Proximal tibial dimensions in a formalin-fixed neonatal cadaver sample: an intraosseous infusion approach

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Abstract

Purpose: Methods to administer intramedullary medication and fluid infusion in both adults and children date to the early 20th century. Studies have shown that intraosseous access in the proximal tibia is ideal for resuscitation efforts as fewer critical structures are at risk, and neither is the blood flow to the lower limbs compromised. Insertion of a needle in children younger than 5 years does have the risk to damage to the epiphyseal growth plate. Therefore, the aim of this study was to determine the ideal intraosseous insertion site distal to the epiphyseal growth plate in neonates.

Methods: The samples consisted of both the left and right sides of 15 formalin-fixed neonatal cadavers. The dimensions were measured on the superior surfaces of each section, anteromedial border, cortical thickness, medullary space.

Results: The most desirable location to gain vascular access is at 10 mm inferior to the tibial tuberosity.

Conclusion: The smallest cortical thickness (1.32 mm), the largest medullary space (4.50 mm) and the largest anteromedial surface (7.72 mm) was seen at 10mm inferior to the tibial tuberosity. It is imperative that health care professionals are familiar with the osteological sites that could be safely used for an intraosseous infusion procedure.

Keywords

resuscitation, cortical bone, infusions, growth plate, new-born, surface anatomy, vascular access devices

Introduction

Methods to administer intramedullary medication and fluid infusion in both adults and children date to the early 20th century. The insertion site in the proximal tibia is ideal for resuscitation efforts as fewer critical structures are at risk, and blood flow to the lower limbs are not compromised [9, 5]. According to Chokshi *et al.* (2010)*,* inserting a needle in children younger than five years should be performed 10 mm to 30 mm inferior to the tibial tuberosity on the flat anteromedial surface. The needle should be angled inferiorly to the distal end of the tibia at 40 to 60 degrees [4]. A study by Boon *et al*.(2003) sought to find the ideal site for intraosseous infusion in neonates. They found that with an anteromedial approach, the ideal location in 14 neonatal cadavers with an 18-gauge spinal needle, is 10 mm distal to the inferior border of the tibial tuberosity. This location showed that all the needles inserted at that location missed the epiphyseal growth plate and did not have undesirable cortical bone thickness. Boon *et al*.(2003) found it difficult inserting a needle 20 mm inferior to the tibial tuberosity as the cortical bone thickness was too thick [3]. Wald *et al.*(2019) recommend that the needle be inserted 10 to 20 mm inferior to the tibial tuberosity on the medial surface [12]. Intraosseous lines inserted by Ellemunter *et al.* (1999) was placed in the medial plane 5 mm to 10 mm inferior to the tibial tuberosity in a total of 27 neonatal patients. Ellemunter *et al.*(1999) did not report any major complications and did not experience any failed attempts [7].

The formation of the tibia is achieved by a process called endochondral ossification – the process where a hyaline precursor model is transformed into bone via osteoid deposition and mineralization. Capillaries will grow into the shaft of the developing bone, forming a primary ossification center. This will eventually become a network of trabecular bone surrounded by a denser cortical bone [10]. A major bony landmark on the tibia is the tibial tuberosity. It's a rough area on the anterior surface of the proximal end of the tibia which allows insertion of the patellar ligament [13].

There are a few contraindications to consider when attempting an intraosseous infusion at the proximal tibia. Bone diseases such as osteomyelitis, osteogenesis imperfecta, osteopetrosis or any infectious disease such as septicemia or superficial infections would all be contraindications to gain vascular access through intraosseous infusion. When the needle is inserted incorrectly it will result in subperiosteal infusion or leakage, mild local bleeding, or damage to the growth plate [9]. This emphasizes the need to identify the ideal needle insertion site and provide accurate anatomical guidelines for an intraosseous infusion.

Materials and methods

Materials: The sample consisted of both the left and right sides of 15 formalin-fixed neonatal cadavers (Ethics clearance: 447/2018). At the time of death, all the cadavers were younger than six weeks. Cadavers were obtained and stored according to the standards set out in the South African National Health Act (61 of 2003). All sample demographics are presented in Table 1. We excluded cadavers with any developmental abnormalities of the lower limb, or which were previously dissected and disrupted the normal anatomy of the region.

Table 1: Demographic information of the neonatal cadavers used to measure the dimensions of the proximal tibia. (n= number of individuals)

	n	Range	Minimum	Maximum	Mean	Std. deviation
Height (cm)	15	19	38	57	45.7	6.3
Weight (kg)	15	3.2	0.8	4.0	2.0	0.8

n number of individuals

Methods: Neat 10 mm thick cross-sectional sections were made with a band saw starting at the plane of the tibial tuberosity and extended 30 mm inferior to the tibial tuberosity. The measurements were recorded with a mechanical dial caliper with an accuracy of 0.01 mm. To achieve the following measurements the superior surfaces of each section was used (Figure 1).

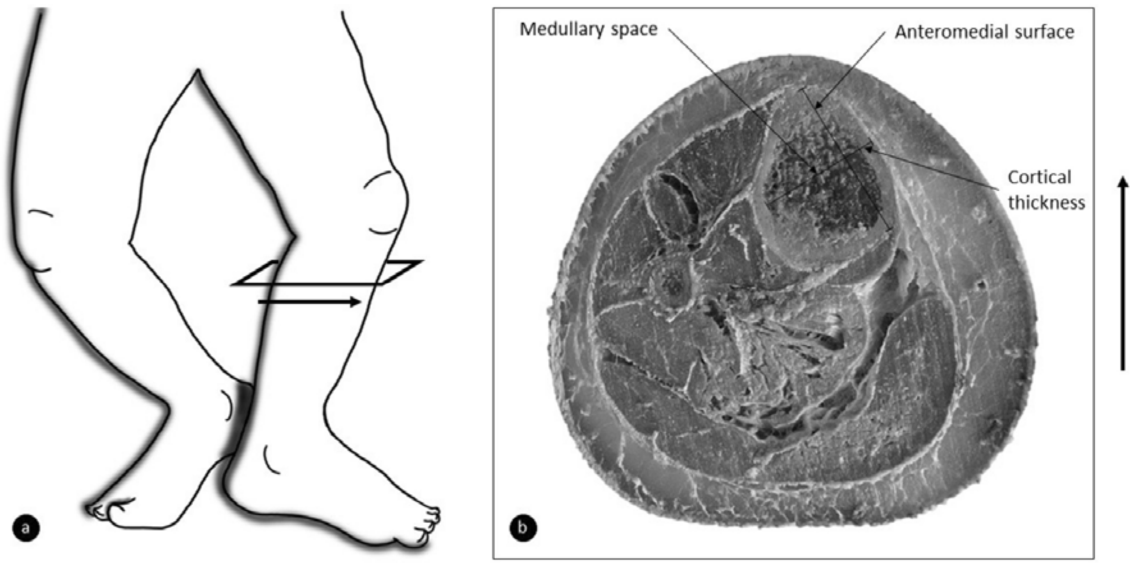

Figure 1: Transverse sections below the knee of a neonatal cadaver (a). Corresponding measurements indicated on the cadaver slice (b).

To determine the width of the anteromedial border of the tibia the distance between the anterior and the medial border of the tibia was measured. The cortical thickness of the tibial bone was determined by measuring from the outer cortical layer of the anteromedial surface to the inner cortical layer. Finally, to determine the medullary space of the tibia the measurement from the inner cortical layer of the anteromedial surface to the opposite inner cortical layer was measured perpendicular to the anteromedial surface.

Statistical Analysis: The data were summarized using descriptive statistics, including mean, median, standard deviation and 95% confidence intervals. We compared measurements from the respective left and right sides using a paired t-test or Wilcoxon Signed Rank test, depending on the distribution of the data, after outliers were removed via standardized values. We used an inter- and intra-observer error analysis to test for repeatability and accuracy, following Bland and Altman (2010).

Results

Quantitative: The Paired t-test and the Wilcoxon Signed Rank test revealed no significant difference between the measurement pairs involved, except the left and right measurement made at 20mm inferior to the tibial tuberosity for the tibial thickness. 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.

Anteromedial surface of the Tibia

The largest anteromedial surface was seen 10 mm inferior to the tibial tuberosity at a mean distance of 7.7 ± 1.4 mm (mean ± standard deviation), and the smallest average anteromedial surface was measured at 30 mm inferior to the tibial tuberosity. With a confidence interval of 95%, the anteromedial surface of the tibia at 10 mm ranged from 7.2 mm. to 8.2 mm while at 30 mm it ranged from 5.6 mm to 6.4 mm.

Table 2: Descriptive statistical analysis and 95% confidence interval in mm, combined left and right sides for the width of the anterionedial surface of the tibia. (n= number of individuals; Min= Minimum; Max= Maximum)

	n	Range	Min	Max	Mean		Std. deviation	95% confidence interval of mean	
					Statistic	Std. error		Lower	Upper
10 mm	28	6.5	5.8	12.3	7.7	0.3	1.4	7.2	8.2
20 mm	30	3.8	4.9	8.7	6.6	0.2	1.2	6.2	7.0
30 mm	30	3.7	4.2	7.9	6.0	0.2	1.1	5.6	6.4

n number of individuals, *Min* Minimum, *Max* Maximum

Cortical thickness

The largest cortical thickness was observed at 30mm inferior to the tibial tuberosity at a mean thickness of 1.7 ± 0.3 mm, the smallest average cortical thickness of 1.3 ± 0.5 mm was measured at 10 mm inferior to the tibial tuberosity. With a confidence interval of 95%, the cortical thickness of the tibia at 20 mm ranged from 1.3 mm to 1.6 mm.

Table 3: Descriptive statistical analysis and 95% confidence interval in mm, combined left and right sides for the cortical thicknes of the tibia. (n= number of individuals; Min= Minimum; Max= Maximum)

	n	Range	Min	Max	Mean		Std. deviation	95% confidence interval of mean	
					Statistic	Std. error		Lower	Upper
10 mm	29	1.5	0.8	2.3	1.3	0.1	0.5	1.2	1.5
20 mm	28	1.2	0.8	2.0	1.5	0.1	0.4	1.3	1.6
30 mm	29	1.2	1.1	2.3	1.7	0.1	0.3	1.6	1.8

n number of individuals, *Min* Minimum, *Max* Maximum

Medullary space

The largest medullary space was seen at 10 mm inferior to the tibial tuberosity with a mean diameter of 4.5 ± 1.5 mm, while the smallest average medullary space was measured at 30 mm inferior to the tibial tuberosity with an average diameter of 2.5 mm ± 0.6 mm. With a confidence interval of 95%, the medullary space of the tibia at 20 mm ranged from 2.4 mm to 3.0 mm.

Table 4: Descriptive statistical analysis and 95% confidence interval in mm, combined left and right sides for the diameter of the medullary space of the tibia. (n= number of individuals; Min= Minimum; Max= Maximum)

	n	Range	Min	Max	Mean		Std. deviation	95% confidence interval mean	
					Statistic	Std. error		Lower	Upper
10 mm	29	5.5	2.1	7.6	4.5	0.3	1.5	3.9	5.1
20 mm	28	3.2	1.4	4.6	2.7	0.2	0.8	2.4	3.0
30 mm	30	2.0	1.5	3.5	2.5	0.1	0.6	2.2	2.7

n number of individuals, *Min* Minimum, *Max* Maximum

Interobserver error analysis: An interobserver error analysis was conducted. No clinically significant difference for the interobserver measurement was identified.

Discussion

As expected, the most important finding of this study was to confirm the conclusions made by Boon *et al.* (2003) that the most desirable location to gain vascular access is 10 mm. Our findings are based on the ratio between the cortical thickness and the size of the medullary space, which was the highest 10mm inferior to the tibial tuberosity. This is followed by the locations at 20 mm and 30 mm inferior to the tibial tuberosity, respectively.

In life-threatening conditions, the venous structures are suspected to collapse [6, 11]. Additionally, it is not recommended to spend more than 90 seconds attempting to gain peripheral vascular access [8]. In circumstances where intravenous access is challenging or impossible, an intraosseous infusion provides a rapid, safe and effective alternative. The preferred site for intraosseous insertion is the proximal tibia [1, 8, 4], although current needles that are accompanied by a small battery-powered drill simplifies the procedure precautions should be taken not to go beyond the bone marrow and traverse the tibial bone [8]. The cross-sectional dimensions of the tibia in this study are explained with the help of Table 5 in intervals of 10mm inferior to the tibial tuberosity.

Table 5: Mean statistic of the measurements at 10 mm interval inferior to the tibial tuberosity.

	Anteromedial surface (mm)	Cortical thickness (mm)	Medullary space (mm)
10 mm	7.7	1.3	4.5
20 mm	6.6	1.5	2.7
30 mm	6.0	1.7	2.5

At 10 mm inferior to the tibial tuberosity the anteromedial border of the tibia averaged 7.7 ± 1.4 mm, and with a 95% confidence interval, the width of the anteromedial border ranged between 7.2 mm and 8.2 mm. Using the tibial and the cortical thickness the distance that the tip of the needle should be advanced can be described the needle should be advanced through the skin and fascia to the medial cortical layer where the tip of the needle should be advanced, on average, a further 1.3 ± 0.5 mm through the cortical layer. This would place tip of the needle in the medullary space, which averaged 4.5 ± 1.5 mm and ranged with a 95% confidence interval between 3.9 mm and 5.1 mm.

The technique to insert a needle in the proximal tibia outlined by King and Moses (1990) explains that the tip of the needle should be angled between 90 and 60 degrees inferiorly where the tip of the needle is pointed towards the foot and away from the epiphyseal plate [9]. Chokshi *et al*.(2010) recommends that the needle should be angled between 60 and 40 degrees inferiorly [4]. To prevent damage to the epiphyseal plate, the tip of the needle should be pointing towards the feet. The ideal location to puncture the proximal tibia ranges between 10 mm to 30 mm [4, 12] inferior to the tibial tuberosity, while Ellemunter *et al*.(1999) punctured the proximal tibia between 5mm and 10mm and did not observe any adverse side effects [7]. Table 6 illustrates the ratios between the mean distances between the different measurements. The ratio between the cortical thickness and the medullary space indicates that the most advantageous location to puncture the tibia where it provides the least resistance into the largest medullary space. The ratio between the cortical thickness and the width of the anteromedial surface, providing the least resistance through the cortical layer in relation to the most surface area available to perform the procedure. Boon *et al*. (2003) sought to find the ideal location to puncture the proximal tibia and found placing the tibial intraosseous needle 10 mm inferior to the tibial tuberosity was the preferred needle insertion site. Placement of the needle 20 mm inferior to the tibial tuberosity was hindered by thicker cortical bone layer and made the location undesirable.[3] The same conclusion made by Boon *et al*.(2003) was made in this sample population.

Table 6: Ratios of the mean distances between measurements.

	Cortical thickness/medullary space	Cortical thickness/anteromedial border	Medullary space/anteromedial border
10 mm	0.3	0.2	0.6
20 mm	0.6	0.2	0.4
30 mm	0.7	0.3	0.4

The ratio between the mean medullary space and the width of the anteromedial surface of the tibia at 10 mm inferior to the tibial tuberosity is much more desirable when comparing the medullary space to the anteromedial surface. The second-best ratio when comparing the medullary space in relation to the width of the anteromedial surface was found at 20 mm and 30 mm inferior to the tibial tuberosity. The mean medullary space in relation to the mean tibial thickness depicts the medullary space present within the tibial thickness and the larger medullary space within the tibia would be more desirable. In this sample 10 mm is preferred above 20 mm, and 30 mm, and would have resulted in the largest medullary space in comparison to the tibial thickness.

Limitations

This study has several limitations. As with any neonatal sample, it may be difficult to obtain donated cadavers. In addition, the 10 mm neat section were extremely fragile.

Conclusion

The ideal location to insert a tibial intraosseous needle at 90 degrees would be at 10 mm inferior to the tibial tuberosity. This location presents with the smallest cortical thickness (1.3 ± 0.5 mm), the largest medullary space (4.5 ± 1.5 mm) together with the largest width of the anteromedial surface (7.7 ± 1.4 mm) of the tibia when compared to the same measurements at 20 mm and 30 mm inferior to the tibial tuberosity.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data Availability

The quantitative and qualitative data used to support the findings of this study are included within the article, additional data may be requested from the corresponding author.

Author Contributions

All the authors had substantial contributions to the conception of the work, analysis, or interpretation of data for the work. This included drafting the work or revising it critically for important intellectual content. The final version of this document was approved by all authors before submission. Additionally, all the authors agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

DJ van Tonder: Protocol development, Data collection, Data analysis, Manuscript writing.

ML van Niekerk: Protocol development, Manuscript editing.

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Ethics approval

This research was part of a research project at the University of Pretoria, which was submitted to and approved (Ethics clearance: 447/2018) by the Ethics Committee at the University of Pretoria. We certify that the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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