ANESTHESIOLOGY

Acoustic Shadowing Facilitates Ultrasound-guided Radial Artery Cannulation in Young Children

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ABSTRACT

Background: Arterial cannulation in young children can be challenging. Ultrasound guidance using focused acoustic shadowing may be suitable for guiding radial artery puncture in young children. The present research tested the hypothesis that ultrasound guidance using focused acoustic shadowing helps increase the success rate of radial artery cannulation in this population.

Methods: In a double-blinded, parallel-group trial, 79 young children undergoing surgery under general anesthesia were randomly assigned to two groups (1:1 ratio): the traditional ultrasound group and the novel ultrasound group. Young children in the traditional group underwent conventional ultrasound-guided radial artery puncture, whereas those in the novel ultrasound group underwent radial artery puncture guided by acoustic shadowing ultrasound with double developing lines. All radial artery punctures were performed using the short-axis out-of-plane approach. The primary endpoint was the success rate of cannulation at the first attempt. The secondary endpoints included cannulation failure rate, ultrasound location time, and puncture time.

Results: The success rate of cannulation at the first attempt in the novel ultrasound group (35 of 39 [90%]) was significantly higher than that in the traditional ultrasound group (24 of 40 [60%]; difference: 30% [95% CI, 12 to 48%], $P = 0.002$). None of the patients in the ultrasound with acoustic shadowing group experienced failure of radial artery puncture and cannulation. The ultrasound location time and puncture time in the ultrasound acoustic shadowing group were significantly lower than that in the traditional ultrasound group (location time: median [interquartile range]: 6 [5, 8] *vs.* 18 [15, 21] s; puncture time: 24 [15, 41] *vs.* 40 [23, 56] s).

Conclusions: Acoustic shadowing *via* the use of double developing lines significantly improved the success rate of radial artery puncture in young children, compared with that achieved with the use of traditional ultrasound guidance.

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Arterial cannulation in infants and young children is particularly challenging
- Ultrasound guidance facilitates arterial cannulation, but the success rate is still highly dependent on operator experience and skills

What This Article Tells Us That Is New

- This prospective, randomized trial in young children shows that a modified ultrasound-guided approach, using focused acoustic shadowing, results in a higher success rate and shorter cannulation time of the radial artery when compared with traditional ultrasound guidance

Radial artery cannulation is commonly performed in the operating room, intensive care unit, and emergency room for invasive arterial pressure monitoring and arterial blood gas analysis to guide the treatment of shock and electrolyte disturbance.[1] Radial artery cannulation is particularly challenging in young children owing to the small caliber of the artery. Multiple attempts attributable to failure of cannulation may lead to an arterial hematoma.[2] Radial artery cannulation is traditionally performed using anatomic landmarks and palpation of the radial pulse. The successful use of this technique requires experience, especially in young children. Some studies have shown that ultrasound-guided cannulation is more successful than the palpation technique.[3,4] In a randomized trial, critically ill children who required radial artery puncture for invasive monitoring were randomly divided into an ultrasound-guided group and a palpation technique group. The success rate of radial artery cannulation at the first attempt in the ultrasound-guided group was significantly greater than that in the palpation technique group.[4] However, the ultrasound-guided radial artery cannulation was not faster than the traditional palpation technique.[4] Although the success rate of puncture has improved with the ultrasound-guided technique, the success rate is largely dependent on the ultrasound operator's experience and skills. This is largely attributable to the two-dimensional nature of ultrasound imaging. The operator requires good hand–eye coordination, technical skills, and some experience to overcome this shortcoming of ultrasound, which limits the advantages of

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ultrasound-guided vascular puncture, especially for operators with insufficient experience.[5–7] We adopted a new technique involving the use of double developing lines on the ultrasound probe to ameliorate this shortcoming of ultrasound. We hypothesized that ultrasound-guided vascular puncture with double developing lines could help increase the success rate of radial artery puncture in young children. The primary endpoint was the success rate of cannulation in the first attempt. The secondary endpoints were ultrasound localization time and puncture time.

Materials and Methods

This study was approved by the institutional review board of the Beijing You'An Hospital, Capital Medical University, Beijing, China. Written informed consent was obtained from the guardians of all participants before their enrollment. This trial was registered in the Chinese Clinical Trial Register (ChiCTR-INR-17011421; principal investigator: Zhefeng Quan; date of registration: May 17, 2017; http://www.chictr.org.cn/). This manuscript adheres to the reporting requirements specified in the Consolidated Standards of Reporting Trials guidelines.

Sample Size Calculation

The sample size of this study was based on the preliminary experiment, in which the success rate of the first puncture in the group with double developing lines was 85%, whereas the success rate in the control group was 55%. The test level α was taken as 0.05, Z0.05/2 = 1.96. The power level, $1 - \beta$, was taken as 0.8. Therefore, a sample size of 34 was required in each group. Taking into account the rate of withdrawal (~15%), the final sample size for each group was identified as 40, necessitating a total study population of 80 patients.

Radial Artery Puncture

Young children undergoing elective surgical procedures that required continuous arterial pressure monitoring between May 12, 2017 and January 16, 2019 at the Beijing You'an Hospital and Beijing Friendship Hospital of Capital Medical University were eligible for inclusion. The inclusion criteria were: age range, 4 to 24 months; weight range, 4 to 10 kg; and American Society of Anesthesiologists grades I to IV. The exclusion criteria were: negative Allen's test; abnormal ulnar artery; infection near the radial artery puncture site; congenital heart disease; hemorrhagic or cardiogenic shock; patients who had undergone arterial puncture within the 1-month period immediately preceding the commencement of the trial. The young children who were enrolled were randomly assigned to the traditional ultrasound or ultrasound with double developing lines group (hereafter referred to as the novel ultrasound group) by sealed envelope (1:1 ratio) randomization assignment; envelopes prepared by statisticians were opened by the research assistant at the time of enrollment. All patients were enrolled by the researchers, and data were recorded by residents who were blinded to the group allocation.

In the operating room, electrocardiogram, noninvasive arterial blood pressure, and peripheral oxygen saturation were monitored with IntelliVue MP70 (Philips, The Netherlands). After induction of general anesthesia, the left hand was chosen for radial artery puncture. All punctures were performed by attendants who had performed more than 50 ultrasound-guided punctures. Data were recorded by residents who were blinded to the group allocation.

The forearm was raised by 3 cm and the wrist was extended over a roll, with the hand positioned in dorsiflexion. Aseptic preparation of the skin around the site of insertion (2 cm proximal to the wrist joint on the palmar side of the forearm) was undertaken with povidone iodine. The ultrasonic probe with disposable sterile covers was connected to an ultrasound system (MINDRAY Medical International Company, China). The probe with a frequency of 11 MHz and a depth of 1 cm was adjusted to optimize the image. All radial artery punctures were performed using the short-axis out-of-plane procedure. Young children in the traditional group underwent conventional ultrasound-guided radial artery puncture, whereas radial artery puncture in the novel group was guided by ultrasound with double developing lines.

The metal-containing strand taken from x-ray–detectable surgical gauze was bound parallelly (interval: 2 mm) to the ultrasound probe and positioned perpendicular to the long axis of the probe. An ultrasonic couplant and sterile 3M membrane were applied over the ultrasound probe to fix the double developing lines (fig. 1). The probe was adjusted such that the radial artery was positioned between these shadows on the ultrasound image. These two lines produced two low-density shadows in the ultrasound image. Subsequently, the needle was inserted at an angle of 30° to the skin, between the two lines on the probe, and along the edge of the probe. The needle tip, which appeared as a white spot on the ultrasound screen, was directed toward the arterial lumen while remaining between the two small acoustic shadows on the screen (fig. 2) Once the needle had entered the radial artery, the angle of the needle was reduced from 30° to 15° and the needle was slowly pushed forward for 1 to 2 mm. The dynamic positions of the double developing lines, the needle tip, and the radial artery on the ultrasound screen during puncture are shown in figure 3. After retracting the needle a few millimeters into the cannula, the latter was fully introduced into the radial artery. Then the cannula was fixed and the blood pressure was monitored with a pressure transducer.

Observation Indices

The patient's general condition was recorded along with the measurement of the depth between the skin and the radial artery and the internal diameter of the radial artery. The primary endpoint was the success rate of cannulation at first attempt. The secondary endpoints were ultrasound localization

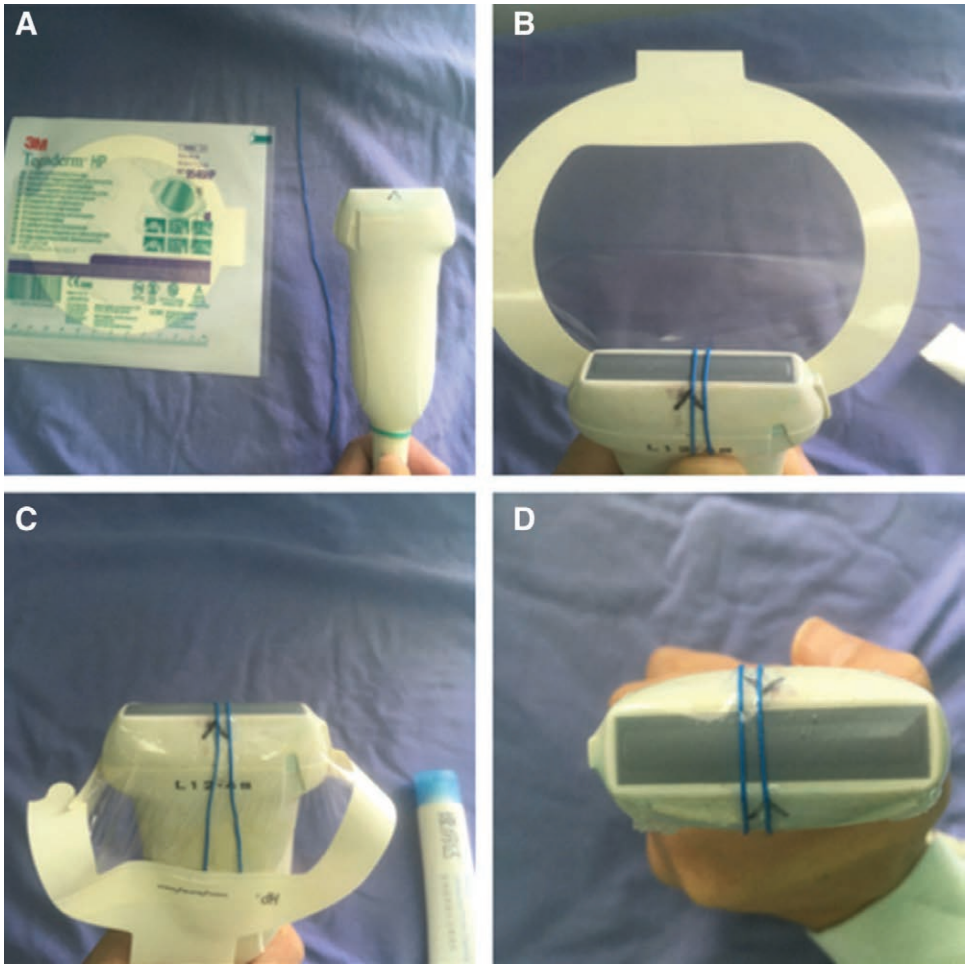

Fig. 1. The double developing lines on the ultrasound probe. Double parallel developing lines were bound to the midpoint of the ultrasound probe perpendicular to its long axis. (*A*) The ultrasound probe, the developing line, and the sterile 3M membrane. (*B*) The developing line was bound as double parallel lines on the midpoint of the ultrasound probe perpendicular to its long axis. The ultrasonic couplant was added on the ultrasound probe. (*C*) Sterile 3M membrane was used to cover the ultrasound probe. (*D*) The front view of double developing lines on the ultrasound probe.

time and puncture time. Successful puncture was considered to be a smooth insertion of the cannula into the radial artery. Failure of cannulation of the radial artery after three or more attempts was defined as puncture failure. Ultrasound localization time was defined as the time from the placement of the ultrasound probe over the skin to the penetration of the puncture needle into the skin. Puncture time was defined as the time that elapsed between the penetration of the puncture needle into the skin to the time of its penetration into the radial artery. The incidence of vascular complications, including bleeding and hematoma formation, was recorded.

Data Analysis

Statistical analysis was undertaken using Minitab 16.0 (Minitab Inc., USA). Data pertaining to normally distributed variables are presented as mean ± SD. Nonnormally distributed variables are presented as the median with the interquartile range. The Anderson–Darling test was used to test normality of data. The *t* test (two-sample, independent, unpaired) or Mann–Whitney *U* test was used to assess between-group differences. Data on the successful puncture rate and the incidence of adverse reactions were analyzed using Fisher exact test. Differences in incidence and the associated 95% CI were calculated. Two-tailed tests were used; *P* values less than 0.05 were considered indicative of statistically significant difference.

Results

Eighty young children were randomly divided into two groups. However, one patient dropped out because of cancellation of the surgery. The remaining 79 young children completed the study. There were no missing data. There

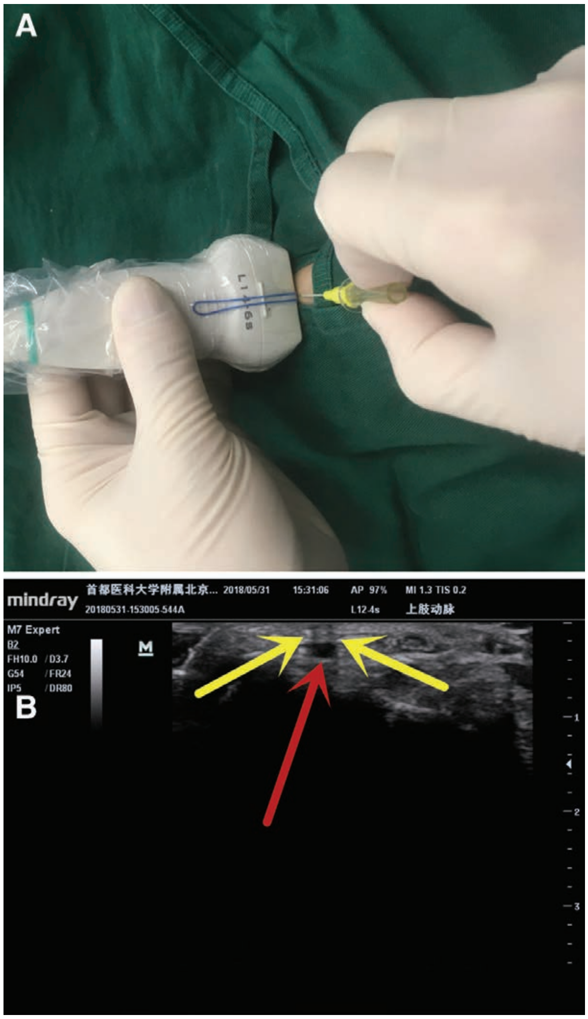

Fig. 2. The positions of ultrasound probe with double developing lines and needle. (*A*) Positions of the ultrasound probe with double developing lines and the needle. (*B*) Ultrasonic image of the radial artery (*red arrow*) and the low-density shadow of the double developing lines (*yellow arrow*).

were 40 patients in the traditional ultrasound group and 39 patients in the novel ultrasound group. The baseline characteristics of patients are shown in table 1. There were no significant between-group differences with regard to the depth of the radial artery from the skin (2 ± 0 *vs.* 2 ± 0 mm, P = 0.732) or the inner diameter of the radial artery (2 ± 0 *vs.* 2 ± 0 mm, P = 0.947; table 1). In the novel ultrasound group, the success rate of cannulation at the first attempt (35 of 39 [90%]) was significantly greater than that in the traditional ultrasound group (24 of 40 [60%]; difference: 30% [95% CI, 12% to 48%], P = 0.002). Four patients experienced failure of cannula insertion in the traditional ultrasound group, as against none in the novel ultrasound group. The median ultrasonic location time in the novel ultrasound group was 6 s (interquartile range: 5, 8), compared with 18 s (interquartile range: 15, 21) in the traditional ultrasound group (P < 0.001). The median puncture time was 24 (interquartile range: 15, 41) s in the novel ultrasound group and 40 (interquartile range: 23, 56) s in the traditional ultrasound group (P = 0.012; table 2). Moreover, 12 of 40 (30%) young children in the traditional group and 4 of 39 (10%) young children in the novel group experienced bleeding at the puncture point (difference: 20% [95% CI, 2.65 to 36.84%], P = 0.029). There was no significant between-group difference with regard to the incidence of hematoma (7 of 40 [18%] *vs.* 3 of 39 [8%], P = 0.190; table 3).

Discussion

In the novel ultrasound group, the success rate of radial artery puncture at first attempt as well as the location time and puncture time were approximately 30% higher and 13 and 16 s shorter, respectively, than in the traditional ultrasound group. This may be related to the fast positioning and accurate guidance provided by ultrasound with double developing lines.

The procedure of radial artery puncture can be divided into three steps.[8] The first step involves localization of the puncture point, whereas the second step involves the puncture of the artery. The final step involves the insertion of the cannula into the radial artery. The double developing lines technique helps locate the projection point of the midpoint of the radial artery on the skin surface to enable quick and accurate determination of the puncture point. During the puncture, the direction of the needle is maintained at the same level as that of the developing lines of the ultrasound probe, which helps guide the puncture. This novel ultrasound technique isolates the contact between the ultrasound probe and the skin through the double developing lines on the ultrasound probe, thereby displaying a vertical low-density shadow in the ultrasound image. Thus, the needle can be positioned accurately prior to skin penetration, which indirectly compensates for the shortcomings of the method guided by two-dimensional ultrasound.

Nakayama *et al.* found that the success rate of ultrasound-guided radial artery puncture is highest when the depth of the radial artery is 2 to 4 mm.[9] The proximity to the skin does not improve the success rate of ultrasound-guided puncture. This finding is related to the shortcomings of two-dimensional ultrasound because the puncture needle can only be discovered by the two-dimensional ultrasound probe when it reaches a certain depth.[9]

The dynamic needle-tip positioning technique has been shown to significantly improve the clinically relevant aspects of radial artery catheterization.[10,11] However, this technique relies on the experience and skill of the ultrasound operator.

In this study, the radial artery was placed between the two low-density shadows of double developing lines by adjusting the ultrasound probe. Then the puncture needle was placed at the intersection of the double developing lines and the skin, which is the projection point of the radial

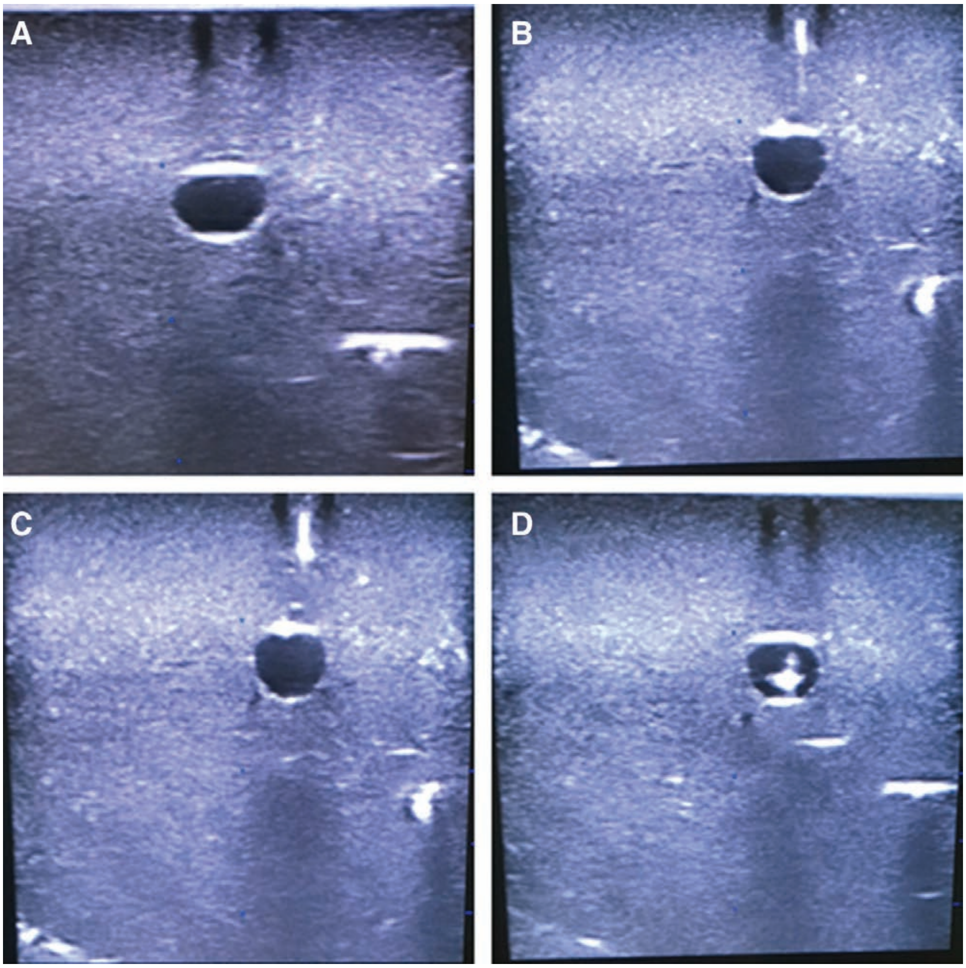

Fig. 3. The process of radial artery puncture guided by acoustic shadowing ultrasound with double developing lines. The developing lines are made of metal-containing strands taken from x-ray–detectable surgical gauze. The *silver line* indicates the needle tip. The *black circle* indicates the radial artery. (*A*) The needle tip is about to pierce the skin; (*B*) the needle tip has pierced the skin but has not reached the vessel; (*C*) the needle tip pierces deeper; (*D*) the needle tip is in the vessel.

Table 1. Baseline Characteristics of the Study Subjects

Parameter	Traditional Ultrasound Group (n = 40)	Novel Ultrasound Group (n = 39)	*P* Value
Age, months	9 ± 3	10 ± 2	0.876
Weight, kg	7 ± 1	7 ± 1	0.285
Height, cm	67 ± 4	66 ± 5	0.209
ASA Grade II, n	3 (7%)	2 (5%)	0.872
ASA Grade III, n	25 (63%)	27 (69%)	
ASA Grade IV, n	12 (30%)	10 (26%)	
Male, n	17 (43%)	18 (46%)	0.744
Mean arterial pressure, mmHg	55 ± 6	53 ± 5	0.109
Depth from skin to artery, mm	2 ± 0	2 ± 0	0.732
Inner diameter of artery, mm	2 ± 0	2 ± 0	0.947

Data presented as mean ± SD or as frequency and percentage (%). ASA, American Society of Anesthesiologists.

Table 2. Comparison of Success Rate of Cannula Insertion at First Attempt, Failure Rate, Location Time, and Puncture Time between the Two Groups

Parameter	Traditional Ultrasound Group (n = 40)	Novel Ultrasound Group (n = 39)	*P* Value	Proportion Difference (95% CI)
Success rate of cannula insertion at first attempt	24 (60%)	35 (90%)	0.002	−0.297 (−0.477 to −0.118)
Failure rate of cannula insertion	4 (10%)	0	0.359	0.1 (0.007 to 0.193)
Ultrasound location time, s	18 (15, 21)	6 (5, 8)	< 0.001	
Puncture time, s	40 (23, 56)	24 (15, 41)	0.012	

Data presented as number and percentage (%) or median (interquartile range).

Table 3. Vascular Complications during Radial Artery Puncture

Parameter	Traditional Ultrasound Group (n = 40)	Novel Ultrasound Group (n = 39)	*P* Value	Proportion Difference (95% CI)
Bleeding, n (%)	12 (30%)	4 (10.3%)	0.029	0.197 (0.027 to 0.368)
Hematoma, n (%)	7 (17.5%)	3 (7.7 %)	0.190	0.098 (−0.046 to 0.243)

artery on the surface. This technique greatly shortens the ultrasonic location time. After the localization of the puncture point, when the needle stays at the same level as the double developing lines, it is easy to obtain the image of the vertical direction of the needle, which helps shorten the puncture time. Another advantage of this method is that the operator can focus on the two low-density shadows instead of staring at the full screen of the ultrasound monitor. When the needle stays at the same level as that of the double developing lines, the needle is between the two low-density shadows. An experienced operator can visualize the needle tip indenting the anterior wall of the radial artery within this two-line shadow. For inexperienced operators or those who are unable to visualize the position of the needle tip, the insertion of the needle into the artery can be ascertained by observing blood return in the needle hub.

In this study, the incidence of bleeding in the novel ultrasound group was lower than that in the traditional ultrasound group, which is likely attributable to the higher initial success rate of the puncture in the former group. There were no significant between-group differences with regard to the incidence of other adverse reactions.

A limitation of this study was that it was not a double-blind trial. During the puncture, the operator needs to simultaneously pay attention to the ultrasound image to ensure the needle stays at the same level as the double developing lines. Additionally, only skilled attendants who have carried out more than 50 ultrasound-guided punctures participated in this study. Therefore, we cannot determine how much the level of expertise influenced the success rate. Given the special anatomic characteristics of young children, it may not be appropriate to generalize these data to other populations, which is another potential limitation of this study.

Conclusions

The double developing lines technique not only helps shorten the ultrasound location and puncture time, but also improves the success rate of radial artery puncture at the first attempt in young children, and thereby facilitates radial artery cannulation in young children.

Research Support

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Competing Interests

The authors declare no competing interests.

Reproducible Science

Full protocol available at: 15811190059@126.com. Raw data available at: 15811190059@126.com.

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