric measurements as OMD +6 mm could only predict 51% of correct nail length.[3] The OMD−5 mm is also a poor predictor of nail length and Venkateshwaran et al. also did not recommend using OMD as a predictor of nail size.[1] Blair et al. calculated a regression equation from which the shortest and longest nail size was calculated. They showed a statistically significant correlation between OMD and TT-MM distance and proposed a range of nail length range from OMD–50 mm to OMD as the preoperative range of tibial nails to be available to the surgeon.[5] Galbraith et al. were able to predict correct nail lengths in 50% of their cases using this parameter.[7]

Hegde et al. have found a good correlation between TT-MM and OMD and recommended the use of OMD as a preoperative assessment tool. On regression analysis, they showed age, gender and BMI have no statistically significant bearings on these parameters.[10] This study has shown wide limits of agreement using OMD as a predictor for nail length.

Among other parameters in the literature, Isaac et al. found that the TT-AJL had the best accuracy of 81% if 11 mm was added to it. They also calculated that if 25 mm was subtracted from the KJL-AJL,



Figs 4A to E: (A) Bland Altman plot of nail length to arm lengths by observer 2; **(B)** Bland Altman plot of nail length to olecranon to fifth metacarpal base by observer 2; **(C)** Bland Altman plot of nail length to tibial tuberosity to medial malleolus by observer 2; **(D)** Bland Altman plot of nail length to tibial tuberosity to medial malleolus minus 20 mm by observer 2; **(E)** Bland Altman plot of nail length to knee joint line to medial malleolus by observer 2

then nail prediction accuracy was 76%.[3] Venkateshwaran et al. in their two-phase study found that the ideal nail length and KJL to AJL distance–20 mm had the best correlation of 0.982.[1] Galbraith et al. also calculated accuracy of 56% for KJLAJL.[7]

Radiological methods including scanogram, full-size X-rays or CT scans were found to be most accurate preoperatively for nail length assessment.[7] The literature suggests the ideal nail length, as measured radiographically, is 5-10 mm from the proximal tibial articular surface to 10 to 20 mm from the distal tibial articular surface.[1,5-7] Radiological methods have their own disadvantages, including radiation exposure, positioning of the limb on X-ray and magnification scale. Among the radiological methods, Galbraith et al. found AP scanogram to be 100% accurate in predicting tibial nail length. The guidewire technique was incorrect only 6% of the time, and this was borne out in our error of 5.5% using this technique. They concluded that using radiological methods with known magnification factors or the intraoperative guidewire method were better predictors of nail length compared to anthropometric methods.[7] Keltz et al. also have found better accuracy in predicting nail size using radiographic templating and recommended using a digital graphic program with planning on the contralateral leg for predicting tibial nail length.[11] They calculated the intercorrelation coefficient for planned tibial nails to be 0.97 for length and 0.84 for diameter in AP views and 0.98 and 0.86 in lateral

Table 4: Repeatability assessment using Bland-Altman method for anthropometric parameters

	Observer 1 vs Observer 2	
Anthropometric measurement to nail length	*Average difference*	*Limits of agreement*
Arm length (AL)	−0.02	−19.04 to 19.01
Olecranon to fifth metatarsal base (OMD)	−1.4	−10.9 to 8.1
Tibial tuberosity to medial malleolus (TT-MM)	−0.9	−9.4 to 7.5
Tibial tuberosity to medial malleolus minus 20 mm (TT-MM−20 mm)	−0.02	−19.0 to 19.0
Knee joint line to medial malleolus (KJL-MM)	−0.6	−11.9 to 10.7

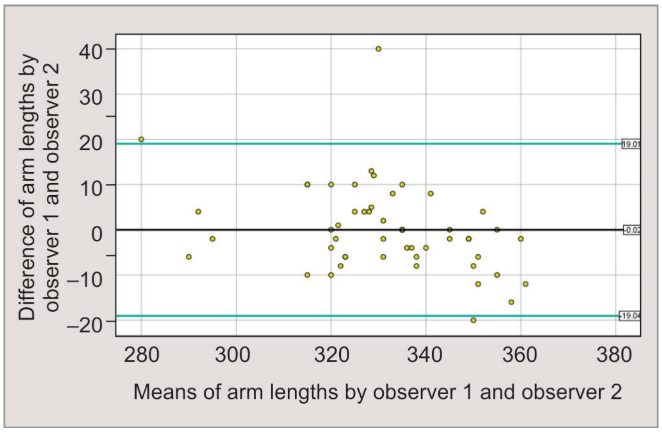


Fig. 5: Bland Altman plot for repeatability done for arm length measured by the two observers

views for length and diameter, respectively. However, such facilities may not be available everywhere, thereby limiting their utility.

AL has not been conventionally used to estimate tibial nail length. Versluys et al. have shown that AL is proportional to forearm length with an intra-limb ratio of 0.817, which suggest that upper AL may be used for a preoperative assessment of tibial nail length.[12] This study shows that AL had the least average difference to nail length for all observations made with narrow limits of agreement. On repeatability assessment using the BlandAltman method, we found that AL showed a difference of −0.02 mm on average when measured by different observers and the limits of agreement at −19.04 to 19.01, indicating good repeatability. Although none of the anthropometric measurements investigated here was able to meet the set agreement limits of ±10 mm, AL came closest to these set agreement limits (Tables 3 and 4). Conventionally, the tibial nails are manufactured with 20 mm differences in length. Based on the data of this study, any single measurement of AL by one observer will produce an estimate of nail length that will range from being 28.4 mm smaller to being 25.8 mm larger than optimum in 95% of cases. This range corresponds to one nail length size difference only. This infers that with the single-AL measurement, the surgeon will be able to estimate the correct nail length to within one size of the optimum. For example, if the surgeon measures AL preoperatively in a patient and it comes out to be 320 mm, then the surgeon could expect the optimum nail size to be either the same as measured AL, one size smaller or one size larger than 320 mm in 95% of patients. The surgeon should ensure the availability of 300, 320 and 340 mm nail length in the operation theatre, and by doing so, the surgeon will be correct 95% of the times.

Our study was limited by relatively small sample size and a non-homogenous study population that was predominantly male. We were not able to corroborate anthropometric readings using a preoperative scanogram. Due to the above limitations to the study, more studies are required for further evaluation of the AL as an upper limb parameter.

Conclusion

AL can be used as an anthropometric predictor for tibial nail length in the preoperative period. More studies with larger sample size and more homogenous population are required for further validation.

Clinical Significance

AL can be used as an anthropometric parameter for the estimation of tibial nail, especially in situations where lower limb parameters cannot be measured and appear to be more accurate than OMD length.

Acknowledgments

We would like to thank Prof. Sreenivas Vishnubhatla, Department of Biostatistics, All India Institute of Medical Sciences, New Delhi, India, for his insight and guidance. The Institution's Ethics Committee confirmed that ethics clearance was not required as it was an observational study.

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