Anatomical analysis of proximal tibia: selecting ideal sites for pediatric intraosseous infusion

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SUMMARY

Intraosseous access is a safe and efficient method to administer medications to patients that require advanced life support when intravenous access is not easily available. This study aims to narrow down the ideal insertion site for intraosseous access within the proximal tibia in a pediatric population. The study utilized computed tomography scans that were retrospectively collected from scans of five infant patients between four-weeks and two-years old, seven young children between two-years and six-years old, and ten children between six-years and twelve-years of age. Analysis of the computed tomography scans started at 10mm and extended to 50mm distally to the tibial tuberosity at 10mm increments.

The smallest cortical thickness to medullary space ratio and most desirable cortical thickness to anteromedial border ratio across all three groups – infants, young children, and child – was identified as 10mm inferior to the tibial tuberosity. Meanwhile, the largest medullary space to anteromedial border ratio was at 10mm inferior to the tibial tuberosity for the infants and young child groups, and at 30mm for the child group. This study showed that, overall, the ideal needle insertion site to gain vascular access for an intraosseous infusion procedure in the proximal tibial in infants, young child, and children is 10mm distal to the tibial tuberosity.

Key words: Cortex – Medullary – Proximal tibia – Tibia – Vascular access – Computed tomography – DICOM

INTRODUCTION

In patients that require advanced life support, administration of intravenous medications is not always quick and easily achieved. Especially in neonates and infant patients, the intraosseous (IO) route offers a comparable and advantageous alternative. IO infusions have been used since the twentieth century and have been included in pediatric

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advanced support guidelines since 1988 (Clemency et al., 2017). IO access is considered a safe and efficient method of administering all medications that can be administered intravenously with a comparable onset of action (Kleinman et al., 2010). Multiple studies have identified various IO sites of insertion, including proximal tibia, proximal humerus, clavicle, sternum, and radius. Among the ideal insertion sites for the IO route, the proximal tibia can be easily palpated with surface landmarks and is a distance away from vital areas where resuscitation efforts might be required, for example, the chest (Ngo et al., 2009).

The proximal tibia was reported to have a higher first-attempt success rate compared with other sites such as the humeral head (Clemency et al., 2017). In 2003, Boon et al. studied the ideal site on the proximal tibia for IO needle insertion in neonates. In this study, they used 18-gauge spiral needles on a total of 14 neonate cadavers (28 tibias), noting the ease of needle insertion and relation of the needle to the epiphyseal growth plate in the four different sites of insertion tested. They found that the ideal site of IO needle insertion was at least 10mm distal to the tibial tuberosity on the anteromedial surface; they showed that this site best fitted both parameters studied. On the other hand, they found that sites 10mm proximal to the distal tuberosity and 20mm distal to the tibial tuberosity were resistant to needle insertion due to increased cortical bone thickness and resulted in a perforated epiphyseal plate respectively (Boon et al., 2003). Another study by Chokshi et al. (2010) had similar findings, as they reported that the ideal place for needle insertion is between 10 and 30mm distal to the tibial tuberosity, with the needle angled inferiorly 40 to 60 degrees (Chokshi et al., 2010). Previously, Ellemunter et al. (1999) reported successful IO resuscitation in preterm and full-term infants admitted to the neonatal intensive care units, with no major reported complications and zero failed insertion attempts; their chosen needle insertion site was between 5mm to 10mm distal to the tibial tuberosity on the medial surface.

The tibia is a long, weight-bearing bone that has important landmarks for muscle attachments. For example, the tibial tuberosity can be easily palpated approximately 50mm distal to the patella in an adult population, and it is a protrusion on the anterior tibial surface that serves for the attachment site of the patellar ligament (White and Folkens, 2005). The tibia develops through a process called endochondral ossification, where ossification starts from the cartilaginous model of the tubular bone and continues till birth. The growth plates (physis) of the tibia are situated at the proximal and distal ends between the epiphysis and diaphysis, known as the shaft of the tibia. Longitudinal bone growth ensues until late adolescence, marked by the ossification of the growth plate and fusion of epiphysis and metaphysis, which is the portion of the bone that flairs outwards (Monsell et al., 2018).

Although IO infusion is a relatively safe and easy route for resuscitation, there are some important contraindications to keep in mind. These include bone diseases such as osteogenesis imperfecta, osteoporosis, osteomyelitis, fractured lower limb, and cutaneous infection in the area. In addition, difficulty identifying landmarks and accessing the area due to inflammation, any past surgical history on the tibia or knee, and any mass or malignancy near the insertion site would be considered contraindications for IO resuscitation. Lastly, if the needle is inserted incorrectly, potential complications include subcutaneous infusion, osteomyelitis, extravasation of fluid, infection at injection site, and compartment syndrome (Ryder et al., 1991; Ngo et al., 2009). This study focuses on narrowing down the ideal insertion site for the IO route to better guide medical providers and emergency responders.

MATERIALS AND METHODS

Patients and Methods

The sample consisted of CT scans of 5 infant patients between four weeks and two years old, 7 young child patients between two years and six years, and 10 child patients between six years and twelve years of age. These were retrospectively obtained from the Department of Radiology at the Steve Biko Academic Hospital in South Africa, with permission from both the Head of the Department of Radiology and the CEO of the hospital (Ethics clearance: 447/2018). The mean sample

Table 1. Age (in days) of the cadavers used to measure the dimensions of the proximal tibia. (n= number of individuals).

	n	Range	Minimum	Maximum	Mean	Std. Deviation
Infants	5	670	34	704	377.20 (1 year)	250.06 (0.7 years)
Young Child	7	744	1402	2146	1796.71 (4.9 years)	252.69 (0.7 years)
Child	10	1876	2478	4354	3267.70 (9 years)	628.67 (1.7 years)

age for each age category is presented in Table 1. The study excluded patients that were diagnosed by the consulting radiologist to either have an abnormal degree of kyphosis and/or scoliosis, obvious visceromegaly or a space-occupying lesion. Additionally, sex and ancestry were not considered as an exclusion factor.

RadiAnt, a Digital Imaging and Communications in Medicine (DICOM) viewer, was used to analyze the CT scans starting at the plane of the tibial tuberosity and extending 50mm inferior to the tibial tuberosity at 10mm increments. The following measurements were used (see Fig. 1).

The width of the anteromedial border of the tibia was determined by measuring the distance between the anterior and the medial border of the tibia. By measuring from the outer cortical layer of the anteromedial surface to the inner cortical layer, the cortical thickness of the tibial bone was determined. The medullary space of the tibia was measured from the inner cortical layer of the anteromedial surface to the opposite inner cortical layer, perpendicular to the anteromedial surface (Fig. 2).

Statistical Analysis

The data were summarized using descriptive statistics, including mean, standard deviation and 95% confidence intervals. Measurements from the respective left and right sides were compared using a paired t-test or Wilcoxon Signed Rank test, depending on the distribution of the data.

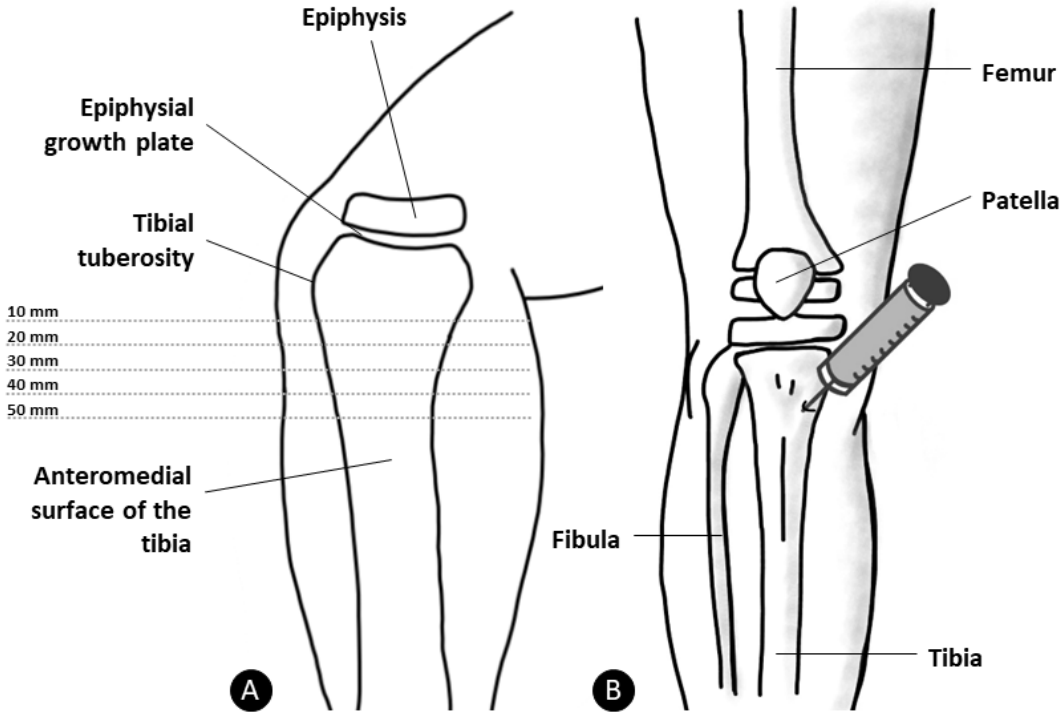

Fig. 1.- A. Schematic representation of IO needle insertion at levels 10, 20, 30, 40, and 50mm respectively inferior to the tibial tuberosity on the anteromedial surface of the leg. **B**. Schematic frontal view of the approximate site of IO needle insertion on the proximal tibia.

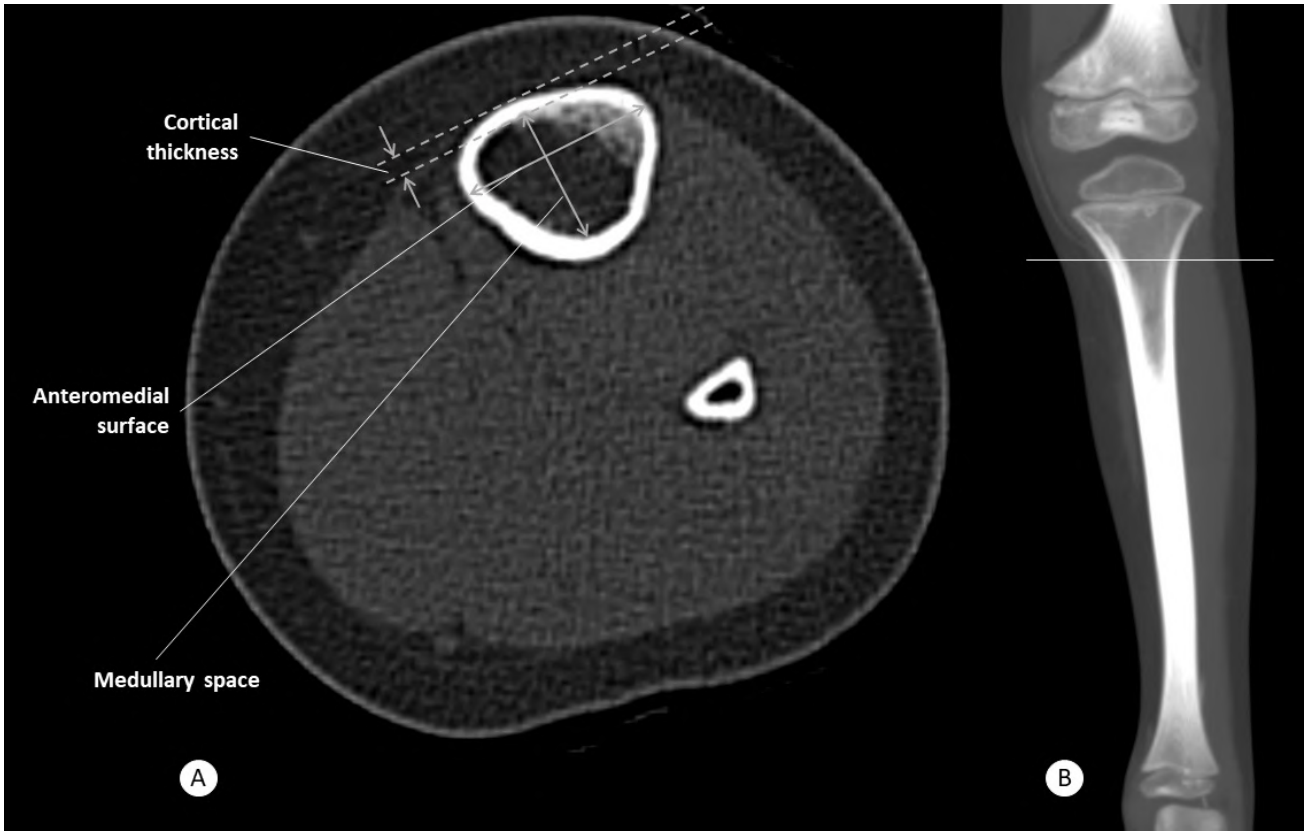

Fig. 2.- A. Transverse CT scan distal to the tibial tuberosity in a 3-year-old child. The measurements show the anteromedial surface, cortical thickness, and medullary space. **B**. Indicate line at which horizontal section was determined.

RESULTS

The sample size for the infants was insufficient for a Paired t-test and a Wilcoxon Signed Rank test to reveal any significant difference between the measurement pairs involved. As such, each measurement pair was compared in order to determine whether there was any clinically significant difference between the two. If no clinical significance was present, the applicable left and right sides were then combined. However, for both the young child and child, a Paired t-test and the Wilcoxon Signed Rank test was conducted and revealed no significant difference between the measurement pairs involved. The applicable left and right sides were then combined. Descriptive statistical analysis for the combined measurements together with a 95% confidence interval is shown for each of the respective measurements.

Infants (4 weeks – 2 years)

Anteromedial surface of the Tibia

At 10mm inferior to the tibial tuberosity, the largest anteromedial surface was observed with a mean distance of 13.8 ± 4.4mm (mean ± standard deviation), and the smallest average anteromedial surface was determined at 30mm inferior to the tibial tuberosity. With a confidence interval of 95%, the anteromedial surface of the tibia at 10mm ranged from 12.8 to 19.3mm (Table 2).

Cortical thickness

At 50mm inferior to the tibial tuberosity, the thickest cortical thickness was observed, and the smallest average cortical thickness of 3.1 ± 0.3mm was measured at 10mm inferior to the tibial tuberosity (Table 2).

Medullary space

The largest medullary space was seen at 10mm inferior to the tibial tuberosity with a mean diameter of 5.1 ± 2.3mm. With a confidence interval of 95%, the medullary space of the tibia at 10mm ranged from 4.4 to 7.9mm (Table 2).

Young Child (2-years to 6-years)

Anteromedial surface of the Tibia

The largest anteromedial surface was seen 10mm inferior to the tibial tuberosity at a mean distance of 23.4 ± 4.2mm, with a confidence inter-

Table 2. Descriptive statistical analysis and 95% confidence interval in mm for the combined left and right sides of the tibia in infants. (n= number of individuals).

mm	n	Range	Min	Max	Mean		Std. Deviation	95% Confidence Interval of Mean	
					Statistic	Std. Error		Lower	Upper
Anteromedial surface									
10	7	11.9	7.7	19.5	13.8	1.7	4.4	12.8	19.3
20	7	9.4	8.8	18.2	13.5	1.2	3.0	11.2	17.8
30	7	6.1	10.6	16.7	13.0	1.0	2.6	10.4	17.1
40	6	7.4	9.9	17.3	13.4	1.1	2.8	9.5	17.3
50	6	6.8	10.5	17.3	13.6	1.0	6.0	10.2	16.9
Medullary space									
10	8	7.3	2.2	9.4	5.1	0.8	2.3	4.4	7.9
20	7	6.0	2.1	8.1	4.1	0.7	1.9	2.6	6.4
30	7	4.7	2.6	7.3	3.6	0.6	1.7	1.7	5.5
40	6	4.3	2.3	6.6	3.3	0.7	1.7	1.6	5.1
50	6	3.4	2.8	6.2	4.2	0.6	1.5	2.7	5.8
Cortical thickness									
10	8	2.2	2.0	4.2	3.1	0.3	0.7	2.8	3.9
20	7	2.3	2.3	4.5	3.3	0.3	0.8	2.7	4.2
30	7	3.0	1.9	4.9	3.5	0.4	1.0	3.1	4.6
40	6	2.3	2.9	5.1	3.8	0.3	0.8	3.0	4.7
50	6	1.6	3.0	4.5	3.6	0.3	0.6	3.0	4.3

val of 95%, the anteromedial surface of the tibia at 10mm ranged from 20.9 to 25.9mm. At 50mm below the tibial tuberosity, the anteromedial surface ranged between 17.1 to 20.4mm (Table 3).

Cortical thickness

The smallest average cortical thickness of 3.0 ± 1.3mm was measured at 10mm inferior to the tibial tuberosity, ranging from 2.2 to 3.8mm with a confidence interval of 95% at 10mm (Table 3).

Medullary space

The largest medullary space was seen at 10mm inferior to the tibial tuberosity with a mean diameter of 14 ± 3.2mm, while the smallest average medullary space was measured at 50mm inferior to the tibial tuberosity with an average diameter of 10.2 ± 2.9mm. With a confidence interval of 95%, the medullary space of the tibia at 10mm ranged from 12.1 to 16.0mm (Table 3).

Child (6 years to 12-years)

Anteromedial surface of the Tibia

The largest anteromedial surface was seen 10mm inferior to the tibial tuberosity at a mean distance of 27.7 ± 4.4mm. With a confidence interval of 95%, the anteromedial surface of the tibia at 10mm ranged from 25.6 to 29.7mm, while at 50mm inferior to the tibial tuberosity it ranged from 21.3 to 25.3mm (Table 4).

Cortical thickness

The thinnest cortical thickness was observed at 10mm and 50mm inferior to the tibial tuberosity at a mean thickness of 3.2 ± 0.6mm, and the thickest average cortical thickness of 3.3 ± 0.8mm was measured at 20, 30, and 40mm inferior to the tibial tuberosity. With a confidence interval of 95%, the cortical thickness of the tibia at 30mm ranged from 2.9 to 3.6mm (Table 4).

Medullary space

The largest medullary space was seen at 10mm inferior to the tibial tuberosity with a mean diameter of 15.9 ± 3.0mm, while the smallest average medullary space was measured at 50mm inferior to the tibial tuberosity with an average diameter of 12.9 ± 2.9mm. With a confidence interval of 95%, the medullary space of the tibia at 10mm ranged from 14.5 to 17.3mm, and at 50mm be-

Table 3. Descriptive statistical analysis and 95% confidence interval in mm for the combined left and right of the tibia in young children. (n= number of individuals).

mm	n	Range	Min	Max	Mean		Std. Deviation	95% Confidence Interval of Mean	
					Statistic	Std. Error		Lower	Upper
Anteromedial surface									
10	13	13.0	16.9	29.9	23.4	1.2	4.2	20.9	25.9
20	13	10.8	16.1	26.9	21.7	1.0	3.6	19.56	23.9
30	13	11.1	15.1	26.2	20.6	1.0	3.6	18.4	22.7
40	13	8.9	14.8	23.7	19.4	0.8	3.0	17.6	21.2
50	13	8.3	14.9	23.2	18.7	0.8	2.7	17.1	20.4
Cortical thickness									
10	13	5.1	1.5	6.6	3.0	0.4	1.3	2.2	3.8
20	13	4.0	1.6	5.5	2.9	0.3	1.0	2.3	3.6
30	13	3.6	1.4	5.0	3.0	0.3	0.9	2.4	3.5
40	13	2.8	1.7	4.6	2.9	0.2	0.8	2.4	3.4
50	13	2.8	1.9	4.7	2.9	0.2	0.8	2.4	3.5
Medullary space									
10	13	10.5	9.4	19.9	14.0	0.9	3.2	12.1	16.0
20	13	9.5	9.1	18.6	13.0	0.8	3.1	11.2	14.9
30	13	8.1	8.2	16.3	11.9	0.8	2.8	10.2	13.6
40	13	8.6	7.4	16.0	11.0	0.8	2.7	9.4	12.7
50	13	8.4	6.5	14.9	10.2	0.8	2.9	8.4	11.9

Table 4. Descriptive statistical analysis and 95% confidence interval in mm for the combined left and right of the tibia in children. (n= number of individuals).

mm	n	Range	Min	Max	Mean		Std. Deviation	95% Confidence Interval of Mean	
					Statistic	Std. Error		Lower	Upper
Anteromedial surface									
10	20	17.2	20.6	37.8	27.7	1.0	4.4	25.6	29.7
20	20	16.0	20.3	36.3	26.4	1.0	4.4	24.4	28.4
30	20	15.1	19.9	35.0	25.2	1.0	4.4	23.1	27.2
40	20	15.5	17.9	33.4	23.8	1.0	4.3	21.8	25.8
50	20	14.8	18.3	33.1	23.3	1.0	4.3	21.3	25.3
Cortical thickness									
10	20	2.3	2.3	4.7	3.2	0.1	0.6	2.9	3.5
20	20	3.5	2.4	5.9	3.3	0.2	0.8	2.9	3.6
30	20	2.9	2.5	5.4	3.3	0.2	0.8	2.9	3.6
40	20	3.6	2.4	6.1	3.3	0.2	0.8	2.9	3.7
50	20	2.3	2.5	4.8	3.2	0.1	0.6	2.9	3.5
Medullary space									
10	20	12.4	9.3	21.7	15.9	0.7	3.0	14.5	17.3
20	20	11.7	8.7	20.4	15.1	0.7	3.0	13.7	16.5
30	20	14.2	5.4	19.6	14.5	0.7	3.3	12.9	16.0
40	20	15.5	3.0	18.5	13.5	0.7	3.3	11.9	15.0
50	20	12.8	4.5	17.3	12.9	0.7	2.9	11.6	14.3

low the tibial tuberosity it was between 11.6 and 14.3mm (Table 4).

DISCUSSION

This study builds on the previous work of Boon et al. (2003) and van Tonder et al. (2022) to determine the ideal tibial IO insertion sites. Although the studies conducted by Boon et al. (2003) and van Tonder et al. (2022) focused on newborn infants, this study expanded this to three categories; infants (28 days to 2 years), young children (2 years to 6 years), and children (6 years to 12 years). Boon et al. (2003) suggested that the best insertion site on their sample size of 14 neonatal cadavers was at least 10mm distal to the tibial tuberosity to avoid injury to the epiphyseal growth plate (Boon et al., 2003). The study by van Tonder et. al. (2022) on 15 neonatal cadavers showed that vascular access was ideal at 10mm inferior to the tibial tuberosity (van Tonder et al., 2022). On further application, this study aimed to prove this efficacy on older children to apply this to their guidelines as well. To do so, the ratios between the cortical thickness and the size of the medullary space were used to find the most suitable location and ease of insertion for each age category. This study's results align with previous neonatal research, indicating that 10mm distal to the tibial tuberosity is still the optimum insertion point, even in children up to 12 years old (n=22). These measurements should be emphasized as the epiphyseal growth plates in all three age groups have not yet closed, and the ideal needle insertion site is crucial to avoid damage to the epiphyseal growth plates (Crowder and Austin, 2005).

It is important to recognize the necessity in gaining quick vascular access in children under urgent care, especially those that are in dehydrated or shocked states (Boon et al., 2003; Chokshi et al., 2010; Clemency et al., 2017). However, in those conditions, hypovolemia, vasoconstriction, and peripheral vessel collapse are possible, increasing venipuncture difficulty (De Sá et al., 2012). This requires a mix of the provider's skills and the patient's stability, with timely parenteral access required before it is associated with an increase in morbidity (Neuhaus, 2014). Thereafter, the IO infusion technique should be considered where it reaps its benefits in those difficult-venous-access pediatric cases (Neuhaus, 2014), including when umbilical venous catheterization (UVC) is not possible due to the umbilical cord drying out (Scrivens et al., 2019). Any infusible intravenous substance can be administered intraosseously, which indicates the value of IO administration in life-threatening cases, especially neonates, where drug delivery is critical for survival (Dornhofer and Kellar, 2022). In those cases, IO access can be achieved in as few as 20 seconds compared to the challenging intravenous access, which is when it should be prioritized (Dornhofer and Kellar, 2022). Its plausibility emerged due to the high vascularization in bones, especially the red bone marrow, which allowed for quick fluid infusions into the bloodstream bypassing the absorption process (De Sá et al., 2012). In addition, blood collection is possible from these sites (De Sá et al., 2012). However, upon tibial metaphyseal examination, it was found that there was trabecular bone instead of a developed marrow cavity in neonatal patients, making aspiration difficult. Having said that, the decreased bone marrow cavity seemed to have a positive association with needle stability (Eifinger et al., 2021). There was less dislodgement of the IO needle during angled insertion (Eifinger et al., 2021). In this study, cross-sectional dimensions of the tibia were obtained starting with 10mm inferior to the tibial tuberosity and progressing at 10mm intervals to determine the optimal insertion site.

The aim of the needle insertion is to maximize vascular access while minimizing the risk of harming the epiphyseal plate. Hence, it is more favorable to have a larger anteromedial surface (due to larger surface area) and higher medullary space likewise (since this space is what the needle should be inserted into). Whereas, for the cortical thickness it is more favorable to have as little as possible to encounter the least resistance with needle insertion. The anteromedial surface remains the largest at 10mm across the three groups (infant, young child, and child), measuring 13.8mm, 23.4mm, and 27.7mm, respectively. Similarly, the medullary space follows the same trend, with the biggest measurement for all three groups being at 10mm, measuring 5.1mm, 14.0mm, and 15.9mm,

Table 5. Mean statistic of the measurements at 10mm interval inferior to the tibial tuberosity for an infants, young child, and child.

Infant (4-week to 2-years)			
	Anteromedial surface (mm)	**Cortical thickness (mm)**	**Medullary space (mm)**
10mm	13.8	3.1	5.1
20mm	13.5	3.3	4.1
30mm	13.0	3.5	3.6
40mm	13.4	3.8	3.3
50mm	13.6	3.6	4.2
Young child (2-years to 6-years)			
	Anteromedial surface (mm)	**Cortical thickness (mm)**	**Medullary space (mm)**
10mm	23.4	3.0	14.0
20mm	21.7	2.9	13.0
30mm	20.6	3.0	11.9
40mm	19.4	2.9	11.0
50mm	18.7	2.9	10.23
Child (6-years to 12-years)			
	Anteromedial surface (mm)	**Cortical thickness (mm)**	**Medullary space (mm)**
10mm	27.7	3.2	15.9
20mm	26.4	3.3	15.1
30mm	25.2	3.3	14.5
40mm	23.8	3.3	13.5
50mm	23.3	3.2	12.9

respectively (Table 5). However, the cortical thickness hardly varies within each group and across groups. Therefore, taking the ratios of these three measurements is a more useful tool to have an indication of the ideal proportions of these measurements to direct the needle insertion site.

The smallest (most desirable) cortical thickness to medullary space ratio across all three groups – infants, young children, and child – was at 10mm. The largest (least desirable) cortical thickness to medullary space ratios across the same groups was at 40mm, and 50mm for young child and children, respectively (Table 6). This study's results are comparable to those of Boon et al. (2003) and van Tonder et al. (2022), with the conclusion that the ideal insertion site for IO needle insertion is 10mm distally inferior to the tibial tuberosity border. In addition, they suggest angling the needle inferiorly to avoid damage to the epiphyseal plates (Boon et al., 2003). Along the same lines, the smallest (most desirable) cortical thickness to anteromedial border ratio across the three groups – infants, young child, and child – was again at 10mm. Lastly, the largest (most desirable) medullary space to anteromedial border ratio for the three groups was at 10mm for the infants and young child groups, and at 30mm for the child group. The smallest (least desirable) medullary space to anteromedial border ratio for the infants' group was at 40mm, whereas, for the young child and child groups it was at 50mm for both (Table 6).

For clinicians, anatomical landmarks such as the tibial tuberosity can be of great help in directing needle insertion via the IO route. Harcke et al. (2020) reported the ideal needle insertion site was one finger below the tibial tuberosity. In this study, the difference between the various age groups is highlighted as several authors (Ryder et al., 1991; Ellemunter et al., 1999; Boon et al., 2003; Chokshi et al., 2010; Neuhaus, 2014; Scrivens et al., 2019; Dornhofer and Kellar, 2022) have found these tibial landmarks advantageous. Eifinger et al. (2021)

Table 6. Ratios of the mean distances between measurements for an infants, young child, and child.

Infant			
	Cortical thickness / Medullary space*	**Cortical thickness / Anteromedial border***	**Medullary space / Anteromedial border****
10mm	0.61	0.22	0.37
20mm	0.80	0.24	0.30
30mm	0.97	0.27	0.28
40mm	1.15	0.28	0.25
50mm	0.86	0.26	0.31
Young child			
	Cortical thickness / Medullary space*	**Cortical thickness / Anteromedial border***	**Medullary space / Anteromedial border****
10mm	0.21	0.13	0.60
20mm	0.22	0.13	0.60
30mm	0.25	0.15	0.58
40mm	0.26	0.15	0.57
50mm	0.28	0.16	0.55
Child			
	Cortical thickness / Medullary space*	**Cortical thickness / Anteromedial border***	**Medullary space / Anteromedial border****
10mm	0.20	0.12	0.57
20mm	0.22	0.13	0.57
30mm	0.23	0.13	0.58
40mm	0.24	0.14	0.57
50mm	0.25	0.14	0.55

* Smaller values are better
** Bigger values are better

compared measurements of humerus, tibia, and femur bones in neonates, infants, and children in a cadaveric and CT-based study; of particular relevance to this study, they found that in contrast to the distal tibia, the proximal tibia had the largest diameter and cross-sectional area. Additionally, the tibial bone is more oval shaped in its proximal end, making the proximal tibia ideal for IO access by providing more surface area for the needle insertion (Eifinger et al., 2021).

CONCLUSION

Considering the analysis conducted in this study, it is evident that determining the ideal tibial IO insertion sites for infants, young children, and children holds significant clinical implications. By building upon prior research and extending the investigation across multiple age categories, this study not only reaffirms but also expands upon the findings of previous studies conducted on neonatal cadavers. This study showed that the ideal needle insertion site to gain vascular access in IO infusions in infants, young children, and children is at 10mm distal to the tibial tuberosity, as compared with all other more distal insertion sites analyzed such as at 20, 30, 40, and 50mm. This was shown by obtaining the lowest cortical thickness to medullary space ratio, the lowest cortical thickness to anteromedial surface ratio, and one of the largest medullary spaces to anteromedial surface ratio, all at the 10mm insertion site across the three age groups. The consistent identification of the 10mm distal to the tibial tuberosity as the optimal insertion point underscores the robustness and generalizability of this conclusion across various pediatric age groups, emphasizing its practical relevance and applicability in clinical settings.

Limitations

Obtaining CT scans of healthy pediatric patients is not easy, as for this demographic group data such as weight and height of patients is not always regularly available. Hence, the results within this study may be limited by the small sample size. To locate the optimum insertion site, this study utilized ratio comparisons between measurements, whereas previous studies only used mean diameters, which may affect comparability.

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AUTHORS' CONTRIBUTIONS

Mr. DJ van Tonder was primary responsible for protocol development, data collection, data analysis, manuscript writing, and critical review of the final manuscript.

Ms. L Al Safadi and Ms. P Samaha both participated in manuscript writing, and the critical review of the final manuscript.

Prof FE Suleman was responsible for data collection as well as protocol development, manuscript editing, and the critical review of the final manuscript.

Prof ML van Niekerk initiated research idea and was involved in protocol development, manuscript editing, together with the critical review of the final manuscript.

Prof A van Schoor supervised the design and execution of the study by partaking in protocol development, data collection, data analysis, manuscript writing, and the critical review of the final manuscript.

Ethics approval and consent to participate

The studies involving human participants were reviewed and approved (Ethics clearance number: 447/2018) by the Health Sciences Research Ethics Committee at the University of Pretoria, South Africa. All methods and observations were carried out in accordance with the relevant requirements, guidelines, and regulations stipulated in the South African National Health Act (61 of 2003).

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