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ARTICLE

Selection of the Preferred Puncture Site on Manual Intraosseous Infusion: Proximal Humerus or Proximal Tibia?

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Abstract

Aims/Background Establishing an intraosseous infusion (IO) pathway can rapidly open an urgent route of drug administration for critically ill patients. This study aims to assess different puncture sites on the efficacy of manual intraosseous infusion.

Methods Upon applying computed tomography (CT), we compared compact bone thickness and CT values at the same individual's proximal humerus and proximal tibia puncture sites (n = 40). Additionally, cadaveric experiments were used to compare the efficiency of manual puncture at two different insertion sites of the proximal humerus and proximal tibia in the same individual (n = 5).

Results The compact bone thickness and CT values at the proximal humerus were significantly lower than those at the proximal tibia. The cadaveric experiments further confirmed that the proximal humerus was superior to the proximal tibia as an insertion site, indicating the proximal humerus is a more suitable insertion site for manual bone marrow puncture needles.

Conclusion Selection of the puncture site markedly influences the effectiveness of manual intraosseous infusion, with the proximal humerus potentially offering better puncture efficacy than the proximal tibia.

Key words: manual intraosseous infusion; compact bone thickness; computed tomography; puncture site

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Introduction

Currently, in clinical practice, the routes of administration mainly include peripheral veins, central veins, endotracheal intubation, and intraosseous infusion (IO). Many hospitals prefer establishing peripheral venous access, and central venous access is performed when this puncture fails. However, for the treatment of critically ill patients, it is crucial to quickly establish infusion access, which is often difficult to achieve with peripheral intravenous infusion. For example, tissue collapse, peripheral circulation failure, and poor peripheral vein filling in patients with cardiac arrest or shock affect the success rate and duration of peripheral vein puncture (Paterson et al, 2022; Prottengeier et al, 2016). Healthcare professionals require expertise in the technique, and central venous infusion often requires a longer time to achieve, with a puncture success rate of 10–40% (Leidel et al, 2012),

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especially for patients who need uninterrupted compressions due to cardiac arrest, which is even more difficult (Lee et al, 2015; Phulli et al, 2021). Endotracheal catheterization is only applicable to some drugs. At the same time, the use of fluids is limited and might be associated with adverse conditions such as uneven drug distribution, airway irritation and injury, and drug blockage of the catheter (Wagner et al, 2018). Conversely, the establishment time of intraosseous infusion access is generally 10–30 s, and the success rate of puncture is as high as 82–92%, allowing the fluid or drug to reach the heart rapidly, which makes it a good alternative method (Wang et al, 2023).

In critically ill patients where peripheral venous access cannot be achieved, infusion is an expedient alternative for vascular access establishment. Anatomically, the medullary cavity comprises a reticular network of spongy venous sinusoids encompassing many highly differentiated, non-collapsible venous networks. These include the vertically oriented Haversian canals and the horizontally aligned Volkmann's canals, which are all interconnected with the systemic circulation. Even in instances of shock or substantial blood loss due to trauma, where peripheral veins are prone to collapse, the venous network within the medullary cavity, which is shielded by the skeletal structure, maintains its connection with the systemic circulation, ensuring a relatively stable blood flow (Phillips et al, 2010). When an intraosseous catheter is utilized for infusion, the infused substances traverse the medullary space through the vascular system into the central circulation. Preclinical and clinical studies have physiologically corroborated that the pharmacokinetics, pharmacodynamics, and dosages of drugs administered via the medullary cavity are analogous to those administered intravenously (Von Hoff et al, 2008; Smith et al, 2016). A clinical study involving 25 adult patients confirmed that there were no significant differences in the pharmacokinetic parameters, including the maximum drug concentration, the time to reach peak plasma concentration, and the area under the plasma concentration-time curve, between morphine sulfate administered through intravenous and intraosseous routes (Von Hoff et al, 2008).

Current intraosseous infusion devices are predominantly categorized into three types: electrically-powered devices (Harper and Incavo, 2024), percussive-driven devices (Olaussen and Williams, 2012), and manually-operated devices (Ohchi et al, 2015). In regions around the globe that are constrained by limited resources, the high cost of electrically and percussively driven intraosseous needles renders manual intraosseous puncture and infusion as an alternative. The manual intraosseous puncture needle is favoured for its low cost and independence from electrical power, making it exceptionally suitable for emergency situations under various extreme conditions (Ohchi et al, 2015). However, requiring substantial external force to penetrate the compact bone often leads to a relatively high failure rate for manual punctures. Thus, selecting an appropriate intraosseous puncture site is crucial for enhancing the success rate of manual marrow cavity infusion punctures. Potential sites for intraosseous infusion puncture include the proximal tibia, distal tibia, proximal humerus, sternum, and distal femur (Lairet et al, 2013; Muir et al, 2016). In clinical practice, the proximal tibia and proximal humerus are the most frequently chosen puncture sites (Reades et al, 2011). An ideal puncture site should have a thin cortical bone that is amenable to penetration, with discernible bony landmarks, and should be devoid of critical adjacent tissue structures to meet the exigencies of emergency settings. Compact bone is a type of tissue in the skeleton, accompanied by higher density and strength, and is mainly composed of dense bone cells and bone matrix (Nygren et al, 2014). The computed tomography (CT) value is a numerical value used in medical imaging to represent tissue density (Hu et al, 2024). Bone density is often assessed by measuring compact bone's thickness and CT values. Changes in the compact bone thickness and CT values will affect the localization and orientation of the bone marrow infusion needle, directly reflecting the difficulty and effectiveness of intraosseous infusion. Therefore, in this study, we measured and compared compact bone thickness and CT values at the puncture sites of the proximal humerus and proximal tibia in 40 patients. We hypothesize that the choice of the puncture site might affect the efficiency of the manual marrow puncture needle insertion. Cadaveric experiments were also used to validate the selection of the puncture site. These insights provide a basis for determining the optimal puncture site for manual intraosseous puncture needles and aid in further refining manual marrow cavity infusion puncture techniques.

Methods

Patient Condition

The patients enrolled in this study were admitted to the Nanchuan Hospital of Traditional Chinese Medicine, Chongqing. Before commencing the study, we obtained informed consent from all patients. We adhered strictly to the ethical principles outlined in the Declaration of Helsinki (as revised in 2013) and secured approval from the Ethics Committee of the Nanchuan Hospital of Traditional Chinese Medicine, Chongqing (Approval No.: 2024-NZYLL03-3).

Comparison of Compact Bone Thickness and CT Values

Individual attributes, such as stature, body mass, gender, age, level of physical exertion, and the presence of osteoporosis, can influence the density of compact bone and its CT values. Consequently, in this study, we performed a comparative analysis of each patient's compact bone thickness and CT values at two puncture sites: the proximal humerus and the proximal tibia. We conducted a retrospective review of the CT imaging database of patients at the Nanchuan Hospital of Traditional Chinese Medicine, Chongqing and identified 40 patients with available CT images for both the proximal humerus and proximal tibia.

Procedure of Intraosseous Puncture

The cadavers of 5 patients were used to compare the differences in IO efficiency caused by the selection of different puncture sites. The bone structure of each cadaver was not changed. To avoid differences in force, skill proficiency, and subjective assessment between different operators, all punctures were performed by the same operator, using the same manual intraosseous puncture needle to puncture both the proximal humerus and proximal tibia in each cadaver and to compare the success rate and time to successful puncture at two different sites. Successful puncture was defined as successful penetration of the bone cortex with a sudden sensation of emptying. However, puncture failure was defined as when the needle appeared bent, broken, or curled at the tip and was not successfully punctured within 3 minutes.

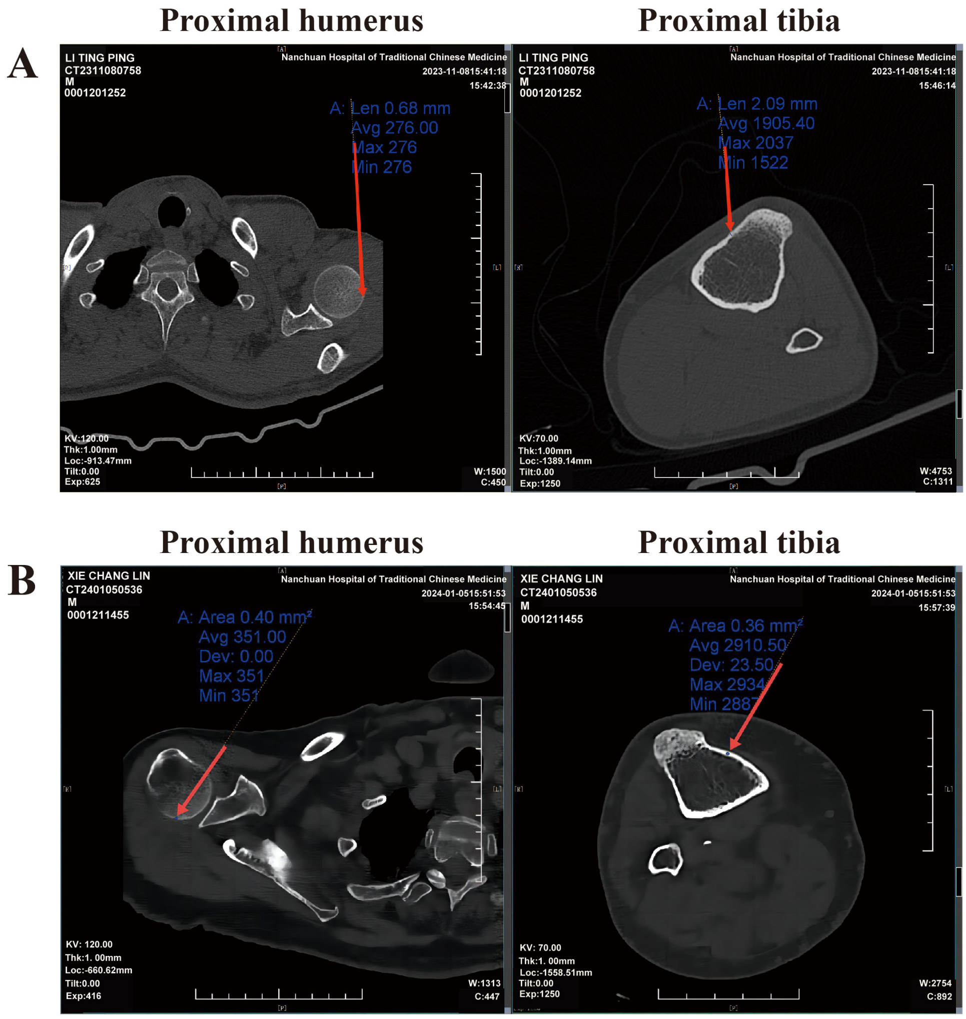

Fig. 1. Representative computed tomography (CT) images. (A,B) Comparison of compact bone thickness and CT values between the proximal humerus and the proximal tibia in two representative cases. The red arrows indicate the specific position to be observed on the proximal humerus and proximal tibia.

The proximal humerus was localized by placing the patient's hand on the abdomen with the arm close to the body. Subsequently, the operator marked the patient's anterior shoulder and palpated his or her greater tubercle of the humerus to determine the humeral puncture site. The intraosseous infusion needle's puncture angle was set at a 45-degree angle (similar to aiming at the patient's own opposite hip). For the puncture of the proximal tibia, we extended the patient's leg and found the tibial tuberosity. The insertion site was approximately 2 cm medial or at the midpoint between the medial and lateral sections along the flat portion of the anterior tibia based on the patient's anatomy. The operator inserted the needle at a 90-degree angle into the bone.

Statistical Analyses

The normality of the data was assessed to confirm that the data approximately followed a normal distribution for subsequent statistical analyses. Experimental data were expressed as mean ± standard error (SD). Group comparisons were conducted using *t*-tests, with statistical analyses and plotting performed using GraphPad Prism8 software (GraphPad Software, San Diego, CA, USA). Differences were considered statistically significant at $p < 0.05$.

Results

Comparison of Compact Bone Thickness and CT Values at Proximal Humerus and Proximal Tibia

In the present study, we measured the compact bone thickness and determined the CT values at different puncture sites of the proximal humerus and the proximal tibia in 40 patients (Figs. 1,2; Table 1). This patient group comprised 21 males and 19 females aged 15 to 97 years. The findings indicated that the average thickness of compact bone at the proximal humerus was 1.08 mm, while the average thickness of compact bone at the proximal tibia was 1.49 mm. With the exception of case 2, compact bone thickness at the proximal humerus was consistently lower than that at the proximal tibia in the remaining 39 patients. Specifically, the minimum and maximum thicknesses of the compact bone at the proximal humerus were 0.68 mm and 1.77 mm, respectively, whereas the corresponding values for the proximal tibia were 0.94 mm and 2.26 mm. Furthermore, the average CT value of the proximal humerus was 434 Hu, while the average CT value of the proximal tibia was 1764 Hu. The CT values of the compact bone at the proximal humerus were significantly lower than those at the proximal tibia in all 40 patients, with a range from 141 Hu to 926 Hu for the proximal humerus, and from 578 Hu to 2936 Hu for the proximal tibia. According to these observations, it was reasonable to hypothesize that the proximal humerus as an insertion site for manual intraosseous puncture needles is superior to the proximal tibia.

Puncture Practice Based on Two Different Insertion Sites

The results of cadaveric experiments based on different insertion sites showed that the greater tubercle of the humerus was the insertion site for manual bone marrow puncture operation. The one-time success rate of puncture was superior to that of the tuberosity of the tibia. Meanwhile, the time spent on a successful puncture at the greater tubercle of the humerus was significantly shorter than that of the tuberosity of the tibia. The average puncture time for the proximal humerus was 12.0 s. However, the proximal tibia took 26.6 s (Fig. 3).

Table 1. Comparison of compact bone thickness and computed tomography (CT) values at different puncture sites.

Sequence	Gender	Age	Compact bone thickness of proximal humerus	Compact bone CT values of proximal humerus	Compact bone thickness of proximal tibia	Compact bone CT values of proximal tibia
1	Male	87 years	0.69 mm	511 Hu	0.94 mm	1991 Hu
2	Female	61 years	1.77 mm	428 Hu	1.48 mm	1747 Hu
3	Female	41 years	0.90 mm	443 Hu	1.49 mm	2936 Hu
4	Female	28 years	1.24 mm	318 Hu	1.46 mm	2667 Hu
5	Male	35 years	1.20 mm	649 Hu	1.55 mm	2329 Hu
6	Male	80 years	1.56 mm	486 Hu	1.67 mm	1645 Hu
7	Male	51 years	1.01 mm	285 Hu	1.46 mm	1248 Hu
8	Female	56 years	1.03 mm	339 Hu	1.48 mm	2332 Hu
9	Male	76 years	0.70 mm	347 Hu	0.98 mm	1580 Hu
10	Female	57 years	1.04 mm	383 Hu	1.14 mm	2303 Hu
11	Male	53 years	0.96 mm	444 Hu	1.27 mm	2281 Hu
12	Female	90 years	1.39 mm	182 Hu	1.43 mm	1541 Hu
13	Male	71 years	0.98 mm	411 Hu	1.52 mm	1940 Hu
14	Male	54 years	1.67 mm	432 Hu	1.85 mm	2758 Hu
15	Male	97 years	0.72 mm	351 Hu	1.51 mm	2910 Hu
16	Female	72 years	1.32 mm	141 Hu	1.47 mm	1302 Hu
17	Female	70 years	0.97 mm	322 Hu	1.25 mm	1803 Hu
18	Female	43 years	0.91 mm	604 Hu	1.12 mm	2593 Hu
19	Male	51 years	0.71 mm	926 Hu	1.74 mm	2516 Hu
20	Female	56 years	1.02 mm	255 Hu	1.38 mm	2277 Hu
21	Female	71 years	0.99 mm	216 Hu	1.23 mm	990 Hu
22	Male	56 years	1.04 mm	716 Hu	2.26 mm	2711 Hu
23	Female	42 years	1.49 mm	268 Hu	1.67 mm	2790 Hu
24	Female	70 years	1.09 mm	286 Hu	1.77 mm	1334 Hu
25	Male	50 years	0.68 mm	630 Hu	2.09 mm	2131 Hu
26	Female	60 years	1.08 mm	496 Hu	1.35 mm	855 Hu
27	Male	35 years	1.22 mm	521 Hu	2.09 mm	1689 Hu
28	Male	51 years	1.11 mm	359 Hu	1.91 mm	1880 Hu
29	Female	33 years	1.27 mm	529 Hu	1.60 mm	1708 Hu
30	Female	69 years	1.00 mm	326 Hu	1.23 mm	925 Hu
31	Male	58 years	1.13 mm	575 Hu	1.83 mm	1454 Hu
32	Male	56 years	0.97 mm	533 Hu	1.15 mm	1518 Hu
33	Male	15 years	1.00 mm	326 Hu	1.35 mm	840 Hu
34	Female	51 years	1.03 mm	435 Hu	1.28 mm	1621 Hu
35	Female	75 years	1.05 mm	641 Hu	1.41 mm	829 Hu
36	Female	79 years	1.11 mm	615 Hu	1.21 mm	840 Hu
37	Male	86 years	1.05 mm	355 Hu	1.65 mm	578 Hu
38	Male	27 years	0.95 mm	208 Hu	1.30 mm	958 Hu
39	Male	51 years	0.94 mm	570 Hu	1.76 mm	1067 Hu
40	Male	72 years	1.14 mm	497 Hu	1.37 mm	1150 Hu

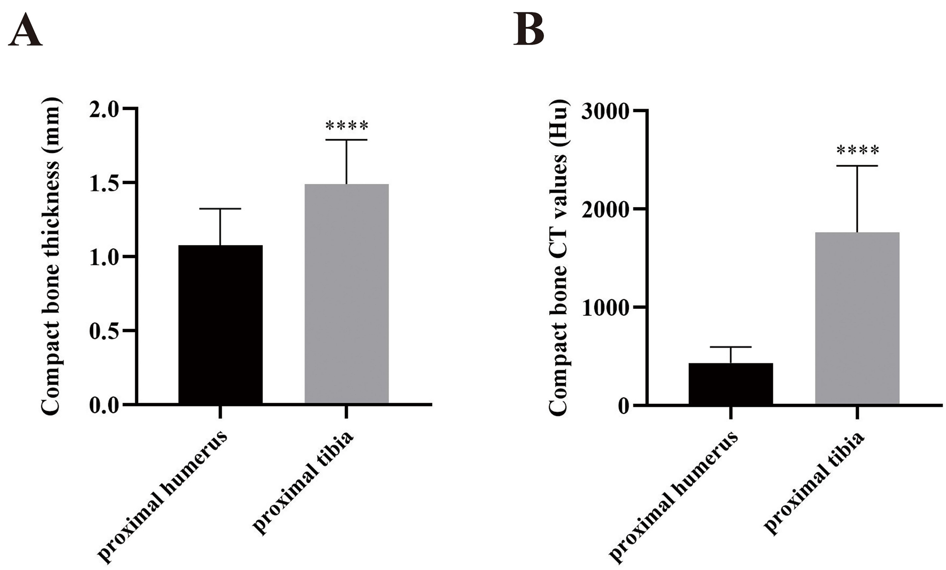

Fig. 2. Comparison of compact bone thickness and CT values at the proximal humerus and the proximal tibia. (A) Compact bone thickness. (B) CT values. The values represent the means ± SDs. **** represents significant differences at $p < 0.0001$ (n = 40).

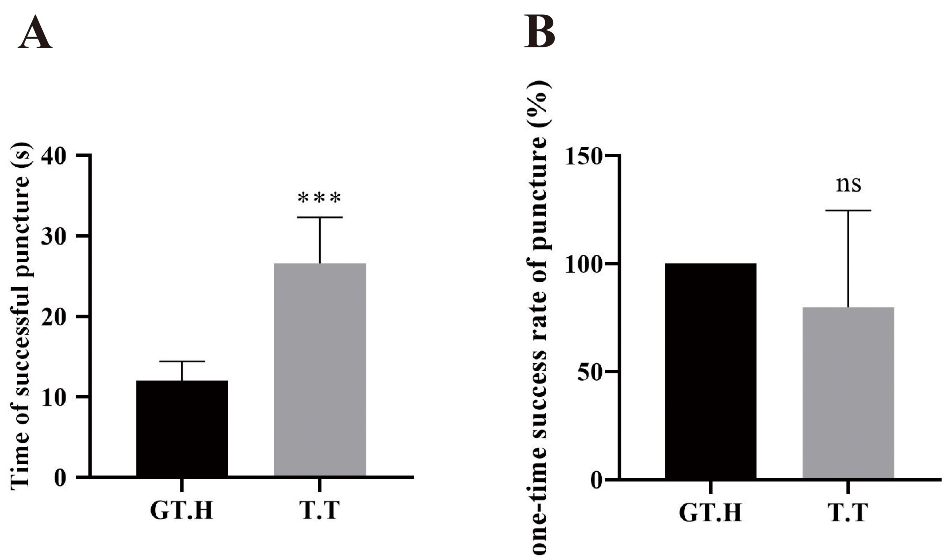

Fig. 3. Cadaveric experiments comparing the time of successful puncture and the one-time success rate of puncture at the proximal humerus and proximal tibia for manual bone marrow puncture needles. (A) Time of successful puncture. (B) One-time success rate of puncture. GT.H represents the greater tubercle of the humerus; T.T represents the tuberosity of the tibia. The values represent the means ± SDs. *** represents significant differences at $p < 0.001$; ns represents not significant differences.

Discussion

Rapidly establishing a vascular access route is paramount for timely medication administration to critically ill patients, serving as a prerequisite for fluid resuscitation (Wang et al, 2024). In China, most hospitals prioritize the establishment of peripheral venous access. However, in clinical emergencies, such as cardiac arrest, severe trauma, hemorrhage, severe dehydration, or burns, successfully establishing peripheral venous access is often challenging. Conversely, intraosseous infusion broadly applies to the resuscitation of critically ill patients in various scenarios where peripheral venous access cannot be established. Compared to traditional methods of peripheral venous catheterization, intraosseous infusion offers the advantages of being straightforward to perform (Itoh et al, 2019), time-efficient (Lewis and Wright, 2015), rapid in infusion rate (Johnson et al, 2016), high in success rate (Garabon et al, 2023), and low in complication incidence (Lee et al, 2022).

Selection of puncture sites for IO necessitates a multifactorial consideration, encompassing the patient's age, physical condition, available puncture equipment, anatomical structural characteristics, and the operator's proficiency in locating anatomical landmarks. The principle of choosing a puncture site should be one that is straightforward and does not impede emergency rescue measures such as cardiopulmonary resuscitation (Singh et al, 2016). An ideal IO puncture site should possess traits such as thinner cortical bone, amenability to penetration, flat surface, minimal overlying tissue, and discernible osseous landmarks. The proximal tibia, proximal humerus, and sternum meet the above conditions, but the sternum is unsuitable for cardiopulmonary resuscitation. Under normal circumstances, for pediatric patients, the preferred sites for intraosseous infusion are primarily the proximal or distal ends of the tibia, and the distal end of the femur (Pfeiffer et al, 2023). In adults, the preferred sites for medullary cavity puncture are often the tibia, humerus, or the manubrium of sternum (Singh et al, 2018). In clinical practice, the proximal tibia and humerus are frequently selected as sites for intraosseous puncture. Puncture needles for bone marrow infusion, actuated by an electric drill or an impact mechanism, can deliver sufficient pressure, which renders the proximal tibia a frequently chosen site for puncture. This preference is attributed to its identifiable bony landmarks and flat surface, which facilitate the process of operator localization. However, in resource-scarce rural areas, manual insertion of an intraosseous infusion needle relies predominantly on the skill of the operator. Thus, the judicious selection of the puncture site is crucial and directly influences the likelihood of successful puncture with a manual intraosseous needle. Our findings indicated that the compact bone thickness and CT values at the proximal humerus were markedly inferior to those at the proximal tibia, leading us to hypothesize that selecting the proximal humerus as the insertion site for manual intraosseous puncture might be more advantageous than the proximal tibia. In addition, cadaveric experiments based on different puncture sites demonstrated that the proximal humerus as the insertion site was superior to that of the proximal tibia. This result differs from the selection of puncture sites for most intraosseous infusion devices driven by electric drills or impact mechanisms. We included more possible influencing factors, such as blood vessel distribution and muscle coverage, to consider the selection of the manual bone marrow puncture sites. Vascular distribution was present in both the proximal humerus and proximal tibia, but neither had large vessels. The greater tubercle of humerus is covered by the deltoid muscle, which makes it difficult to find the accurate puncture sites but makes it easy to penetrate the joint cavity by mistake. The tuberosity of tibia is directly located under the skin without muscle coverage, making it easier to locate. However, due to the thicker and harder bone cortex at the proximal end of the tibia, greater force is often required for puncture, which not only increases the difficulty but also leads to repeated procedures and longer puncture times. The position of the proximal humerus is difficult to discern, but its thinner bone cortex makes the puncture practice easier and smoother. Therefore, for manual bone marrow puncture without mechanical external force support, the puncture efficiency of the proximal humerus as the insertion site is better than that of the proximal tibia.

In summary, intraosseous infusion, as an indispensable emergency fluid administration method, merits widespread adoption within the field of emergency medicine in China. However, exorbitant costs associated with electrically and percussively driven intraosseous infusion equipment and consumables have hindered its widespread dissemination. In regions where resources are scarce, use of manually operated bone marrow puncture needles, which offers a more favourable cost-effectiveness ratio, presents a pragmatic alternative. Our research provides invaluable insights for optimizing the selection of insertion sites for manual intraosseous infusion techniques, and the proximal humerus is a more suitable insertion site for manual bone marrow puncture procedure than the proximal tibia. Nonetheless, this study still had some limitations. The puncture personnel in this study had to be well-trained to master the positioning and angulation of puncture practice with the proximal humerus as the insertion site. In reality, unskilled personnel might be unable to perform the puncture due to positioning and angulation because the proximal humerus has a more muscular and soft-tissue surface than the proximal tibia. Therefore, when employing manual bone marrow puncture needles, it is imperative to meticulously consider the impact of operational dexterity and the precision of puncture localization on the procedure's success rate.

Conclusion

Selection of the puncture site remarkably influences the effectiveness of manual bone marrow puncture needles. Our research found that the puncture effect of the proximal humerus was superior to that of the proximal tibia, which optimizes the manual bone marrow cavity infusion puncture technique. This finding might have significant implications for clinical practice. When faced with patients requiring bone marrow aspiration, healthcare professionals could be more inclined to choose the proximal humerus as the puncture site to achieve superior infusion puncture results, thereby improving the efficiency and success rate of manual bone marrow aspiration.

Key Points

- The compact bone thickness and CT values at the proximal humerus are lower than those at the tibial proximal end.
- The successful puncture time of the proximal humerus as the insertion site was less than that of the proximal tibia for a manual bone marrow puncture procedure.
- The success rate of the proximal humerus as the insertion site was higher than that of the proximal tibia for manual bone marrow puncture procedure.
- Compared to the proximal tibia, the proximal humerus is a more suitable insertion site for manual bone marrow puncture procedure.

Availability of Data and Materials

The data used to support the findings of this study have been included in this article.

Author Contributions

LH conceived and designed this research. RH, ZYX, KQL, XHP, and SQT were responsible for data analysis and prepared figures. LH reviewed the manuscript editing. RH performed the writing of the original draft. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Informed consent was obtained from all patients for this study. Strictly abide by the Declaration of Helsinki (revised in 2013) and obtain the approval of the Ethics Committee of Nanchuan Hospital of Traditional Chinese Medicine (No. 2024-NZYLL03-3).

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Conflict of Interest

The authors declare no conflict of interest.

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