ANESTHESIOLOGY

Comparison of Single-operator Laser-assisted Ultrasound-guided Radial Arterial Cannulation in Young Children with Traditional Ultrasound Guidance: A Randomized Clinical Trial

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ABSTRACT

Background: Radial artery cannulation in young children is challenging. A single-operator laser-assisted ultrasound-guidance system was invented to project the path of the target artery on the skin surface. The hypothesis was that this system would improve the first-attempt success rate of radial arterial cannulation in young pediatric patients relative to traditional ultrasound guidance.

Methods: This single-center, prospective, parallel-group, randomized controlled study enrolled pediatric patients (n = 80, age less than 2 yr) requiring radial artery cannulation during general anesthesia. The participants were randomized into the traditional ultrasound-guidance group or the single-operator laser-assisted ultrasound-guidance group. After inducing general anesthesia, ultrasound-guided radial artery cannulation was performed by two experienced operators. The primary outcome was the first-attempt success rate. The secondary outcomes included the procedure time to success within the first attempt, midmost rate of first attempt, first needle-tip position, and average number of adjustments.

Results: In total, 80 children were included in the analysis. The first-attempt success rate in the single-operator laser-assisted ultrasound-guidance group (36 of 40 [90%]) was significantly greater than that in the traditional ultrasound-guidance group (28 of 40 [70%]; absolute difference, 20% [95% CI, 2.3% to 36.6%]; P = 0.025). The median procedure time to success within the first attempt was shorter in the single-operator laser-assisted ultrasound-guidance group compared with the traditional ultrasound-guidance group (31 s [27, 36 s] *vs.* 46 s [39, 52 s]; $P < 0.001$). The incidence of hematoma in the single-operator laser-assisted ultrasound-guidance group (1 of 40, 3%) was significantly lower than that in the traditional ultrasound-guidance group (11 of 40, 28%; $P = 0.002$). Regarding the initial needle-tip position after skin puncture, the median score (4 [3,4] *vs.* 2 [2,3]; $P < 0.001$); position 3, 4, or 5 (38 [95%] *vs.* 13 [33%]; $P < 0.001$); and position 4 or 5 (26 [65%] *vs.* 5 [13%]; $P < 0.001$) were all in favor of single-operator laser-assisted ultrasound guidance.

Conclusions: Compared with traditional ultrasound guidance, the single-operator laser-assisted ultrasound-guided system is a useful add-on to the ultrasound dynamic needle-tip puncture technique. It improves the first-attempt success rate of radial artery cannulation in children younger than 2 yr by projecting the path of the artery on the skin and provides better procedural conditions (stable ultrasound probe).

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Radial artery cannulation in young children is challenging
- Technologies to optimize radial artery cannulation in young children remain incompletely explored

What This Article Tells Us That Is New

- In this prospective randomized study, laser-assisted ultrasound guidance, projecting the path of the target artery onto the skin surface, improved the speed and the success rate of radial artery cannulation in young children when compared to traditional ultrasound-guided cannulation

Continuous invasive measurement of blood pressure by arterial cannulation is the most common method of monitoring hemodynamics and arterial blood gases in patients who are severely ill or undergo major surgery.[1] Even for experienced anesthesiologists, radial artery cannulation remains challenging, with a relatively high failure

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rate. Based on clinical experience and literature data, the main reasons for failure of arterial puncture or cannulation can be summarized as follows: (1) inappropriate puncture point due to the subtle sliding of the ultrasound probe over the skin; (2) insufficient hand–eye coordination; (3) arterial lumen collapsed as a result of excess pressure being applied on the ultrasound probe; (4) too-large or too-small needle angle with the skin; (5) deviation of the needle direction from the anatomical path of the artery (vertical or angular deviation); (6) the target artery being pushed away by the needle tip or collapsed depending on whether the wrist is under- or overstretched; (7) multiple attempts leading to arterial spasm or local hematoma; (8) the tip of the needle being too close to the posterior wall, resulting in difficult cannulation; and (9) arterial anatomical abnormalities.[2,3]

In view of various failure factors, compared with the traditional palpation approach, the advantages of ultrasound-guided arterial puncture are becoming increasingly notable.[4–7] In the recent decade, relevant studies have continuously proposed the optimization and improvement of ultrasound-guided arterial puncture technology and the methods to improve its success rate, such as using a dynamic needle tip,[8–10] developing lines,[11] intelligent glasses,[12] subcutaneous injection of normal saline or nitroglycerin,[3,13,14] guide wire assistance, or choosing an alternative artery.[15,16] Notwithstanding these advancements, there is no general consistency as to how to optimize radial artery cannulation for young pediatric patients. The aim of our study was to evaluate an original single-operator laser-assisted three-dimensional ultrasound-guided system and to compare the success rate of first-attempt cannulation of the radial artery in young children with the traditional ultrasound-guided short-axis, out-of-plane, dynamic needle-tip positioning technique.

Materials and Methods

Subjects and Study Design

This was a single-center, prospective, parallel-group, randomized controlled study approved by the Ethics Committee of Clinical Trials of the First Hospital of Jilin University (Changchun, Jilin, China; 21K124-001). A research assistant evaluated eligibility, obtained informed consent from the parents after comprehensive explanation of advantages and risks, and enrolled the participants. The trial was registered in the Chinese Clinical Trial Registry (ChiCTR2100052975; principal investigator, Zhiwen Li; date of registration, November 7, 2021; https://www.chictr.org.cn). This article adheres to the reporting requirements specified in the Consolidated Standards of Reporting Trials guidelines.

The trial was carried out between November 15, 2021, and June 4, 2022, in the first hospital of Jilin University—an urban, academic, class A tertiary hospital with a total number of greater than 5,000 pediatric surgeries per year—and it was ceased after obtaining the recruitment goal. The study enrolled children under 2 yr of age (American Society of Anesthesiologists Grades I to IV) undergoing major elective or emergency surgery under general anesthesia requiring invasive arterial monitoring and intermittent blood sampling. The exclusion criteria were previous puncture at the same site in the previous month; puncture site injury, infection, or hematoma; peripheral vascular disease; the absence of adequate collateral blood flow in the palmar arch as evaluated with Allen's test; congenital heart disease, hypovolemia or cardiogenic shock; and severe arrhythmia.

The single-operator laser-assisted ultrasound-guidance device consisted of the Mindray Ultrasonic System with 0.1-mm accuracy (DC-8 ELITE, Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China), a 3D-printed probe-carrying enclosure with a linear laser transmitter (ZLM120AL650-22130BXS, Shenzhen Zhonglai Technology Co., Ltd., Shenzhen, China; fig. 1A), and a 3D-printed three-axis manipulator arm to connect the enclosure (fig. 1B). We created the blueprint and simulated the combination by SolidWorks software. A corn-extracted biodegradable eco-friendly material, polylactic acid, was adopted in the 3D printer (A-8S, Shenzhen Aurora Technology Co., Ltd., Shenzhen, China) to print the solid components. Ultimately, a novel laser-guided arterial cannulation model based on the traditional ultrasound system was presented in this study (fig. 1, C and D).

Randomization and Blinding

A randomization website (https://www.randomizer.org) was used by the research statistician to generate random unique numbers from 1 to 80, which were then sealed into opaque numbered envelopes with grouping information. The subjects were randomly assigned (1:1) to the single-operator laser-assisted ultrasound-guidance group or the traditional ultrasound-guidance group (fig. 2). A screening criteria questionnaire was attached to each envelope to help reconfirm enrollment before being unsealed by the research assistant after induction of general anesthesia. The operator team that was not involved in any other part of the study, including design, collection, evaluation, and writing, consisted of doctor A and doctor B. The two doctors were selected attending physicians with an average of 5 yr working experience but without any experience in radial artery cannulation of children in our department. Moreover, they had independently accomplished ultrasound-guided arterial cannulation in more than 100 adults. We also designed a training program for standardization of knowledge and acquiring skills (for details, see the Supplemental Digital Content, https://links.lww.com/ALN/D95). Each operator in this study was assigned 40 cases (20 from each group). In each group, an equipment assistant helped in preparations before the start of the operation. In view of the notably different settings of the two techniques, the allocation was not blinded to the operators, equipment assistant, and research assistant. Conversely, the parents of the subjects were blinded to the group assignment and free to withdraw

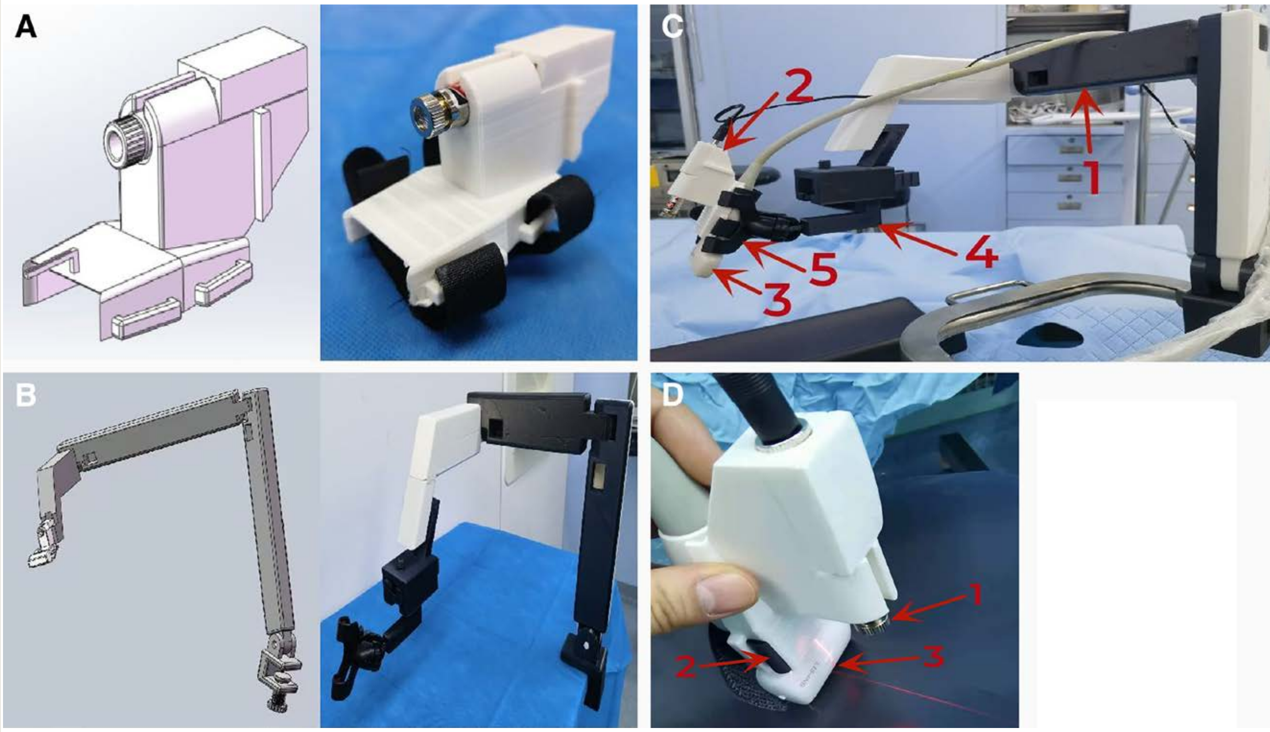

Fig. 1. (*A*) Original design picture (*left*) and real object (*right*) of the 3D-printed laser enclosure. (*B*) Design picture (*left*) and real object (*right*) of the ultrasonic probe manipulator arm. (*C*) Components of the single-operator laser-assisted ultrasound-guided system: manipulator arm (*arrow 1*); laser enclosure (*arrow 2*); ultrasonic probe (*arrow 3*); sliding rail (the ultrasonic probe can move forward and backward parallel through the sliding rail of the manipulator arm and hover at any position; *arrow 4*); and front gripper (which clamps the ultrasonic probe and is usually fixed at a designated angle of approximately 60 degrees; *arrow 5*). (*D*) The real object of the laser device with 3D-printed technique: laser source (*arrow 1*); belt to fasten the laser enclosure (*arrow 2*); and a linear laser is directed perpendicular to the long axis of the ultrasonic probe and passes through the middle marker of the probe (*arrow 3*).

from the trial at any time. All data were collected and analyzed by the same research assistant as in the pilot study.

Anesthesia and Preparatory Phase

As soon as the children entered the operating room, their vital signs were monitored, including electrocardiogram, pulse oxygen saturation, and noninvasive blood pressure. After induction of general anesthesia, the operator performed a bilateral Allen's test to ensure adequate blood supply from the ulnar arteries. Depending on the particular situation of the surgery, the right or left radial artery was selected by the operator after randomization. A probe frequency of 11 MHz and a depth of 2.0 cm were set for optimal image quality in both groups.[17] We used the "dynamic needle-tip positioning" method with the "short-axis out-of-plane" approach in both groups. The patient was anesthetized in the supine position, the chosen arm was extended on the side of the body, and the wrist was placed on a flat holder. A cotton roll was placed underneath to slightly raise the forearm and extend the joint, and four fingers were fixed to the holder by tape. After hand sterilization, the operator disinfected the puncture site and the surrounding skin with iodophor. An aseptic surgical drape was laid subsequently. With the help of the equipment assistant applying the coupling agent on the surface of the ultrasound probe, the operator with sterile gloves tightly wrapped the device composed of the probe, the enclosure, and the manipulator with the sterile sheath. Sterile coupling agent was again applied outside of the sterile sheath after scattered air bubbles were completely extruded.

In the single-operator laser-assisted ultrasound-guidance group, before the patient entered the operating room, the assistant prepared the equipment as follows: (1) the manipulator arm was fixed near the operation table; (2) the laser emitter was fixed to the ultrasonic probe; (3) the ultrasonic probe was fixed with the pretested 3D-printed enclosure and the gripper, which was installed on the manipulator arm; and (4) the adjustable belt was fastened to ensure that the probe was more closely combined with the enclosure. The ultrasound probe was then placed 1 cm below the second wrist crease and moved slightly to cross the center of the vascular section with the middle auxiliary line on the screen. The image was stored for postoperative calculation of the arterial diameter and depth by a professional.

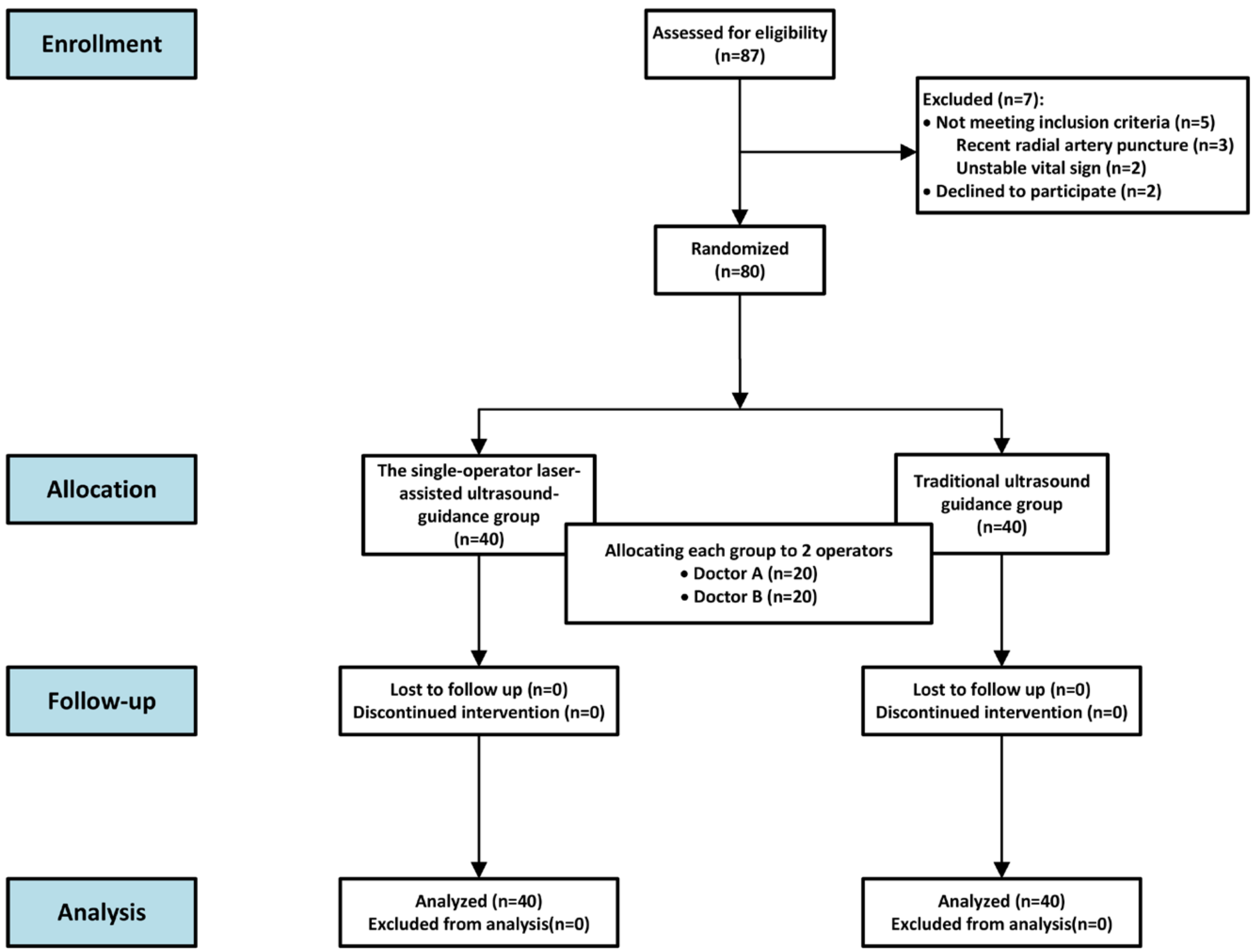

Fig. 2. The Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

A sterile marker pen was used to mark the first point below the middle mark of the ultrasound probe. Then, the probe was moved 1.5 cm to the proximal end. The second point was marked with the same method, where the probe was fixed with an angle of 60 degrees to the skin approximately (the front gripper of the manipulator arm can clamp the ultrasonic probe and is usually fixed at a designated angle of approximately 60 degrees; for details, see fig. 1C). After the laser was turned on, the width and the direction of the projected laser were adjusted by rotating the front of the laser transmitter, so that the laser beam passed through the middle mark of the ultrasound probe (centered on the arterial lumen) and the two marked points: the laser beam thus became the superficial (cutaneous) projection of the underlying anatomical path of the artery (fig. 3). The probe was fixed with the manipulator arm at this point, and the needle was held in the right hand. Eventually, the height of the ultrasonic screen was lowered to the operator's eye level to reduce head and neck movements in favor of guiding convenience. For the traditional ultrasound-guidance group, all preparation procedures were repeated as described in the ultrasound-guided short-axis, out-of-plane, dynamic needle-tip positioning technique.[18]

Radial Artery Cannulation and Data Collection

A 24-gauge cannula needle (0.7 × 19 mm, C0141, Shanghai Puyi Medical Instruments Co., Ltd., Shanghai, China) held with the right hand was introduced through the skin 5 mm in front of the ultrasound probe with an angle up to 30 degrees, while the entire needle coincided with the projected laser (fig. 4). After the needle tip had entered the subcutaneous tissue, assuming a deviation was displayed, the needle tip was adjusted subcutaneously, and the number of adjustments was recorded. The needle remained still when it was first seen in the image with return of blood in the needle, and a screenshot at the puncture site level was stored to record the needle position in the quadrant of the artery and the midmost rate at the first attempt (needle tip position in quadrant 4 or 5; fig. 5A1). When the ultrasonic

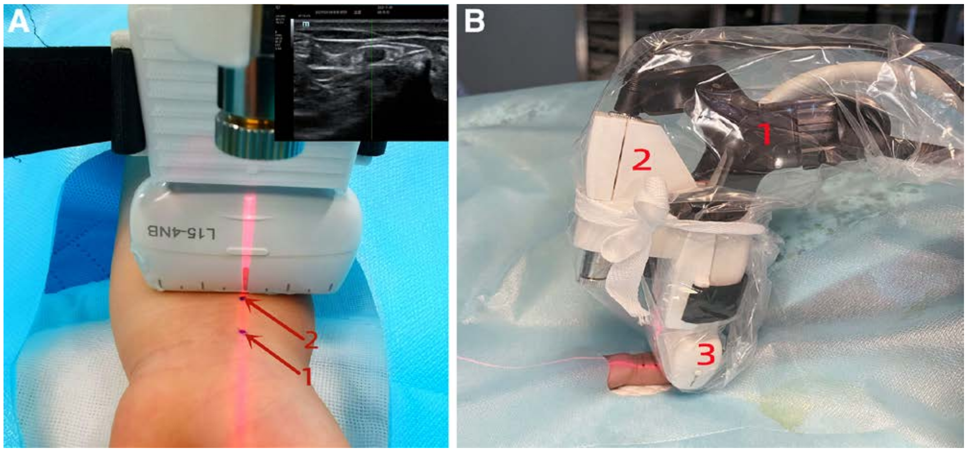

Fig. 3. (*A*) The probe was placed 1 cm below the second wrist striae of the child, and the ultrasound midline passed through the middle of the artery's cross-section (for details, see sonogram at *upper right*). A sterile marker was used to mark point 1 below the ultrasound probe midline marker. Then, the probe was moved to the proximal end 1.5 cm, and point 2 was marked again with the same method. (*B*) Side view of single-operator laser-assisted ultrasound-guidance system: the probe fixed arm (*1*), the laser device (*2*), and the ultrasonic probe (*3*).

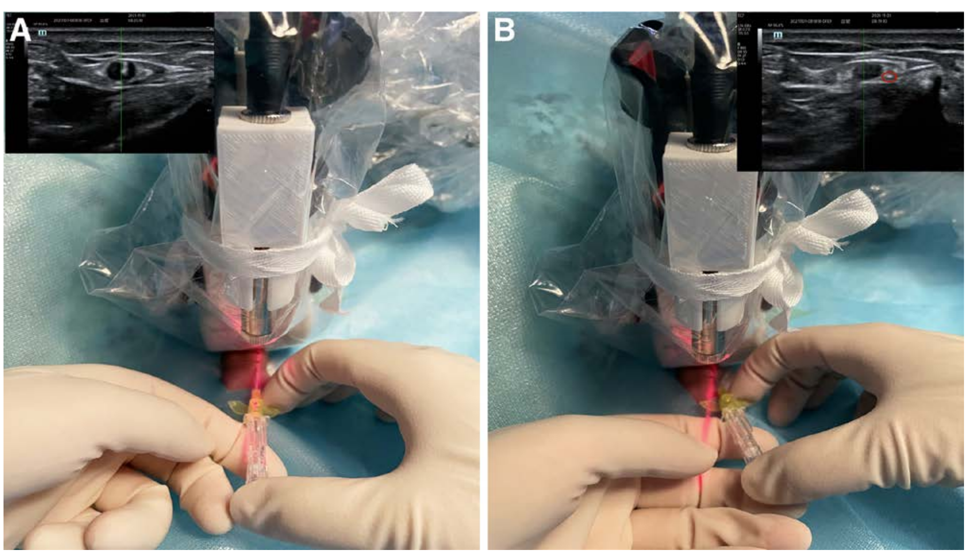

Fig. 4. (*A*) The exploring needle should be fully aligned with the laser beam projected on the skin so that the needle direction is perpendicular to the long axis of ultrasound during artery puncture. If we follow this procedure, as shown in the ultrasound screenshot at the *upper left* (from another real puncture patient, for explanatory purposes only), we can ensure that the needle enters directly above the artery. (*B*) If the needle is angled with the laser beam, the ultrasound screenshot at the *upper right* appears (from another real puncture patient, for explanatory purposes only), with the tip of the needle tilted to the right of the artery marked in the *red circle*.

probe was fully attached to the skin and a stable required image of the artery was right in the middle with the laser passing through the two marked points synchronously, the operator's left hand was used to fix the skin and reduce its tiny movements during skin puncture. We adopted the "dynamic needle-tip positioning" method with "short-axis, out-of-plane" approach in this study. Since the three axes of the manipulator were fixed at right angles, the operator only needed to gently slide the probe forward and backward with his left hand to adjust the ultrasonic image (fig. 1C). When the probe moved to the proximal end and a high bright spot was presented, the probe was moved continually to the proximal end until the high bright spot disappeared. Then, the probe was moved backward to the distal end to find the needle tip level at which the high bright spot just appeared (fig. 6). At that moment,

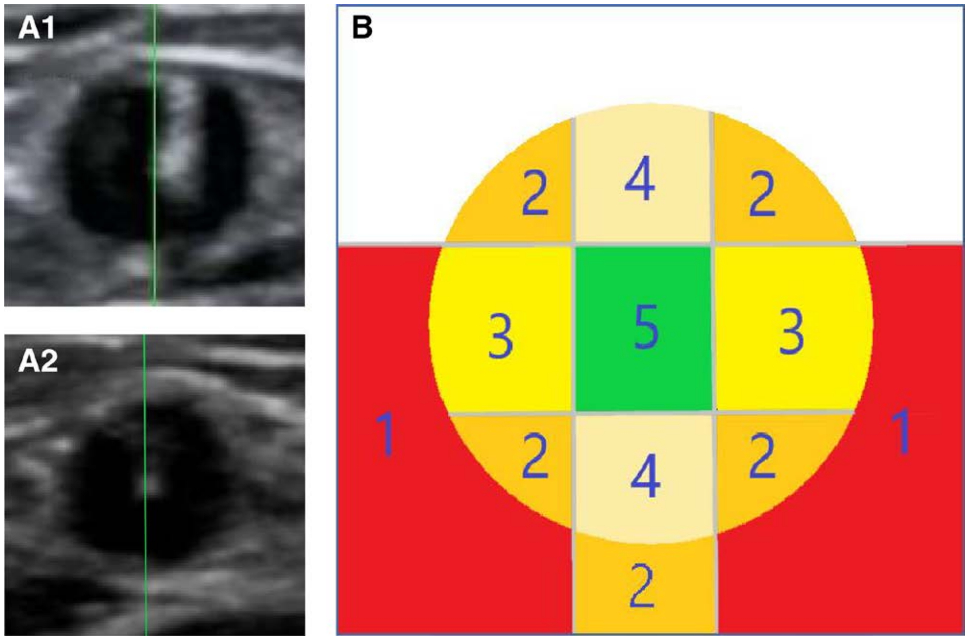

Fig. 5. (*A*) When the needle is visible in the plane of puncture point, ultrasound image 1 is saved (*A1*). The ultrasonic probe moves to the proximal end, and when the highlighted image is spotted, it is the position of the needle tip, and ultrasonic image 2 (*A2*) is saved. (*B*) Criteria used to later score the saved ultrasound images of panel A2.

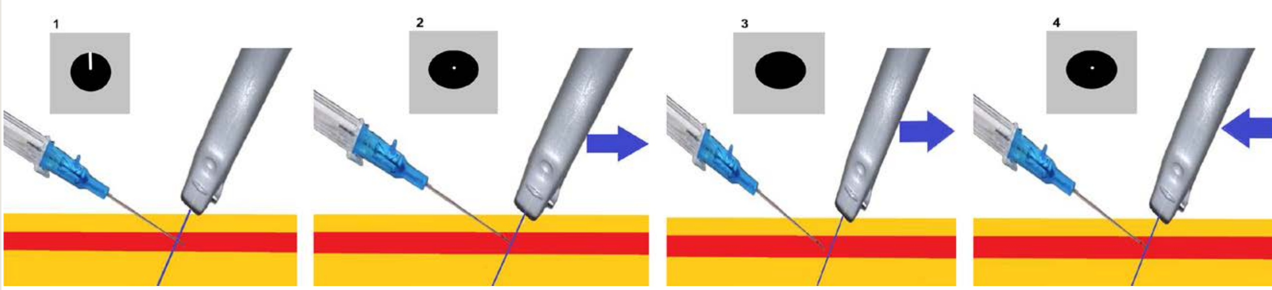

Fig. 6. The main steps of the dynamic needle-tip puncture technique. (*Step 1*) The first linear and highlighted echo shadow seen at the puncture site plane is the needle body, not the needle tip. (*Step 2*) Moving the ultrasonic probe toward the proximal end, the linear highlight slowly changes to a point-like highlight, which may indicate the place where the tip of the needle is. (*Step 3*) Continuing to move the probe toward the proximal end until the highlighted image disappears. (*Step 4*) By moving the probe toward the distal end, the first highlighted image can be identified as the needle tip.

the ultrasound screenshot represented the position of the first needle tip for later analysis and scoring according to the position (fig. 5, A2 and B). Adjustments were made if the tip was not in the center of the artery, and the number of adjustments were recorded. The dynamic needle-tip method was applied under ultrasound guidance to advance the needle by 2 to 3 mm with the tip in the middle of the artery. Both operators were right-handed. The cannula was inserted by the left hand, and a transducer was then connected. If the posterior wall of the artery was penetrated while trying to find the needle tip or if direct cannulation was difficult, the operator could use their experience to determine the appropriate penetration method, which was also recorded.

The primary outcome was the first-attempt success rate of radial artery cannulation. The completion of the cannulation was defined as the presentation of the arterial waveform on the monitor. The secondary outcomes included the procedure time to success within the first attempt, midmost rate of first attempt, first needle-tip position, average number of adjustments, number of unintentional penetration events of the posterior wall, total success rate, overall procedure time, overall number of attempts, and overall complication rate. The midmost rate of first attempt was defined as the rate of needle-tip position scoring 4 or 5 in the quadrant of the artery at the first attempt among all radial artery punctures in this study. The overall procedure time was defined as the time interval from skin penetration to an arterial waveform presented on the monitor. If the second attempt failed or the time exceeded 10 min, the attempt was deemed a failure. When a failure occurred, alternative puncture sites, such as the contralateral radial artery, posterior tibial artery, or other ipsilateral radial artery sites, were chosen for final attempts. After a successful cannulation, the number of attempts, site replacements, and complications such as hematoma, vasospasm (a 25% reduction in arterial diameter),[14] and distal ischemia of the first chosen radial artery were recorded. Ultrasonography was used to monitor and evaluate the progression of complications.

Statistical Analysis

The sample size required for this study was calculated using PASS 21.0 (NCSS, USA). According to a pilot study in our department, the success rate of the first attempt was 92% in the single-operator laser-assisted ultrasound-guidance group and 65% in the traditional ultrasound -guidance group. Considering a dropout rate of 10%, the required sample size in the present study was 40 patients/group (two-sided $\alpha = 0.05$; power = 0.80).

Table 1. Patient Characteristics of the Traditional Ultrasound-guidance Group and the Single-operator Laser-assisted Ultrasound-guidance Group for Radial Artery Cannulation

Characteristics	Traditional Ultrasound-guidance Group (n = 40)	Single-operator Laser-assisted Ultrasound-guidance Group (n = 40)
Age, months	10 ± 6	11 ± 6
Diameter, mm	1.3 ± 0.4	1.3 ± 0.4
Depth, mm	2.4 ± 0.4	2.6 ± 0.6
Newborn		
No	36 (90%)	37 (93%)
Yes	4 (10%)	3 (8%)
Sex		
Male	21 (53%)	23 (58%)
Female	19 (48%)	17 (43%)
ASA Physical Status		
I	4 (10%)	6 (15%)
II	21 (53%)	23 (58%)
III	14 (35%)	11 (28%)
IV	1 (3%)	0 (0.00%)
Surgery		
Cardiac surgery	4 (10%)	3 (8%)
General surgery	23 (58%)	24 (60%)
Neurosurgery	4 (10%)	5 (13%)
Thoracic surgery	9 (23%)	8 (20%)

The data are expressed as means ± SD or numbers (proportion).
ASA, American Society of Anesthesiologists.

The measurement data were tested for normality using the Shapiro–Wilk normality test. The measurement data with normal distribution were described by means ± SD, and the measurement data with non-normal distribution were described by medians (lower quartile, upper quartile). Count data were described by frequency (percentage). The baseline characteristics of the study population were evaluated using the independent *t* test and χ^2 test. The primary outcome was analyzed using χ^2 test. The secondary outcomes were analyzed using the χ^2 test, Fisher's precision probability test, and Mann–Whitney U test. All statistical analyses were performed using IBM SPSS Statistics 24 (SPSS Inc., IBM Corporation, USA). Statistical significance was defined as a two-sided *P* value lower than 0.05.

Results

From November 15, 2021, to June 4, 2022, 87 patients approached by research staff were recruited. Seven patients were excluded for not meeting the inclusion criteria (n = 5) and declining participation (n = 2). Eighty patients were randomized into two groups: the single-operator laser-assisted ultrasound-guidance group (n = 40) and the traditional ultrasound-guidance group (n = 40). The study was conducted in accordance with the original protocol. There were no missing data or loss to follow-up for any of the included participants (fig. 2). Patient characteristics were similar between the two groups: the median age of the patients in both groups was between 10 and 12 months, with American Society of Anesthesiologists status mostly from I to IV; the major type of surgery undertaken was general surgery. However, the depth of the radial artery in the single-operator laser-assisted ultrasound-guidance group was slightly deeper compared with that in the traditional ultrasound-guidance group (2.6 ± 0.6 *vs.* 2.4 ± 0.4 mm; *P* = 0.038; table 1).

As shown in table 2, our primary outcome, the first-attempt success rate, in the single-operator laser-assisted ultrasound-guidance group (36 of 40 [90%]) was significantly greater than that in the traditional ultrasound-guidance group (28 of 40 [70%]; absolute difference, 20% [95% CI, 2.3% to 36.6%]; *P* = 0.025). Among the secondary outcomes, the median procedure time to success within the first attempt was shorter in the single-operator laser-assisted ultrasound-guidance group compared with the traditional ultrasound-guidance group (31 s [27, 36 s] *vs.* 46 s [39, 52 s]; *P* < 0.001). The median procedure time to success within the second attempt was shorter in the single-operator laser-assisted ultrasound-guidance group compared with the traditional ultrasound-guidance group (32 s [28, 33 s] *vs.* 49 s [40, 51 s]; *P* = 0.014). In the single-operator laser-assisted ultrasound-guidance group, the midmost rate of first attempt (38 of 40, 95%) was significantly higher than that in the traditional ultrasound-guidance group (13 of 40, 33%; *P* < 0.001). Only two patients experienced unintentional posterior wall penetration in the single-operator

Table 2. Outcomes of the Traditional Ultrasound-guidance Group and the Single-operator Laser-assisted Ultrasound-guidance Group for Radial Artery Cannulation

	Group			
Parameter	Traditional Ultrasound Guidance (n = 40)	Single-operator Laser-assisted Ultrasound Guidance (n = 40)	χ^2/Z	*P* Value
First-attempt success rate, %	28 (70%)	36 (90%)	5.00	0.025
Procedure time to success within the first attempt, s	46 (39, 52)	31 (27, 36)	-4.23	< 0.001
Success rate within two attempts in less than 10 min, %	33 (83%)	39 (98%)		0.057*
Procedure time to success within the second attempt, s	49 (40, 51)	32 (28, 33)	-2.46	0.014
Midmost rate of first attempt	13 (33%)	38 (95%)	33.81	< 0.001
Number of unintentional penetrating the posterior wall	11 (28%)	2 (5%)	7.44	0.006
Average number of adjustments	2 (1, 3)	0 (0, 1)	-6.65	< 0.001
Use of another puncture site	11 (28%)	5 (13%)	2.81	0.094
Second puncture site on the same radial artery	6 (15%)	2 (5%)		0.263*
Contralateral radial artery	5 (13%)	3 (5%)		0.275*
Posterior tibial artery	0	0		
Use of the transfixion technique	13 (33%)	4 (10%)	6.05	0.014
Overall procedure time, s	48 (39, 61)	32 (27, 36)	-4.23	< 0.001
Overall number of attempts	1 (1, 2)	1 (1, 1)	-6.65	< 0.001
Overall complication at first chosen radial artery, %				
Vasospasm	4 (10%)	2 (5%)	0.72	0.396
Hematoma	11 (28%)	1 (3%)	9.80	0.002
Distal ischemia	0	0		
First needle tip position (five-point scale)	2 (2, 3)	4 (3,4)	-5.85	< 0.001
Positions 3, 4, or 5	13 (33%)	38 (95%)	33.81	< 0.001
Positions 4 or 5	5 (13%)	26 (65%)	23.23	< 0.001

The values are medians (interquartile range) or numbers (proportion).
*Fisher's precision probability test.

laser-assisted ultrasound-guidance group, compared with 11 patients in the traditional ultrasound guidance group. The transfixion technique was used in 4 cases (4 of 40, 10%) from the single-operator laser-assisted ultrasound-guidance group and 13 (13 of 40, 33%) cases from the traditional ultrasound-guidance group ($P = 0.014$). The average number of adjustments was 0 (0, 1) in the single-operator laser-assisted ultrasound-guidance group and 2 (1, 3; $P <$ 0.001) in the traditional ultrasound guidance group. The overall procedure time was shorter in the single-operator laser-assisted ultrasound-guidance group compared with the traditional ultrasound-guidance group (32 s [27, 36 s] *vs.* 48 s [39, 61 s]; $P < 0.001$). The overall number of attempts in this study was 1 (1, 1) in the single-operator laser-assisted ultrasound-guidance group and 1 (1, 2; $P < 0.001$) in the traditional ultrasound guidance group. The statistical difference in radial artery depth measured in this study was not clinically significant. As for overall complications, the incidence of hematoma in the single-operator laser-assisted ultrasound-guidance group (1 of 40, 3%) was significantly lower than that in the traditional ultrasound guidance group (11 of 40, 28%; $P = 0.002$). As for the first needle-tip position scale between the groups, the median score (4 [3, 4] *vs.* 2 [2, 3]; $P < 0.001$), position 3, 4, or 5 (38 [95%] *vs.* 13 [33%]; $P < 0.001$), and position 4 or 5 (26 [65%] *vs.* 5 [13%]; $P < 0.001$) were notable (table 2; fig. 7).

Discussion

The primary finding of our study was that the application of single-operator laser-assisted ultrasound guidance significantly improved the success rate of the first attempt, overall success rate, and puncture time in radial artery cannulation in children younger than 2 yr, compared with the conventional ultrasound-guided puncture. These results may be attributed to the more precise direction of insertion under laser guidance, which increased the probability that the needle would enter vertically above the middle of the artery, and correlated with a higher midmost rate of the needle tip entering the artery for the first time (fig. 7).

Radial artery cannulation in young children is a real challenge, even for anesthesiologists proficient in ultrasound

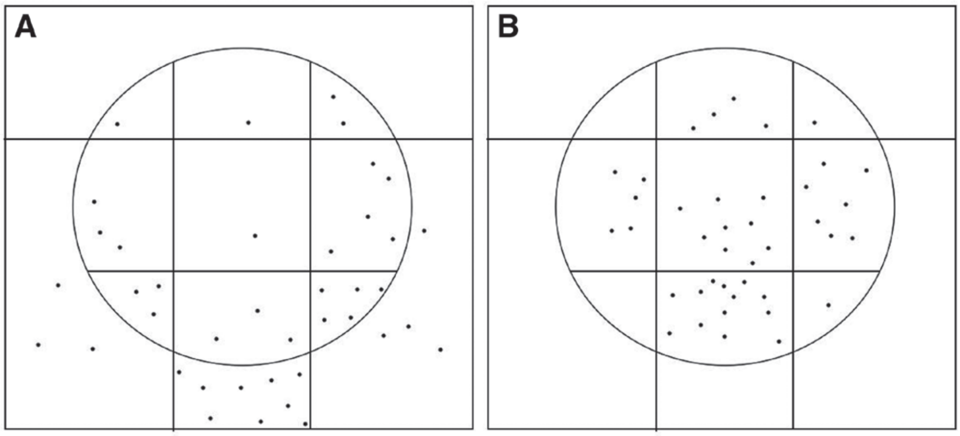

Fig. 7. Ultrasonic recording of the first needle-tip position. (*A*) The first needle-tip position of the traditional ultrasound-guidance group. (*B*) The first needle-tip position of the single-operator laser-assisted ultrasound-guidance group.

guidance. As reported in a recent study, the mean internal diameter of the radial artery was 1.2 ± 0.3 mm in children aged less than 2 yr, and 37.2% of patients had a radial artery diameter of 1 mm or less.[16] This is enough to convince us that radial artery puncture in young children is the most challenging representative in the field of vascular puncture and deserves a more refined and stabilized procedure.

There are four key operating steps of our single-operator laser-assisted ultrasound-guided method. First, the middle mark of the ultrasound probe and the middle auxiliary line on the screen were used to locate the two marked points on the child's wrist. Second, the laser beam was directed to pass through the above two points at the same time, and we adjusted the laser width to be equal to the arterial diameter according to the ultrasonic parameters, so that the laser between the two points could be regarded as the projection of the radial artery on the body surface. Third, we made sure that the puncture needle was completely covered by the laser projection; that is, the puncture needle and the laser completely overlapped, so that the needle was above the middle of the artery and completely perpendicular to the long axis of the ultrasound probe. Finally, it was very important to master the ultrasound-guided dynamic needle-tip puncture technique. Our technique is to save two ultrasound screenshots when the ultrasound probe is moved toward the proximal end to confirm the position of the needle tip after the needle body is seen in the artery. The great advantages of our method are the higher midmost rate of first-attempt needle-tip position and well controlled needle position in the artery, which prevents the needle body from being mistaken for the needle tip at the puncture point plane, thereby reducing the probability of the distal needle tip penetrating the posterior wall of the artery.

Quan *et al.*[11] adopted a technique involving the use of double developing lines on the ultrasound probe to locate the radial artery. This method can situate the ultrasonic probe directly above the artery, but the direction of needle entry cannot be guaranteed; especially when the needle tip is at the depth of the artery, the direction may deviate from the artery or enter one side of the artery, thereby resulting in the wrong direction of the needle tip. In our method, the laser not only guided the entry point accurately but also ensured the correct direction of the needle advancing (if the initial direction of insertion is divergent, the needle tip will be tilted to the left or right side of the artery, as detailed in fig. 4B), so it had a higher first-attempt success rate, higher midmost rate of first needle-tip entry into the artery, and fewer needle adjustments. In addition, compared with other studies,[8,11–14,17–19] we used the ultrasonic probe arm innovatively. That is, after determining the best position of the needle tip, the ultrasonic position was stabilized by the arm, freeing the two hands for a more stable cannulation. Using the probe holder allows the probe to be positioned on the skin without applying pressure, thus preventing the arterial lumen from collapsing under excessive external pressure. The significantly improved primary and secondary outcomes of our study could provide clinical guidance and relevance, especially for inexperienced operators, with the higher first-attempt success rate, shorter procedure time, and fewer complications.

There are some limitations to our study. First, the operator was not blinded to the group allocation. The application of single-operator laser-assisted ultrasound guidance may have biased the results by increasing the operator's confidence. Second, since the preparation of the device was completed by an anesthesia assistant before the children entered the operating room, no time for cannulation was occupied, so we did not calculate the preparation time of the device separately. In addition, the position time of the single-operator laser-assisted ultrasound-guidance group was not measured, but according to our experience, the position time and the preparation time of the single-operator laser-assisted ultrasound-guidance group was mostly within 10s and 30s, respectively (for details see Supplemental Video File, https://links.lww.com/ALN/D94). Third, we selected anesthesiologists with more than 100 cases of ultrasound-guided arterial puncture to participate in this study, so we do not know how physicians without experience in adult arterial puncture or ultrasound-guided arterial puncture would perform. Fourth, the statistical significance of multiple secondary outcomes should be regarded with caution because they were not adjusted for multiplicity. Fifth, although we did not analyze the learning curve of the single-operator laser-assisted ultrasound-guidance application in young children under 2 yr, we found that anesthesiologists with previous experience of ultrasound-guided arterial cannulation and training achievements from our education program mastered it well and became proficient already after about five to six procedures. Finally, due to the specific anatomical characteristics of young children, the relevance of the data and methods from this study for other populations needs to be further verified.

Conclusions

The use of single-operator laser-assisted ultrasound guidance for radial artery cannulation in children younger than 2 yr allows some of the aforementioned causes of failure to be controlled: (1) inappropriate puncture point due to sliding of the ultrasound probe over the skin; (2) arterial lumen collapsing as a result of excessive pressure being applied on the ultrasound probe; (3) deviation of the needle direction from the anatomical path of the artery (vertical or angular deviation); and (4) the tip of the needle being too close to the posterior wall, resulting in difficult cannulation. Moreover, it reduces the risk of hematoma while also providing more stable procedural conditions for a single operator.

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Competing Interests

The authors declare no competing interests.

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Full protocol available at: www.letpub.com. Raw data available at: lizhiwen@jlu.edu.cn.

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Supplemental Digital Content

Supplemental Procedure Demo Video, https://links.lww.com/ALN/D94

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