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ORIGINAL ARTICLE

Appropriate tourniquet pressure for peripherally inserted central catheter placement in the upper arm

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Abstract

Purpose A peripherally inserted central catheter (PICC) placement often requires ultrasound guidance. Previous studies using an adult blood pressure cuff have suggested that veins do not easily collapse at the tourniquet pressure from diastolic to systolic blood pressure. When inserting a PICC into the basilic vein of the upper arm, a narrow blood pressure cuff should be used as a tourniquet to avoid concealing the puncture site. The aim of this study was to determine the appropriate tourniquet pressure using a narrow cuff when inserting a PICC into the upper arm.

Methods We measured the upper arm's blood pressure of seven healthy participants using a pediatric cuff and applied pressure to the upper arm with the pediatric cuff at six levels: 0 mmHg (0), half of the diastolic pressure (*D*/2), diastolic pressure (*D*), pressure obtained by combining the systolic and diastolic pressures and dividing by two (*DS*), systolic pressure (*S*), and blood pressure as the pulse wave disappears ($S+\alpha$). An ultrasound probe compressed the basilic vein through the skin. The pressure at which the vein collapsed at each tourniquet pressure was examined.

Results The venous collapse pressure was higher when the tourniquet pressure was *D*, *DS*, or *S*.

Conclusion *D* to *S* is appropriate for PICC placement in the basilic vein of the upper arm in terms of venous collapse.

Keywords Peripherally inserted central catheter line insertion · Peripheral venous catheterizations · Tourniquets

Introduction

Peripherally inserted central venous catheters (PICCs) have advantages over conventional central venous catheters (CVCs), including no fatal complications such as pneumothoraxes and subclavian or vertebral artery injuries. PICCs can be used for various applications, such as chemotherapy, antibiotics, and intravenous nutrition [1].

The SIP protocol, which outlines the safe insertion of a PICC, recommends using ultrasound guidance for puncture [1]. The protocol does not specify whether a tourniquet should be applied during puncture. However, the tourniquet technique involves the constriction of blood vessels proximal to the peripheral intravenous catheter access site, which has been a standard practice for centuries. Commonly used tourniquets include disposable elastic tourniquets and blood pressure cuff tourniquets, with the latter being capable of showing the objective pressure level. In addition, some articles have suggested that using a tourniquet proximal to the puncture site expands the vein's diameter and facilitates successful PICC placement [2]. Moreover, our previous studies have suggested that veins in the cubital fossa do not easily collapse when compressed with an ultrasound probe when the upper arm is tied at diastolic to systolic blood pressures with an adult blood pressure cuff [3].

According to the SIP protocol, the basilic vein in the bicipital-humeral groove is preferentially selected for PICC placement [1]. Therefore, a narrow blood pressure cuff should be used as a tourniquet on the proximal upper arm for inserting a PICC into the basilic vein instead of an adult cuff, as the width of the adult cuff conceals the puncture site.

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Notably, the size of the blood pressure cuff may affect the measured blood pressure, with narrower cuffs resulting in higher measured blood pressures [4]. The appropriate tourniquet pressure under these circumstances is yet to be determined.

This study aimed to clarify the optimal tourniquet pressure for PICC insertion using a narrow blood pressure cuff to tie the proximal upper arm.

Methods

Research participants

This observational study was approved by the Nagoya City University Graduate School of Medical Sciences and Nagoya City University Hospital Institutional Review Board (Reference number 60-23-0086).

Participants were eligible for inclusion if they were healthy and aged between 18 and 64 years. Those who had hypertension, arrhythmias, or blood disorders and who refused to provide written informed consent were excluded.

Experimental procedure

Blood pressure measurement

The experiment was conducted from December 2023 to April 2024. An aneroid blood pressure monitor was connected to either an adult blood pressure cuff (non-invasive blood pressure adult cuff YP-713T, Nihon Kohden, Japan) or a pediatric cuff (non-invasive blood pressure pediatric cuff YP-711T, Nihon Kohden, Japan) extended with adhesive fasteners (Fig. 1).

The participants were requested to assume a supine or left lateral recumbent position in a room with a temperature set at 22 °C. The blood pressure in the left upper arm of each participant was measured twice using both the adult and pediatric cuffs.

Tourniquet pressure settings

Based on the average of the two blood pressure values measured using the pediatric cuff, we randomly applied pressure to the left upper arm with the pediatric cuff at six different levels as follows: 0 mmHg (0), the pressure at half the diastolic pressure (D/2), the diastolic pressure (D), the pressure obtained by combining the systolic and diastolic pressures and dividing by two (DS), the systolic pressure (S), and the pressure when the fingertip pulse wave measured using the pulse oximeter (bedside monitor PVM-4763 Nihon Kohden, Japan) disappeared ($S+\alpha$). We refer to these as the tourniquet pressures.

Probe pressure measurement

The probe pressure measurement was conducted as follows. First, the pressure-measuring device (IMADA Digital Force Gauge ZTA-50N, Japan) was attached to the probe of the ultrasound system (11L linear 11.0 MHz, LOGIQ E9, GE Healthcare Japan, Japan) via a holder (MP-PH0001-2, ALOKA, Japan). Second, the probe was placed on the electric stand (IMADA EMX-1000N, Japan). Third, the left upper arm was positioned under the stand, with tourniquet pressure applied, and the probe was moved downward at 50 mm per minute to compress the basilic vein through the skin. During compression, care was taken to apply pressure uniformly with the entire probe while ensuring that the vein and probe remained aligned over the humerus. Fourth, video recordings from the ultrasound device were initiated from the first detection of the basilic vein until the point of vein collapse. Finally, the pressure at which the vessel collapsed, defined as the moment when the upper and lower vessel walls came into contact, was measured using Force Recorder

Fig. 1 Devices used for blood pressure measurement and as tourniquets. Left: the original pediatric blood pressure cuff attached to an aneroid blood pressure monitor. Right: the pediatric cuff was extended with adhesive fasteners. The adult and pediatric cuffs can be interchanged through connections

Professional version 1.03 (Imada, Japan) pressure-measuring device (Fig. 2). We refer to this pressure as the probe pressure. The procedure was repeated for each applied tourniquet pressure.

Video analysis

Ultrasound videos were recorded using HD PVR Rocket model 1536 (Hauppauge Inc., Hauppauge, NY, USA) and converted from MP4 to AVI using Wondershare Uniconverter Version 15.0.2 (Wondershare, China). The diameter of the basilic vein in these videos was measured by two authors (MT and HS) using ImageJ2 1.54 h (Image Processing and Analysis in Java) (Fig. 2).

Sample size

Due to the novelty of this study, reference data are lacking. Therefore, the sample size was calculated using values from a previous study that observed venous collapse of the cubital fossa using an adult blood pressure cuff [3].

Since we were most interested in the difference between 0 and D, we used these pairs for our sample size calculations. The mean probe pressures and standard deviations were 2.8 N and 2.7 for 0, 11.5 N and 5.2 for D, respectively. The unit N represents Newton. Assuming an alpha error of 0.05 and a power of 0.80, the required sample size was six.

Outcomes

The primary outcome was the probe pressure for venous collapse when the upper arm was tied at each tourniquet pressure. The secondary outcomes were the diameter of the vein when it was not compressed by the probe with the upper arm tied at each tourniquet pressure and the Numeric Pain Rating Scale score of 0–10 on an 11-point scale at each tourniquet pressure. The diameter of the vessel was measured when the basilic vein was first visible on the video of the ultrasound image.

Statistical analysis

Wilcoxon rank-sum tests were performed for each of the seven pairs of 0 and the other five tourniquet pressures, $D/2$ and D, with S and $S + \alpha$. The statistical significance was set at 0.05. EZR (Saitama Medical Center, Jichi Medical University, Japan), a graphical user interface of R (R Foundation for Statistical Computing, Vienna, Austria), was used for the analysis [5].

Results

Participants

Four healthy males and three females aged 36–58 years were enrolled in the study. All participants provided written

Fig. 2 The experimental system. Left: the entire system. An ultrasound probe was attached to a pressure-measuring device, and they were installed on a motorized table. The upper arm was tied at each tourniquet pressure and was placed under the device, and the pressure-measuring device was moved downward to compress the basilic vein. The pressure at the time of the basilic vein collapses and ultrasound images were output to a personal computer. Right: the pressure and ultrasound image at the time of the basilic vein collapses output to a computer

informed consent and had no disease specified in the exclusion criteria.

The median systolic blood pressure is 110 (interquartile range 100–130) mmHg with the adult cuff and 139 (interquartile range 132–185) mmHg with pediatric cuff. The median diastolic blood pressure was 71 (60–77) mmHg and 94 (87–126) mmHg with the adult and pediatric cuff, respectively. The $S+\alpha$ was > 300 mmHg in all participants; however, it could not be recorded because the pressure on the blood pressure swung off.

Primary outcome

Figure 3 shows the interquartile range of the probe pressure measured with the upper arm tied at each tourniquet pressure. Probe pressures were significantly higher in the other tourniquet pressures than in 0, higher in D than $D/2$, and higher in S than in $S+\alpha$.

Secondary outcomes

The diameter of the basilic vein was significantly larger in all other tourniquet pressures than in 0, but no significant difference between $D/2$ and D, or S and $S+\alpha$ (Fig. 4). The Numeric Pain Rating Scale score did not differ in any of the seven pairs (Fig. 5).

Discussion

This is the first study to examine tourniquet pressure when the upper arm is tied with a narrow blood pressure cuff, assuming PICC insertion into the basilic vein. Blood pressure measurements were higher with pediatric narrow cuff compared to an adult cuff, consistent with the well-established relationship between cuff width and measured blood pressure [4].

The primary outcome demonstrated that if the tourniquet pressure was between D and S, the basilic vein was less likely to collapse. These findings suggest that tourniquet pressure between D to S is appropriate. Secondary outcome measures did not statistically influence the determination of appropriate tourniquet pressures.

In addition, when an artery is adjacent to the vein, it is crucial to distinguish between the two to prevent accidental puncture of the artery. In a previous study observing the veins of the elbow fossa [3], the significant difference between arterial pulse and collapsibility of arteries and veins disappeared when the tourniquet pressure reached or exceeded S, making it difficult to distinguish between arteries and adjacent veins. Thus, tourniquet pressures above S are generally recommended to be avoided. However, in this study, arterial collapsibility was not examined as no arteries were adjacent to the basilic vein.

This study is unique in that it focuses on venous collapse. A previous study [6] reported the dilation of the vein diameter; however, when a puncture needle is advanced into the internal jugular vein under ultrasound guidance, the vein collapses [7, 8].

This study had some limitations. This study assumed the placement of a PICC but did not actually puncture the vein. Appropriate puncture techniques need to be studied separately for clinical application.

Moreover, since only healthy adults were included in this study, the veins of patients with reduced venous return, such as those in shock, may be prone to collapse under appropriate pressures. Future studies with actual patients are needed.

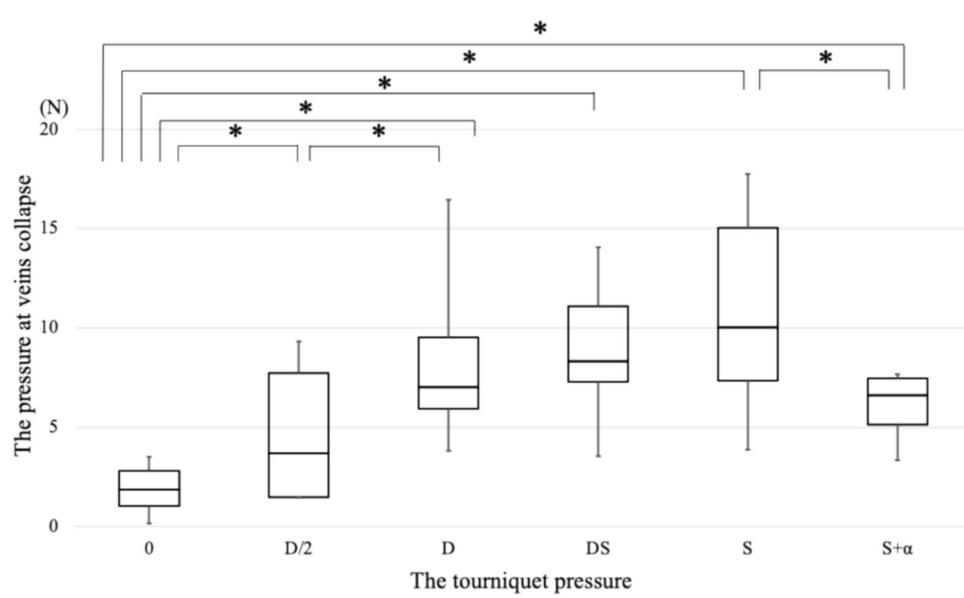

Fig. 3 Box plot of the probe pressure at the time of the basilic vein collapses at each tourniquet pressure. N is Newton. 0 is 0 mmHg, $D/2$ is half the diastolic pressure, D is the diastolic pressure, DS is the pressure obtained by combining the systolic and diastolic pressures and dividing by two, S is the systolic pressure, and $S+\alpha$ is the pressure when the fingertip pulse wave measured with the pulse oximeter disappeared. The box represents the 25th and 75th percentiles, the center line indicates the median, and the whiskers are the maximum and minimum values. $^{*}p < 0.05$

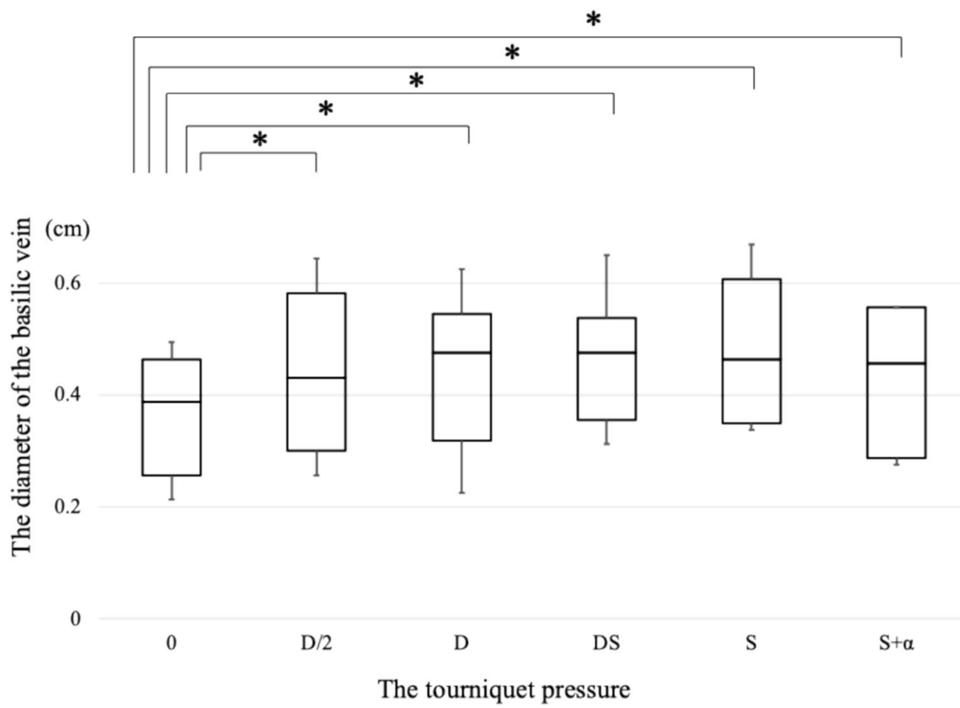

Fig. 4 Box plot of the diameter of the basilic vein at each tourniquet pressure. 0 is 0 mmHg, $D/2$ is half the diastolic pressure, D is the diastolic pressure, DS is the pressure obtained by combining the systolic and diastolic pressures and dividing by two, S is the systolic pressure, and $S+\alpha$ is the pressure when the fingertip pulse wave measured with the pulse oximeter disappeared. The box represents the 25th and 75th percentiles, the center line indicates the median, and the whiskers are the maximum and minimum values. $*p<0.05$

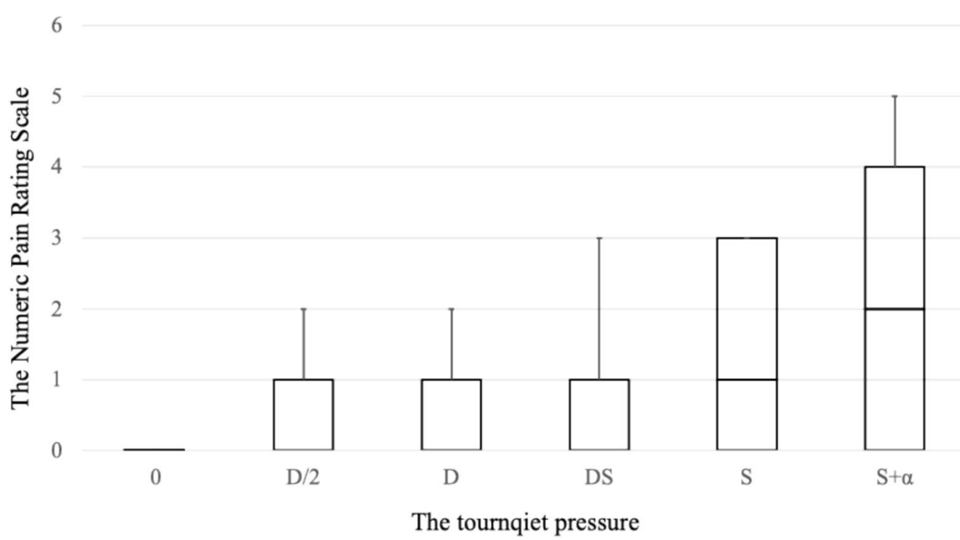

Fig. 5 Box plot of the numeric pain rating scale at each tourniquet pressure. 0 is 0 mmHg, $D/2$ is half the diastolic pressure, D is the diastolic pressure, DS is the pressure obtained by combining the systolic and diastolic pressures and dividing by two, S is the systolic pressure, and $S+\alpha$ is the pressure when the fingertip pulse wave measured with the pulse oximeter disappeared. The box represents the 25th and 75th percentiles, the center line indicates the median, and the whiskers are the maximum value. For all, the minimum value was 0

Our measurement method has some limitations. To place the basilic vein directly under the ultrasound probe, we needed to externally rotate the participant's forearm. This rotation could have caused pain and numbness by irritating the ulnar nerve. External rotation would not have been necessary if we had used a portable probe, but the force applied by the probe to the arm would not have been consistent. In our study, we focused on consistency.

When the tourniquet pressure was $S+\alpha$, the blood pressure value was higher than the measurement range. This could be attributed to the rubber sac not being positioned all the way around the arm. This positioning allowed pulse waves from the radial collateral artery of the forearm or other arteries on the radial side to be detected. To position the rubber sac directly under the basilic vein, it is important to develop a blood pressure cuff with a wider rubber sac. This is because the diameter of the rubber sac built into commercially available pediatric cuffs is smaller than the diameter of the cuff, making it potentially difficult to fit.

Conclusions

With a pediatric narrow blood pressure cuff, the appropriate tourniquet pressure for PICC insertion in the upper arm is the pressure from *D* to *S*. This is attributed to the fact that at this pressure, the vein is less likely to collapse.

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Author contributions Mami Tsubota: writing—original draft (lead); conceptualization (supporting); methodology (lead); investigation (lead); data analysis and interpretation (lead); Marechika Tsubouchi: investigation (supporting);conceptualization (supporting); writing—review and editing (supporting);Yuka Miyazaki, Kenji Iwai, Tetsu Miyoshi, Tsukasa Yajima, Ryohei Matsui, Yota Yamagishi, Asako Matsushima and Tomonori Hattori: writing—review and editing (supporting); Hiroshi Sasano: guarantor, conceptualization (lead); methodology (supporting); data analysis and interpretation (lead); writing—original draft (lead).

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Availability of data and materials The data for this study, though not available in a public repository, will be made available to the researchers upon reasonable request.

Declarations

Ethics approval and consent to participate The study protocol received approval from the Nagoya City University Graduate School of Medical Sciences and Nagoya City University Hospital Institutional Review Board (reference number 60-23-0086). Before participation, all participants were verbally informed about the study's procedures and written informed consent was obtained.

Conflict of interest All the authors have no conflict of interest.

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