

Scale Ultrasound-guided Radial Artery Cannulation in infant: A Randomized Controlled Trial

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Abstract

Background

Cannulation of the radial artery can be extremely challenging in infants. Scale ultrasound can provide accurate arterial location and guidance for operators. We hypothesized that scale ultrasound helps increase the initial success rate of radial artery cannulation in this population.

Method

This is a double-blinded, parallel-group trial prospective study. Seventy-six infants aged 0–3 months who needed arterial puncture after general anesthesia were randomly divided into two groups (1:1 ratio): the scale ultrasound group and the traditional ultrasound group. Patients in the traditional ultrasound group underwent conventional ultrasound-guided radial artery puncture, whereas radial artery puncture was guided by scale ultrasound in the scale ultrasound group. The primary endpoints were the success rate of the first attempt and the total success rate of arterial cannulation. The secondary endpoints were the time of ultrasound location, the time of the needle entering the radial artery, the time of successful cannulation, times of the arterial puncture and the incidence of vascular complications. Data analysis was performed with Minitab 18.0 (Minitab Inc., USA).

Main Results

The success rate of the first attempt and the total success rate of arterial cannulation were 92.1% (35/38) and 100% (38/38) in the scale ultrasound group and 50% (19/38) and 86.8% (33/38) in the traditional ultrasound group ($p < 0.005$), respectively. The median time to ultrasound location, needle entry into the radial artery and successful cannulation in the scale ultrasound group were significantly shorter than those in the traditional ultrasound group: 10 (8.0, 17.2) s, 15 (11.7, 20) s and 65 (53.8, 78.5) s vs 30 (26.5, 43.5) s, 35 (23, 51) s and 224.5 (123.5, 356) s ($p < 0.001$), respectively. The incidence of hematoma was higher in the traditional group ($p < 0.005$).

Conclusions

Scale ultrasound-guided radial arterial cannulation can significantly improved initial success rate and overall success rate, shorten puncture time in infant, compared with that achieved with the use of traditional ultrasound guidance.

Background

Radial artery cannulation is a common and important procedure performed in the operating room, emergency room, and intensive care unit to continuously monitor invasive arterial pressure and analyse arterial blood to guide the treatment of electrolyte disturbance and shock.¹ When large fluid shifts or blood losses are expected and frequent blood sampling is anticipated in the perioperative period, the radial artery is the most common site for arterial puncture because of its low complication rate.^{2–4}

Ultrasound guidance has become widespread for radial artery cannulation because it can increase the success rate, decrease the total procedural time, and decrease the incidence of cannulation complications.⁵⁻¹¹ However, the literature reports that ultrasound-guided radial artery cannulation is not faster than the traditional palpation technique.¹² Therefore, even with ultrasound guidance, arterial cannulation in children can be challenging.¹³ The success rate of puncture and the total procedural time with the ultrasound-guided technique are largely dependent on the experience and skill of the ultrasound operator. This may be attributable to the lack of an accurate correlation between the location of the artery on the ultrasound screen and the location of the artery on the ultrasound probe, which limits the advantages of ultrasound-guided radial artery cannulation. We adopted a new technique involving a corresponding scale that was marked both on the ultrasonic probe and the ultrasonic screen. We hypothesized that an accurate correlation between the location of the artery on the scale ultrasound screen and the scale ultrasound probe can provide an accurate arterial location and improved guidance for the operator, thereby increasing the success rate of radial artery puncture and shortening puncture time in infants. The primary endpoints were the success rate of the first attempt and the total success rate of arterial cannulation. The secondary endpoints were the time of ultrasound location, the time of the needle entering the radial artery, and the time of successful cannulation, times of the arterial puncture and the incidence of vascular complications.

Methods

Ethics

Ethical approval for this study (Ethical Committee N° #287/2019) was obtained from the Institutional Review Board of Children's Hospital of Chongqing Medical University, Chongqing City, China (Chairperson Professor Zhongyi-Lu) on 10 January 2020. The registry Uniform Resource Locator of this study is chictr.org.cn (ChiCTR2000029353, registration date: 26 January 2020). Written informed consent was obtained from parents or guardians as part of the standard requirement for the procedure. The study started in May 2020 and ended in December 2020.

Confirming the Scale on the Ultrasonic Probe and Ultrasonic Screen

To confirm the suitability of the ultrasonic probe and ultrasonic screen for infants under the age of 3 months, we measured the inner diameters of 140 radial arteries in infants ranging from 0 to 3 months. The mean inner diameter of the arteries was 1.61 ± 0.34 mm, the mean age was 20 ± 14.5 days, and the mean weight was 3.6 ± 1.39 kg. Based on our statistical results, the inner diameters of the radial and ulnar arteries reported in other literature,¹⁴ and our pre-experiment, we confirmed the scale on the ultrasonic probe as follows (Figure 1): the total length of the scale on the ultrasonic probe was 2 cm, each scale was spaced 2 mm apart, the midpoint of the ultrasonic probe was the zero point, and the scale lines were evenly distributed to the left and right sides in the direction of ultrasonic probe length detection. The left side was marked as -5, -4, -3, -2, and -1; the midpoint of the ultrasonic probe was marked 0; and the right side was marked as 1, 2, 3, 4, and 5. The length, style, direction and spacing of the scale on the

ultrasonic screen correspond to the ultrasonic probe, and the actual distance between the two scales on the ultrasonic screen was determined by the actual magnification of the ultrasound. Ultrasound with scale on the ultrasonic probe and screen was defined as the scale ultrasound.

Sample Size Calculation

The sample size of this study was calculated by a previous study, in which the first-attempt success rate of radial artery cannulation in the traditional ultrasound group was 60%.¹⁴ Based on our preliminary experiment, the first-attempt success of radial artery cannulation in the scale ultrasound group was 90%. Therefore, we wanted to improve the first-attempt success of radial artery cannulation from 60% to 90%, considering the rate of withdrawal (15%), and the final sample size was identified as 38 for each group.

Arterial Catheterization Procedure

Infants scheduled for elective surgical procedures who required continuous arterial pressure monitoring were enrolled in this study between May and December 2020 at the Children's Hospital of Chongqing, China. The inclusion criteria were as follows: age range of 0 to 3 months and American Society of Anaesthesiologists (ASA) grades I to IV. The exclusion criteria were as follows: an abnormal Allen's test, malformation in the forearm arteries, erosions near the radial artery puncture in the skin, cardiogenic or haemorrhagic shock, and arterial puncture received within 1 month before the commencement of the trial. Patients were randomly assigned to the scale ultrasound group or the traditional ultrasound group using a computer-generated random number (1:1 ratio). Group allocation was enclosed in sealed envelopes. At the time of enrolment, the research assistant opened the envelopes, and the researchers enrolled the patient. Residents who were blinded to the group allocation recorded the data. A flow diagram shows the patient selection process (Figure 2).

Blood pressure, electrocardiogram, and peripheral oxygen saturation were monitored in the operating room. After general anaesthesia was induced, radial artery cannulation was performed. Radial artery catheterization was performed by residents who had experience with at least 50 cases of arterial puncture. The left hand for radial artery puncture was preferred.

The wrist was padded up with a small roll, and the palm of the hand was taped to keep the hand positioned in dorsiflexion. Aseptic preparation of the skin was performed around the insertion site. The aseptic preparation included disinfecting the insertion site with povidone iodine solution and wrapping the ultrasonic probe with disposable sterile covers, sterile gloves, and operating towels. An ultrasound device (GE venue40; GE, Boston, Massachusetts, USA) with a linear transducer (5 to 13 MHz) and a depth of 2 cm was applied to localize the radial artery. A standard 22-gauge catheter (BRAUN Company, Melsungen, Germany) percutaneously punctured the radial artery using the short-axis, out-of-plane procedure. Patients in the traditional ultrasound group underwent conventional ultrasound-guided radial artery puncture, whereas radial artery puncture was guided by scale ultrasound in the scale ultrasound group. The probe with scale was adjusted such that the radial artery was positioned between any two scales on the ultrasound image (Figure 3 a1, the radial artery is positioned on the ultrasound screen

between scale 0 and 1). Subsequently, we chose the position on the ultrasonic probe corresponding to the ultrasonic screen as the arterial puncture point (Figure 3 a2, the arterial puncture point was positioned between scale 0 and 1 on the ultrasonic probe). Between the two scales on the probe, the needle was inserted into the skin at an angle of $30^{\circ}\sim 45^{\circ}$. Because the scale ultrasound screen and the scale ultrasound probe can provide an accurate arterial location and improved guidance for the operator, we can easily find the location of the needle tip, which was directed towards the arterial lumen when the needle entered the subcutaneous region. Then, the probe was moved proximally 2–3 mm to the radial artery again. According to the scale on the ultrasound screen and the probe, we could easily determine the position and direction of the radial artery (Figure 3 b1 and b2, the arterial was positioned between scale 0 and 1, closer to scale 0). After adjusting the direction of the tip of the needle and inserting the needle into the radial artery (Figure 3 c1 and c2), the needle appeared as a hyperechoic dot on the screen and could be distinguished from the nearby tissue. According to the scale on the ultrasound screen and the probe, adjusting the angle and direction of the incoming needle made the needle come forward to the centre of the radial artery. While keeping the needle immobile, the probe was moved proximally a few millimetres until the image of the needle tip disappeared, the radial artery was repositioned according to the scale on the ultrasound image, and the needle was inserted towards the corresponding scale on the ultrasound probe until the image of its tip reappeared. This procedure was repeated until the needle was inserted fully into the radial artery (Figure 3 d1 and d2). Then, the stylet was removed, and a pressure sensor was connected to monitor blood pressure.

Data Acquisition

The patient's general condition was recorded by residents who were blinded to the group allocation, including the patient's age, weight, sex, ASA physical status, heart rate, mean arterial pressure, depth from the skin to the radial artery, and inner diameter of the radial artery. The primary endpoints were the success rate of the first attempt and the total success rate of arterial cannulation. The secondary endpoints were the time of ultrasound location, the time of the needle entering the radial artery, and the time of successful cannulation, times of the arterial puncture and the incidence of vascular complications. Successful puncture was defined as the arterial waveform being verified after arterial cannulation. Puncture failure was defined as more than three attempts to achieve cannulation of the radial artery or any attempts requiring more than 10 min. The time of ultrasound location was defined as the time from the placement of the ultrasound probe on the skin to the insertion of the needle into the skin. The time of the needle entering the radial artery was defined as the time the skin was punctured by the needle to the time the needle entered the radial artery. The time of successful cannulation was defined as the time between when the needle was inserted into the skin and the time the arterial waveform could be verified after arterial cannulation. Complications were recorded, including bleeding and hematoma formation.

Data Analysis

Minitab 18.0 (Minitab Inc., USA) was used for statistical analysis. Descriptive statistics of normally distributed variables were calculated using counts and means \pm SD. Descriptive statistics of nonnormally distributed variables were calculated using the median with the interquartile range. Normality of the data was evaluated by the Anderson–Darling test. If the data exhibited a normal distribution, a two-tailed Student's t-test was used to measure the difference between groups; otherwise, a nonparametric test was used. The chi-square test was used for other categorical data, such as sex and ASA status. Fisher's exact test was used to determine the successful puncture rate and the incidence of adverse reactions, and the differences in incidence and associated 95% CI were calculated. Statistical significance was defined as a P-value less than 0.05.

Results

Demographic Characteristics

A total of 76 patients were enrolled in the randomized study between May and December 2020. There were 38 patients in the scale ultrasound group and the traditional ultrasound group. The patients' baseline characteristics are shown in Table 1. There were no differences in the age, weight, sex, ASA physical status, heart rate, mean arterial pressure, depth from the skin to the radial artery, or inner diameter of the radial artery of the patients (Table 1).

Primary Endpoints

The success rate of the first attempt and the total success rate of arterial cannulation were 92.1% (35/38) and 100% (38/38) in the scale ultrasound group and 50% (19/38) and 86.8% (33/38) in the traditional ultrasound group ($p < 0.005$), respectively (Table 2). In the traditional ultrasound group, five patients experienced failure. One of them was a 31-day-old premature boy with a weight of 3.7 kg who was hospitalized due to intestinal obstruction and who was to undergo an exploratory laparotomy. The inner diameter of her radial artery was 0.9 mm, and the depth from the skin to the radial artery was 1.1 mm. The puncture time for this boy was more than 10 min, and two puncture attempts were required. Another patient was a 53-day-old boy with a weight of 5.5 kg who was hospitalized due to retroperitoneal tumour and who was to undergo an exploratory laparotomy. The inner diameter of her radial artery was 1.2 mm, and the depth from the skin to the radial artery was 2.5 mm. The puncture time for this boy was more than 10 min, and three puncture attempts were required. The other patients were 8-, 30- and 73-day-old boys, with weights of 4.2 kg, 3.5 kg and 4 kg; inner diameters of the radial artery of 1.5 mm, 1.2 mm and 1.7 mm; and depths from the skin to the radial artery of 4.7 mm, 2.5 mm and 4.2 mm, respectively. Four attempts to cannulate the radial artery were made before succeeding in each patient.

Secondary Endpoints

The median time of ultrasound location, needle entry into the radial artery and successful cannulation in the scale ultrasound group were significantly shorter than those in the traditional ultrasound group: 10 (8.0, 17.2) s, 15 (11.7, 20) s and 65 (53.8, 78.5) s vs 30 (26.5, 43.5) s, 35 (23, 51) s and 224.5 (123.5, 356)

s ($p < 0.001$, Table 2), respectively. The incidence of hematoma was higher in the traditional group (0 of 38 [0%] vs. 5 of 38 [13.2%], $P = 0.016$; Table 2). The times of the arterial puncture in the scale ultrasound group was significantly lower than that in the traditional ultrasound group ($P = 0.001$; Table 2). There was no significant between-group difference in the incidence of bleeding. (2 of 38 [5.3%] vs. 4 of 38 [10.5%], $P = 0.393$; Table 2).

Discussion

Arterial puncture in infants is particularly difficult due to low blood pressure, small arterial diameter, loose blood vessels and weak pulses. Ultrasound guidance is beneficial to improve the success rate of infant arterial puncture. However it is very difficult to find the needle tip in ultrasound images in infants, which is also a key factor in determining the puncture success rate and puncture time. An accurate correlation between the location of the artery on the scale ultrasound screen and the scale ultrasound probe can provide accurate arterial location and guidance for the operator. In clinical applications, we found that scale ultrasound can help operators find the tip of the needle more quickly and improve the success rate of punctures in infants, at the same time, scale ultrasound does not require additional invasive procedures and does not increase the risk of infant artery puncture. In our study, the success rate of the first attempt and the total success rate of arterial cannulation in the scale group were higher than those in the traditional ultrasound group, and higher than those in other studies.^{5, 6, 9, 14, 15}

In the scale ultrasound group, the time of ultrasound location, the time of the needle entering the radial artery and the time of successful cannulation were approximately 20 s, 18 s and 144 s shorter, respectively, than in the traditional ultrasound group. Scale ultrasound can improve the efficiency of arterial puncture and shorten the puncture time, which may be related to the rapid positioning and accurate guidance provided by scale ultrasound.

The dynamic needle-tip positioning technique has been shown to significantly improve the clinically relevant aspects of radial artery catheterization.^{8, 11} The first step involves localization of the puncture point for radial artery puncture. Compared with traditional ultrasound, when the ultrasonic probe is placed on the wrist, scale ultrasound can be used to more quickly and accurately locate the projection point on the skin surface of the midpoint of the radial artery, and then quickly determine the puncture point, without repeatedly moving the ultrasonic probe to find the puncture point, similar to traditional ultrasound. The second step involves puncture of the radial artery. Since scale ultrasound has a one-to-one corresponding scale for the direction on the ultrasonic probe and ultrasonic screen, we can easily and conveniently determine the direction of needle-tip puncture according to the position of the needle entering the radial artery after the skin. The final step involves the insertion of the cannula into the radial artery. We recommend that the needle with the catheter be inserted into the radial artery as far as possible under the guidance of ultrasound, and that the needle core be removed; then, the cannula can be inserted into the radial artery.⁸ Scale ultrasound helps one properly adjust the angulation of the needle and maintain information on the position of the needle tip in real time. Thus, scale ultrasound can effectively shorten the time of arterial puncture and improve the success rate of the first attempt. Song et al.

compared the short-axis/out-of-plane and long-axis/in-plane techniques for ultrasound-guided arterial cannulation in children and found that there was no significant difference in the total time of successful cannulation between the two techniques.¹³ Regardless of the type of puncture chosen, long axis or short axis, scale ultrasound is an effective auxiliary for arterial puncture. Arterial puncture is a challenge, even for adults. A meta-analysis found that ultrasound use significantly increased the first-attempt success rate and reduced the number of attempts in adults.¹⁶ The principle of scale ultrasound also applies to ultrasound-guided arterial puncture in adults. We speculate that the application of scale ultrasound can help shorten the time of arterial puncture and improve the success rate of arterial puncture in other age groups. Of course, this conjecture needs further experimental confirmation. Nonetheless, this study provides a new idea for ultrasound-guided arterial puncture.

For the teaching of arterial puncture in children, beginners who are inexperienced with ultrasound-guided downward arterial puncture often take a long time to find the tips and have a long duration, a low success rate, and an increased risk of patient injury. Scale ultrasound is an effective teaching tool that can help them to find the tip of the needle more quickly and to trace the artery's ultrasound image more easily. It can not only improve the learning enthusiasm of beginners, but also minimize the risk of patient injury. Therefore, it can also be promoted as a teaching tool.

A limitation of this study was that we did not include children older than 3 months because we believe that children under 3 months of age undergoing artery puncture represent the most difficult form of this procedure. If scale ultrasound is beneficial to patients of this age undergoing arterial puncture, then scale ultrasound should be conducive to patients of other ages undergoing artery puncture; this hypothesis needs further experimental confirmation. Of course, when scale ultrasound is used for arterial puncture for patients of other ages, the scale label might need to change; notably, this study provides a new idea for ultrasound-guided arterial puncture. Additionally, only residents who had performed at least 50 arterial punctures participated in this study. Therefore, we cannot assess how much the success rate was influenced by different levels of expertise.

Conclusions

Thin blood vessels and narrow wrist of infants greatly increase the difficulty of radial arterial cannulation. Scale ultrasound can provide accurate arterial location and guidance for operators, can significantly improved initial success rate and overall success rate, shorten puncture time in infant, compared with that achieved with the use of traditional ultrasound guidance. It can alleviate the suffering of infant, greatly improve the quality of medical care, and is worthy of wide recommendation.

Abbreviations

ASA
American Society of Anaesthesiologists

Declarations

Ethics approval and consent to participate: Ethical approval for this study (Ethical Committee N° #287/2019) was obtained from the Institutional Review Board of Children's Hospital of Chongqing Medical University, Chongqing City, China (Chairperson Professor Zhongyi-Lu) on 10 January 2020.

Consent for publication: Consent for publication was obtained from parents or guardians.

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests

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Authors' contributions: FY designed and performed the study and contributed significantly to the analysis and manuscript preparation; SL searched the scientific literature and collected the data; HC participated in the design, resolved differences, helped to revise the manuscript; RJ provided technical or material support; XW helped the communication with the legal guardian of infant and signed relevant information; WW helped participated in the design, provided technical or material support; YS helped the technical material support; LL performed statistical analyses and technical support; HG helped the technical or material support; MY contributed to the conception and quality assessment of the study; QW collected the data and resolved differences and performed statistical analyses; ST designed the study and provided administrative, technical, or material support. The authors have read and approved the final manuscript.

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Tables

Table 1. Basic Characteristics of All Patients Enrolled in the Study

Parameter	Scale ultrasound group (n=38)	Traditional ultrasound group (n=38)	P value
Age (days)	33[4.8]58.7	34[7.5]56	0.728
Weight (kg)	3.2 ± 1.1	3.5 ± 1.1	0.313
Gender (M/F)	24/14	23/15	1.000
ASA[1]/[2]/[3]	6/27 /4/1	2/31/4/1	0.517
Heart rate (beats•min ⁻¹)	139 ± 21	145 ± 16	0.163
Mean arterial pressure (mmHg)	41 ± 7	44 ± 11	0.093
Depth from skin to artery (mm)	2.4 ± 0.7	2.7 ± 1.0	0.107
Inner diameter of artery (mm)	1.2 ± 0.2	1.2 ± 0.3	0.145

Data are presented as mean ± SD deviation or the median with the interquartile range. Gender, ASA physical status expressed as numbers.

Abbreviations: M, male; F, female; ASA: American Society of Anesthesiologists' physical;

Table 2: Comparison of Success Rate of Cannula Insertion, Location Time, Puncture Time, Arterial Puncture Times and Complications between the Two Groups

Parameter	Scale ultrasound group (n=38)	Traditional ultrasound group (n=38)	P value	OR (95% CI)
Success rate at first attempt	35 [92.1%]	19 [50%]	0.001	0.421 [0.240 to 0.60]
Total success rate	38 [100%]	33 [86.8%]	0.016	0.131 [0.024 to 0.239]
Time of ultrasound location	10 [8.0, 17.2]	30 [26.5, 43.5]	0.001	20 [16 to 24]
Time of the needle enters the artery	15 [11.7, 20]	35 [23, 51]	0.001	18 [12 to 26]
Time of successful cannulation	65 [53.8, 78.5]	224.5 [123.5, 356]	0.001	144 [81 to 196]
Times of the arterial puncture 1/2/3/4	35/2/1/0	19/12/4/3	0.001	
Bleeding	2 [5.3%]	4 [10.5%]	0.393	-0.053 [-0.173 to 0.068]
Hematoma	0 [0%]	5 [13.2%]	0.016	-0.131 [-0.239 to -0.024]

Values are presented as the median with the interquartile range or number (%).

Abbreviations: CI, confidence interval; OR, odds ratio.

Figures

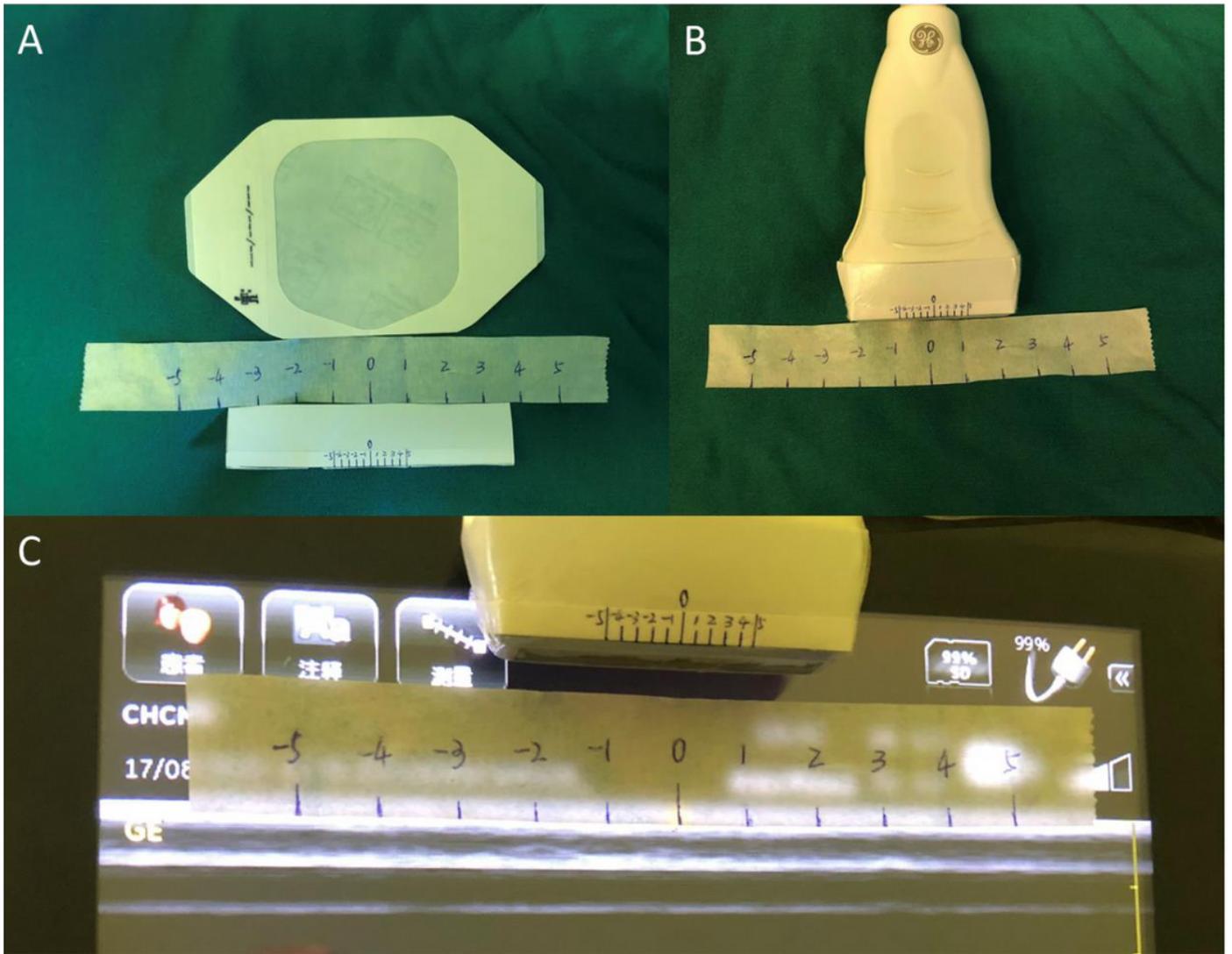


Figure 1

The scale on the ultrasonic probe corresponds to the ultrasonic screen. The total length of the scale on the ultrasonic probe was 2 cm, each scale is spaced 2mm apart, the midpoint of the ultrasonic probe is the zero point, and the scale lines are evenly distributed to the left and right sides in the direction of ultrasonic probe length detection. The left side is marked as -5, -4, -3, -2, -1, the midpoint of the ultrasonic probe marked 0, and the right side is marked as 1, 2, 3, 4, 5. The length, style, direction and spacing of the scale on the ultrasonic screen correspond to the ultrasonic probe, and the actual distance between the two scales on the ultrasonic screen is determined by the actual magnification of the ultrasound. (A) The scale on the ultrasonic probe and ultrasonic screen, and the sterile 3M membrane. (B) The scale was added on the ultrasound probe. Sterile 3M membrane was used to cover the ultrasound probe. (C) The scale on the ultrasonic probe corresponds to the ultrasonic screen.

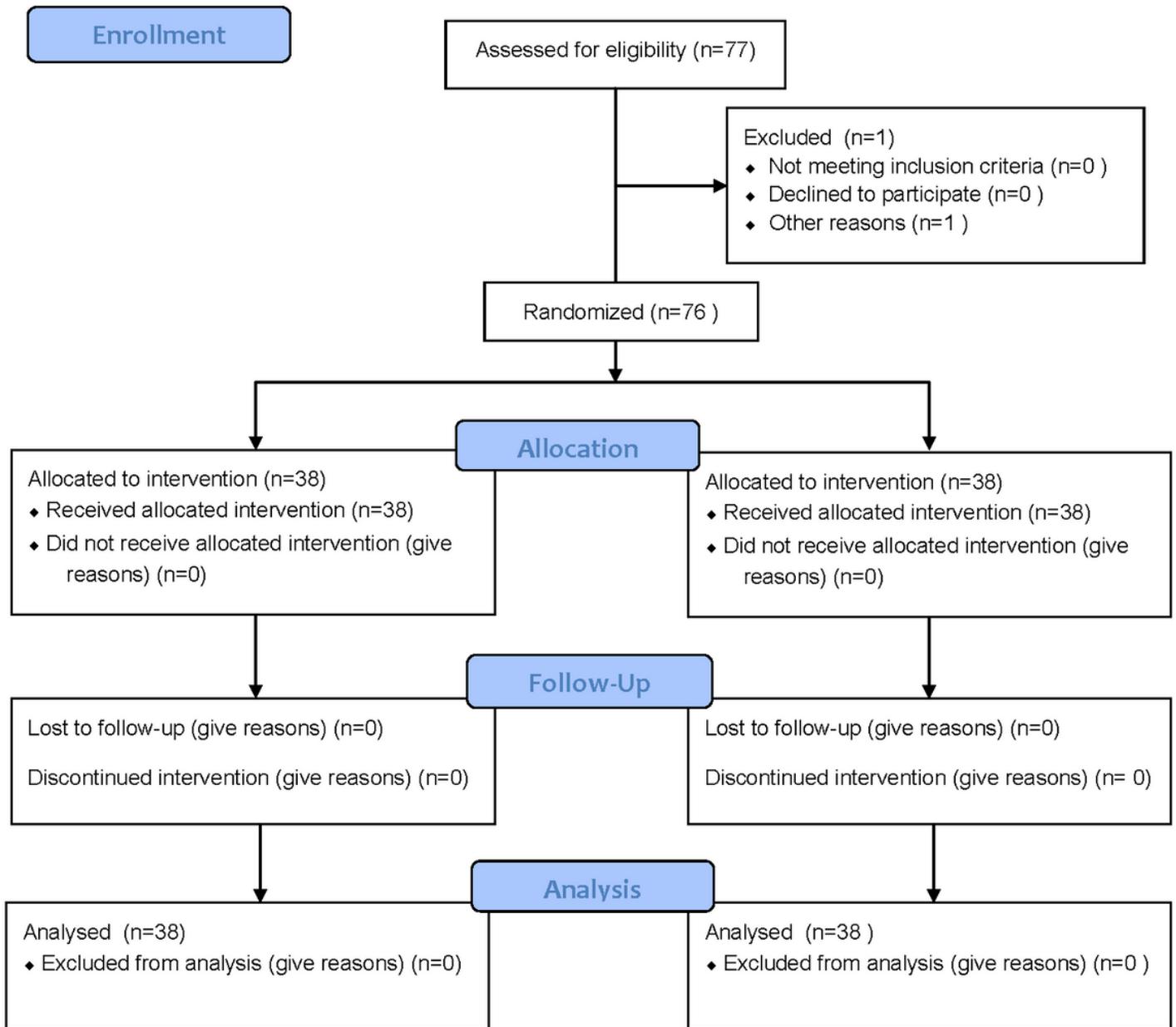


Figure 2

A flow diagram according to the consolidated standards of randomized controlled trial.

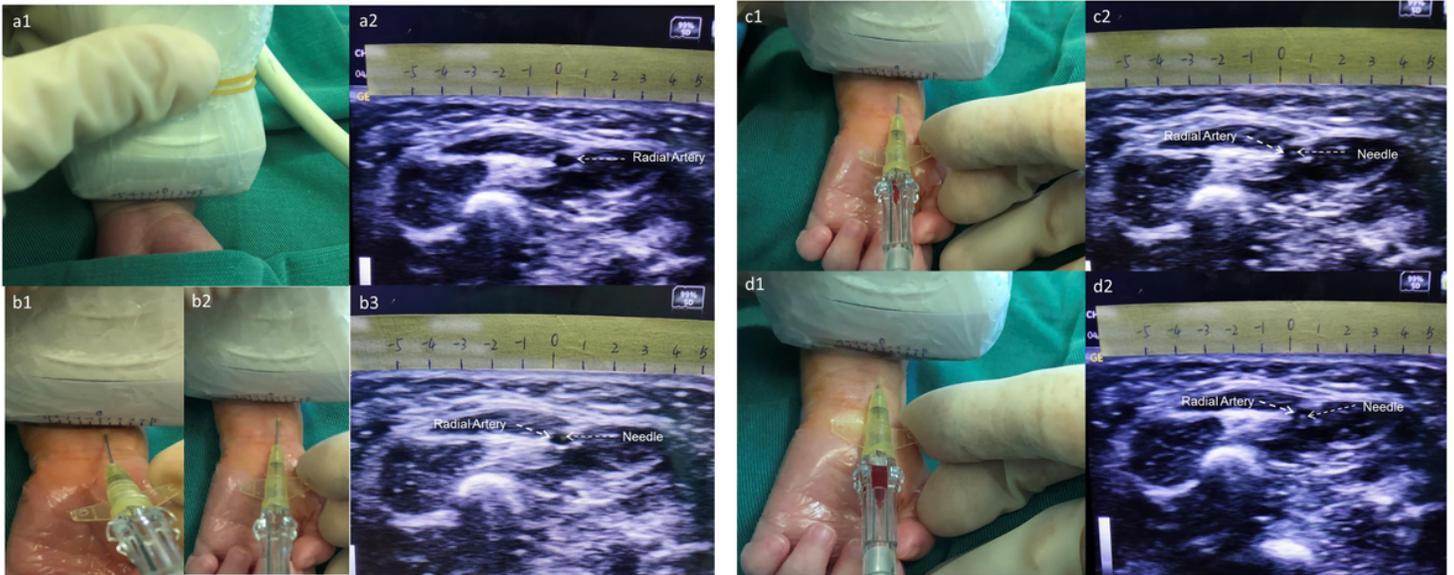


Figure 3

Puncture steps and corresponding ultrasound images. a1, Ultrasonic probe with a sterile cover and sterile coupling agent is placed in the short axis above the distal end of the selected radial artery, moving the probe the radial artery was positioned between any two scales on the ultrasound image. a2, Ultrasonic images corresponding to a1 (The radial artery is positioned on the ultrasound screen between scale 0 and 1). b1, chose the position on the ultrasonic probe corresponding to the ultrasonic screen as the arterial puncture point.(the arterial puncture point was positioned between 0 to 1 on the ultrasonic probe). b2, the probe was moved proximally 2–3 mm, according to the scale on the ultrasound screen and the probe we can easily determine the position and direction of the radial artery. b3, Ultrasonic images corresponding to b2. c1, The needle entered into the radial artery. c2, Ultrasonic images corresponding to c1. d1, the needle was inserted fully into the radial artery. d2, Ultrasonic images corresponding to d1.