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Acoustic shadowing combined with dynamic needle tip positioning facilitates teaching of ultrasound guided radial artery cannulation in standardized training for residents: a randomized controlled trial

Yini Wu
Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

Jimin Wu
Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

Renhong He
Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

Xin Han
Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

Hong Dai
Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

Faxing Wang
Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

Qiaomin Xu
xuqiaomin810@163.com

Lishui Hospital of Wenzhou Medical University, The First Affiliated Hospital of Lishui University, Lishui People's Hospital

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Research Article

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Abstract

Background: Radial artery cannulation is challenging for residents, so it is necessary to establish a simple teaching strategy. The aim of this study was to evaluate the efficiency of three ultrasound-guided radial artery cannulation techniques in the standardized training of residents.

Methods: 93 residents, who had not performed radial artery cannulation, undergoing standardized residency training in the Department of Anaesthesiology were randomly divided into a traditional ultrasound-guided teaching group (Group C), acoustic shadowing-facilitated ultrasound-guided teaching group (Group AS); and acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided teaching group (Group AS-D). Residents received theoretical and practical training before the assessment. After the training, the first-attempt puncture success rate, first-attempt cannulation success rate, ultrasound localization time and puncture time were compared uniformly among the three groups.

Results: The success rate of first puncture was similar in the AS-D and AS groups and was higher than that in group C. However, the success rate of first-attempt cannulation was significantly higher in the AS-D group than in the AS group, and the incidence of local haematoma was lower. In addition, the ultrasound localization time was shorter in both AS-D and AS groups compared with group C. However, the puncture time was significantly longer in the AS-D group than in the AS group.

Conclusion: Acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided radial artery cannulation improves the success rate of the first-attempt cannulation, which is beneficial in the standardized training and teaching of residents.

Introduction

Clinical skills training is an important component of the standardized residency training programs (SRTP). In the standardized training programme for anaesthesia residents, radial artery cannulation requires clinicians to be proficient[1]. Ultrasound guidance has now become an important adjunct to radial artery cannulation, but due to the small calibre of the radial artery, the success rate is largely dependent on the operator's experience and hand-eye coordination[2]. Therefore, radial artery cannulation remains difficult for residents who lack relevant experience[3].

The latest research has shown that acoustic shadowing facilitates ultrasound-guided radial artery puncture is benefcial in the standardized training and teaching of residents[4]. However, in clinical practice, we have found that although the acoustic shadowing technique facilitated rapid puncture but limited depth of entry and the puncture procedure remains blind. As a result, the success rate of inserting the cannula into the artery by the resident is not high. The “dynamic needle tip positioning” technique tracks the tip of the needle in the subcutaneous tissue layer[5]. Therefore, we hypothesised that optimal ultrasound guidance could be achieved by using acoustic shadowing technique for puncture localization, followed by slow needle insertion using the dynamic needle tip positioning technique. The

aim of this study was to evaluate the effectiveness of acoustic shadowing combined with dynamic needle tip positioning technique for teaching radial artery cannulation to residents.

Materials and Methods

Study Design

This is a prospective, randomized, controlled, single-center clinical trial. The trial was approved by the Ethics Committee of Lishui City People's Hospital and retrospectively registered with the Chinese Clinical Trial Registry (chictr.org.cn, No. ChiCTR2500104929) on June 25th, 2025, after enrollment of the first participant.Written informed consent was obtained from all enrolled patients. This study complied with the Helsinki Declaration and its subsequent amendments, and is reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 statement.

Study population

All residents who had not performed radial artery cannulation or received relevant training previously were included. Patients aged 20–60 years who underwent elective surgery requiring the use of invasive arterial pressure monitoring were included in this study. The exclusion criteria included BMI ≥ 30 kg/m^2; negative Allen's test; ulnar artery obstruction; multiple arterial punctures or radial artery cannulation history; puncture area with wound or infection; coagulation dysfunction; unstable vital signs; and patients with peripheral vascular disease.

Randomization

Randomized sequence numbers were generated by SPSS software and Residents were randomly divided into three groups on a 1:1:1 basis, including the traditional ultrasound-guided teaching group (Group C); acoustic shadowing-facilitated ultrasound-guided teaching group (Group AS); and acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided teaching group (Group AS-D).

Intervention

The same instructor provided theoretical training to all residents on radial artery cannulation, explaining the anatomical location of the radial artery, preparation for puncture, puncture procedure and complications. Subsequently, the three groups of residents observed the demonstration and explanation of 10 cases of radial artery cannulation, all of which were performed using the ultrasound out-of-plane technique. Among them, group C learnt traditional ultrasound-guided radial artery cannulation technique, group AS learnt the acoustic shadowing-facilitated ultrasound-guided technique, and group AS-D learnt the acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided

technique. After the observation, each of the three groups of residents performed 10 radial artery cannulation exercises under the guidance of the same level of instructor. A final test was then performed, each student had only one chance. If the puncture failed, a subsequent puncture was performed by the instructor.

After entering the operating room, all patients were placed in the supine position and routinely monitored for vital signs. Sufentanil (0.1 μg/kg) was used for analgesia and vital signs were recorded after 5 minutes, after which radial artery cannulation was initiated. The patient's arm was placed naturally flat on a hand stand with the palm facing up and the wrist elevated 3 cm. The skin around the puncture site was disinfected with povidone-iodine solution and local anaesthesia was administered with 2% lidocaine. The ultrasound probe was fitted with sterile disposable plastic caps and has a frequency of 11 MHz and a depth of 1.5 cm.

In group C, radial artery cannulation was performed under conventional ultrasound-guided technique. The radial artery was placed in the middle of the ultrasound image and the needle was inserted at a 30° angle. Once the needle entered the radial artery, the needle angle was reduced from 30° to 15°, and then the needle was slowly pushed forward 1 to 2 mm to insert the cannula. The AS group separated the metal-containing strands from the surgical gauze that can detect X-rays. Two parallel strands were placed perpendicular to the long axis of the probe and secured with a sterile 3 M membrane, as shown in Fig. 1. The probe was adjusted by moving it from side to side so that the radial artery was located in the middle of two low-density shadows on the ultrasound image. The centre point of the junction of the two visible lines with the skin was the puncture point of the radial artery. The needle was inserted into the skin between the two lines visible on the probe at an angle of 30°. The cannulation procedure was the same as in Group C. The AS-D group was prepared with the same ultrasound probe as the AS group. After inserting the needle in the centre of the two visible lines, when a hyperechoic needle tip shadow was shown on the ultrasound image, the probe was moved proximally across the arm until the needle tip echo disappeared. The needle was advanced a few millimeters again till the hyperechoic tip appeared, and the process was repeated until the cannula was inserted into the artery.

Outcomes

All residents were given a theoretical knowledge test to assess their knowledge base after entering the anesthesiology rotation and documented general information of residents and patients. The primary outcomes included success rate of first-attempt puncture and cannulation. Secondary outcomes included ultrasound localization time, puncture time and the incidence of vascular complications. We defined successful first-attempt radial artery puncture as entry of the puncture needle into the artery, regardless of subsequent successful cannulation. First-attempt cannulation success was not only defined as entry of the puncture needle into the artery, but also included successful cannula insertion. ultrasound localization time was defined as the time from placement of the ultrasound probe on the skin until skin contact with the puncture needle. Puncture time was the time from puncture needle contact with skin to successful cannula insertion. All operating times were recorded by a third person.

Statistical analysis

In preliminary research, the success rate of first cannula insertion was 30%, 60% and 80% in groups C, AS and AS-D, respectively. Thus, a sample size of 25 patients per group was needed, assuming that $\alpha = 0.05$ and $1-\beta = 0.9$. Considering the 20% dropout rate, we ultimately needed to enrol 31 patients per group for a total of 93 patients.

We assessed the normality of the data distribution using the Kolmogorov-Smirnov test. Normally distributed continuous variables are expressed as the mean ± standard deviation (SD), and continuous variables that did not conform to the normal distribution are expressed as the median (interquartile range). One-way analysis of variance (ANOVA) was used to compare normally distributed numerical data. The Kruskal-Wallis test was used compare non-normally distributed numerical data. Categorical variables are described by frequencies or composition ratios, and the $\chi 2$ test or Fisher's exact test was used to examine qualitative data comparisons. All the statistical analyses were performed using the statistical software SPSS version 23.0. A two-tailed P value of less than 0.05 was considered to indicate statistical significance.

Result

From January 2023 to December 2024, 96 residents were included in this study. One students were unable to complete the training due to leave of absence and two students failed to take the final test. 93 residents were ultimately enrolled and randomly assigned to group C (n = 31), group AS (n = 31) or group AS-D (n = 31) (Fig. 2). There were no significant differences in age, gender, or entrance exam scores among the three groups of residents (Table 1). The baseline and demographic characteristics of the patients in the three groups were similar, as detailed in Table 2.

Table 1
General information of residents

Parameter	Group C (n = 31)	Group AS (n = 31)	Group AS-D (n = 31)	P
Age (years)	25.77 ± 1.33	25.26 ± 1.12	25.68 ± 1.11	0.20
Sex, n (%)				0.69
Male	22 (70.97%)	21 (67.74%)	24 (77.42%)	
Female	9 (29.03%)	10 (32.26%)	7 (22.58%)	
Examination scores	84.55 ± 4.34	85.19 ± 3.97	83.90 ± 4.28	0.48
Notes: Data are presented as means ± SDs or numbers (percentages).				

Table 2
Demographic characteristics and clinical data of patients

Characteristic	Group C (n = 31)	Group AS (n = 31)	Group AS-D (n = 31)	P
Age (years)	53.71 ± 7.64	50.90 ± 6.33	49.74 ± 6.92	0.07
Sex, n (%)				0.74
Male	14 (45.16%)	17 (54.84%)	15 (48.39%)	
Female	17 (54.84%)	14 (45.16%)	16 (51.61%)	
BMI (Kg/m^2)	23.61 ± 2.39	23.74 ± 2.60	24.03 ± 2.23	0.78
ASA classification, n (%)				0.51
I	2 (6.45%)	0 (0.00%)	1 (3.23%)	
II	22 (70.97%)	24 (77.42%)	21 (67.74%)	
III	7 (22.58%)	7 (22.58%)	9 (29.03%)	
Heart rate (beats/min)	71.13 ± 9.51	72.48 ± 9.83	69.71 ± 9.41	0.52
Mean arterial pressure (mmHg)	92.61 ± 14.11	93.90 ± 12.74	91.52 ± 10.13	0.75
Transverse diameter of arteries (mm)	2.55 ± 0.51	2.62 ± 0.55	2.65 ± 0.58	0.76
Longitudinal diameter of arteries (mm)	2.16 ± 0.45	2.36 ± 0.37	2.22 ± 0.49	0.22
Depth from skin to centre of radial artery (mm)	4.16 ± 1.16	4.21 ± 0.88	3.94 ± 1.09	0.56
Notes: Data are presented as means ± SDs or numbers (percentages).				

BMI, body mass index; ASA, American Society of Anesthesiologists.

As shown in Table 3, the first-attempt puncture success rate in group AS was significantly higher than that in group C, while the difference between the two groups in terms of first cannulation success rate was not statistically significant. On the contrary, the first puncture success rate and first cannulation success rate of group AS-D were significantly higher than that of group C, and the first cannulation success rate was also significantly higher than group AS. The ultrasound localization time was similar in the AS-D and AS groups, and both shorter than group C. There was no significant difference in the puncture time between group C and group AS-D, but both were significantly longer than group AS. The incidence of local haematoma was significantly lower in group AS-D compared to group C.

Table 3
Results of radial artery cannulation in different groups

Parameter	Group C (n = 31)	Group AS (n = 31)	Group AS-D (n = 31)	P
First-attempt puncture success rate (%)	13 (41.94%)	23(74.319%)*	27 (87.09%)*	0.00
First-attempt cannulation success rate (%)	8 (25.81%)	16 (51.61%)	25 (80.84%)*#	0.00
Ultrasound localization time (s)	18.0 (12.0–24.0)	15.0 (10.0–19.0)*	15.0 (10.0–19.0)*	0.00
Puncture time (s)	28.90 ± 6.68	21.84 ± 3.17*	31.03 ± 7.34#	0.00
Incidence of local haematoma (%)	11 (35.48%)	7 (22.58%)	2 (6.45%)*	0.01

Notes: Data are presented as medians (interquartile ranges), means ± SDs or numbers (percentages). *$P < 0.05$ indicates difference from group C; #$P < 0.05$ indicates difference from group AS.

Discussions

This prospective randomised controlled study showed that acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided radial artery cannulation improved the success rate of cannula insertion and reduced the incidence of local haematomas in residents. This information suggested that this technique is beneficial for standardized training and teaching of radial artery cannulation to residents.

Quan et al [6] made the first attempt to use acoustic shadowing technique for radial artery cannulation in children and showed that the success rate of radial artery cannulation in children was greatly improved by the use of acoustic shadowing technique as compared to traditional ultrasound guidance. In our study, this technique similarly significantly improved the first puncture success rate among residents and also reduced the Puncture time compared with the traditional ultrasound teaching group. The double-developing lines technique helps to determine the projection point of the radial artery on the skin surface, which leads to a fast and accurate determination of the puncture point and helps to shorten the puncture time[7]. Another advantage of this method is that residents can focus on the two low-density shadows without having to stare at the entire ultrasound screen[8]. Therefore, this technique is particularly suitable for residents who do not have extensive experience with ultrasound-guided puncture.

However, in this study, compared with the traditional ultrasound teaching group, the success rate of cannulation with acoustic shadowing technique has not been significantly improved. This may be due to the limited development depth of the development line, which can not track the position of the needle tip

well. The dynamic needle tip positioning method is based on the short-axis out-of-plane ultrasound technique, where dynamic tip tracking is achieved by moving the ultrasound probe and the arterial puncture needle[9]. This technique has been shown to significantly improve the clinically relevant aspects of radial artery cannulation[10–11]. In our study, the successful rate of first-attempt cannulation was significantly higher and the incidence of haematoma was lower in the acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided teaching group than acoustic shadowing group alone. During radial artery cannulation, the success of the first cannulation is critical, but success rates tend to be lower for beginners[12]. The advantage of the dynamic needle tip positioning technique allows the tip position to be dynamically and continuously visible, thus reducing the risk of failure of cannula insertion and the risk of penetrating the posterior wall of the artery, which is crucial for beginners[13]. Additionally, we observed that the localization time in the acoustic shadowing combined with dynamic needle tip positioning group was similar to that of the acoustic shadowing group, but the puncture time was longer. This may be due to the residents' lack of experience with ultrasound machines, which made it difficult to locate the needle tip position in the ultrasound screen during the operation, and therefore required a longer puncture time.

Medical resources in China are relatively unevenly distributed, and some hospitals do not have advanced equipment to assist radial artery cannulation [14–15]. Therefore, how to use simple equipment to improve teaching effectiveness is an ongoing concern for the majority of instructors. The use of acoustic shadowing-facilitated ultrasound guidance technique requires only standard ultrasound equipment and is easy to operate. Combined with the dynamic needle tip positioning technique significantly improves the success rate of cannula insertion, which is suitable for resident teaching and further promotes the homogeneity of standardized residency training.

Our study has some limitations. (1) This study was not a double-blind clinical trial in which the residents could see the developed lines on the ultrasound image during the puncture procedure. (2) When using the dynamic needle tip positioning method, it may be difficult for inexperienced residents to locate the needle tip in the ultrasound screen. (3) This trial included residents who had not performed radial artery cannulation previously, and the results of the study may have been different if residents with some experience had been included. (4) During the course of the study, we could not guarantee that all residents would be taught and tested on the exact same radial artery.

Conclusions

Acoustic shadowing combined with dynamic needle tip positioning-facilitated ultrasound-guided radial artery cannulation although prolonging the puncture time, but can help residents master radial artery cannulation more quickly and improve the success rate of first-attempt cannulation. Therefore, we recommend this teaching method.

Declarations

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Author contributions

QM X and YN W had designed this study. HD performed the statistical analysis of the collected data. QM X and YN W wrote the main manuscript text. RH H, FX W and XH participated in skills teaching and student management. JM W participated in the revision of the manuscript text. All the authors participated in the data collection and reviewed the manuscript.

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Data availability

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Figures

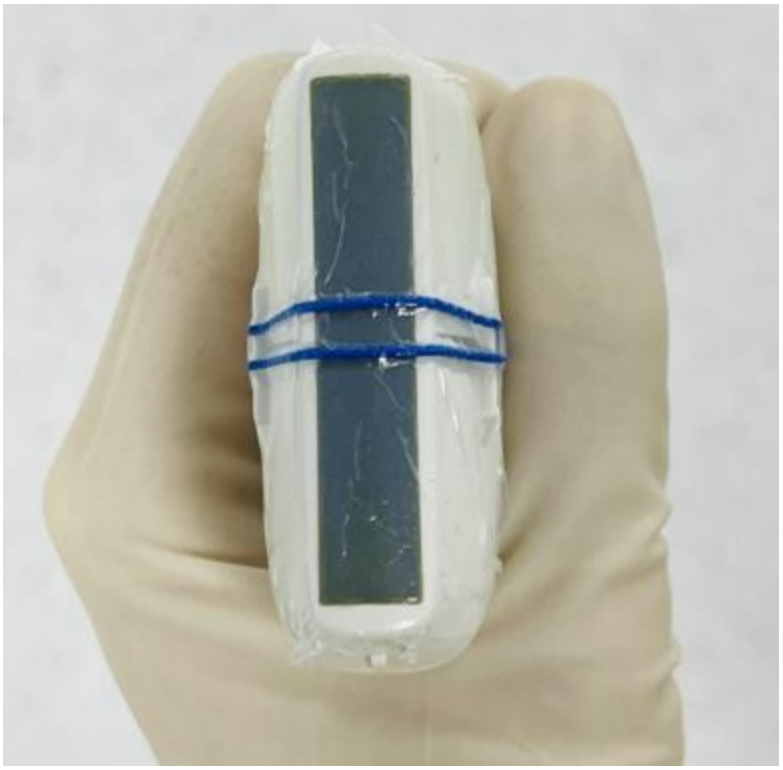


Figure 1

The double developing lines on the ultrasound probe

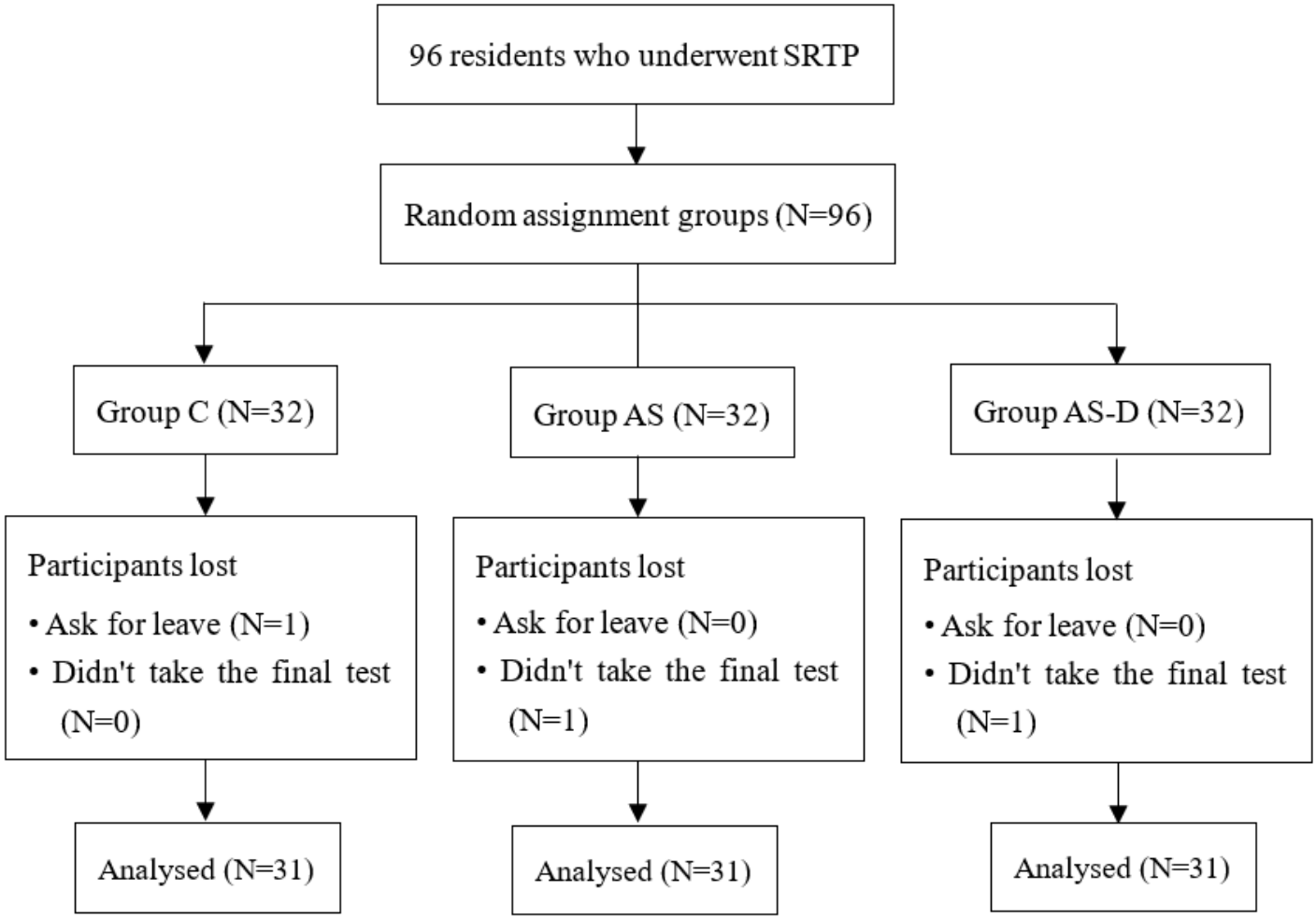


Figure 2

Flow chart for the research

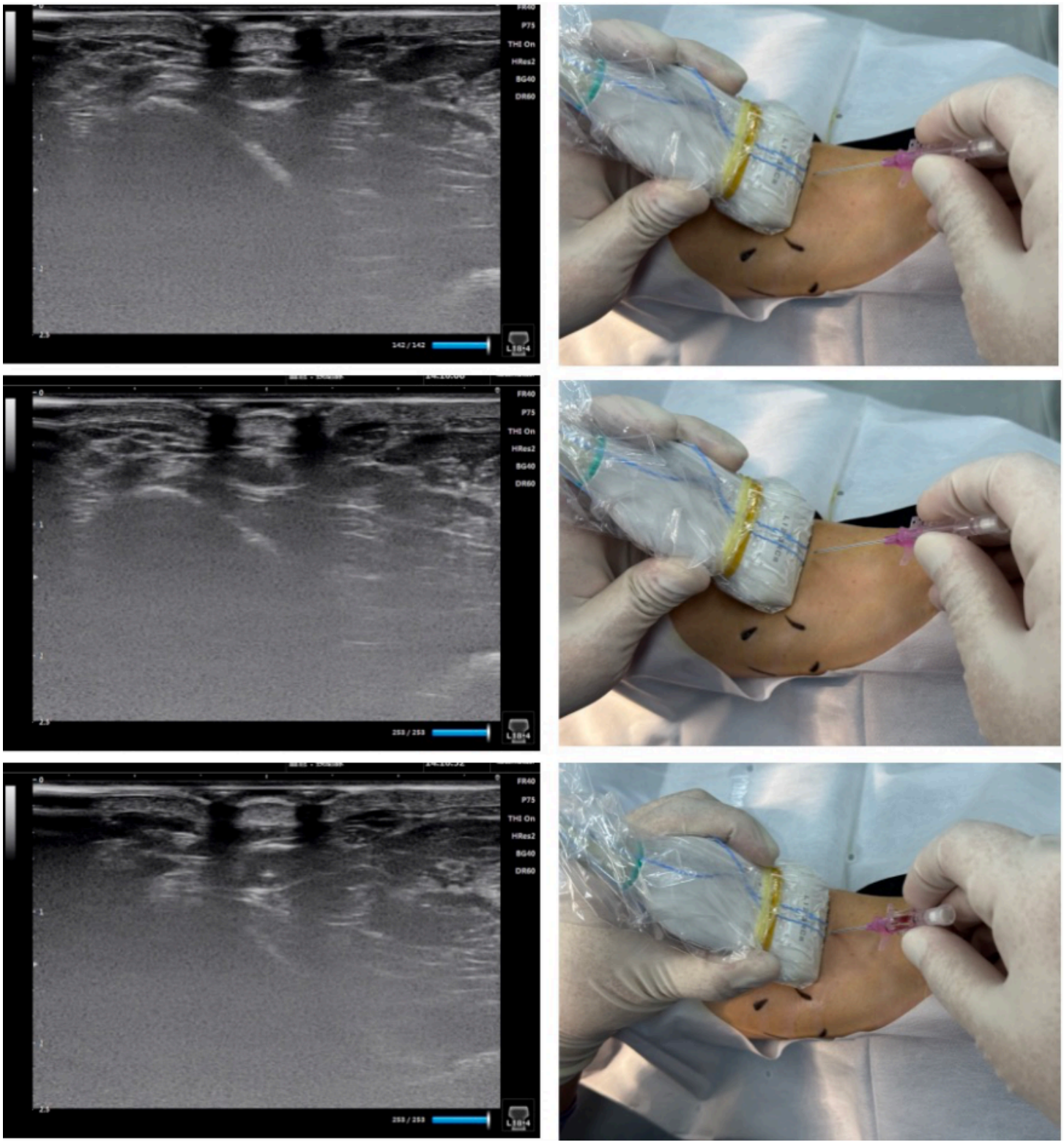


Figure 3

Unnumbered image in the Result section.