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Ultrasonic Technology Improves Radial Artery Puncture and Cannulation in Intensive Care Unit (ICU) Shock Patients

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Manuscript Preparation E
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Background: This study observed the efficacy of ultrasonic technique with out-of-plane orientation and in-plane guidance in radial artery puncture and cannulation in intensive care unit (ICU) shock patients to elucidate the effect of this technique on the security of cannulation.

Material/Methods: A total of 88 ICU shock patients, randomized into a palpation (control) group and an ultrasound (experimental) group, received continuous intravenous sedation and analgesia. The palpation group patients underwent radial artery cannulation using the traditional palpation pulsation approach, and the ultrasound group patients underwent radial artery cannulation under out-of-plane orientation and in-plane guidance using an ultrasonic apparatus. Data were recorded and compared between the 2 groups.

Results: (1) The success rate of the first puncture in the ultrasound group and the palpation group was 80% and 42%, respectively ($P<0.05$). (2) The cannulation duration in the ultrasound group and the palpation group was 8.77±6.33 s and 28.7±26.33 s, respectively ($P<0.01$). (3) Incidence of hematoma and staxis around stoma in the ultrasound group was 2.5% and 5%, respectively, which was significantly lower than that in the palpation group, which was 20% and 32.5%, respectively ($P<0.05$). (4) Time to achieve the early goal-directed therapy in the ultrasound group and the palpation group was 306.73±39.98 min and 356.75±40.97 min, respectively ($P<0.01$).

Conclusions: Compared with the traditional method, radial artery cannulation with out-of-plane orientation and in-plane guidance is a quick and secure cannulation method and is appropriate for use in clinics.

MeSH Keywords: **Shock, Cardiogenic • Ultrasonography**

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Background

Shock patients may experience acute changes in disease conditions and have extremely unstable hemodynamics. Blood pressure and pulse pressure are the most important outcomes in the diagnosis and treatment of shock. Vasopressor drugs are often required to maintain the blood pressure in addition to fluid infusion for the treatment of shock. The *2012 Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock* recommends establishing an artery catheter in patients receiving vasopressor drugs as soon as possible and monitoring the arterial blood gas analysis and the changes in lactate levels. It is apparent that non-ambulatory, noninvasive blood pressure measurement is unable to meet the present clinical requirements. Therefore, it is necessary to establish an invasive blood pressure monitoring method as soon as possible that can not only observe the real-time pressure but also facilitate arterial blood sampling for shock patients. Radial artery cannulation has become the most commonly used artery cannulation method due to its superficial location and less severe complications [1].

Currently, the traditional blind cannulation method is commonly used in radial artery cannulation in the intensive care unit (ICU), which includes cannulation through palpating artery pulsation. The puncture success rate of this method relies on the skill of operators and vascular conditions of patients. However, blind cannulation is difficult to achieve and is prone to cause local damage in shock patients due to hypovolemia and poor angiosclerosis, as well as impalpable, weak radial artery pulsation. This leads to prolonged puncture duration and increased puncture frequency, in which the sustained and repeated needle stimulation to the vascular wall tends to aggravate and prolong the hyper-reactivity of the radial artery [2], deteriorating the arterial spasm. Therefore, a fast and secure method of radial artery cannulation is needed in clinics, for which the introduction of ultrasonic technique may be beneficial.

As a new visualization technique, the ultrasonic technique tends to improve the puncture success rate and reduce the puncture damage. Ultrasound guidance can be divided into out-of-plane and in-plane approaches, each having its own advantages and disadvantages. At present, most domestic and foreign studies used a single-puncture approach, and a combination of the 2 approaches has been rarely reported. This study combined the advantages of the 2 methods; the technique of out-of-plane orientation and in-plane guidance was applied to perform radial artery cannulation, aiming to discover an optimal method and provide clinical reference for conducting radial artery cannulation in shock patients.

The aim of the study was to observe the efficacy of ultrasonic technique with out-of-plane orientation and in-plane guidance in radial artery puncture and cannulation in ICU shock patients to elucidate the effect of this technique on the security of cannulation.

Material and Methods

Instruments and drugs

(1) Mobile two-dimensional ultrasonic apparatus: Site Rite 5, frequency 5–10 MHz (Bard Company, UT, USA). (2) Multifunctional electrocardiogram monitor: MP50 (M8004A) (Philips: Hewlett-Packard, Boeblingen, Germany). (3) Pressure transducer: Batch No. 2805813 (ICU Medical Inc., CA, USA). (4) Surflo Flash: Model 20G 51 mm (Terumo Corporation, Japan). (5) Ultrasonic coupling agent: Model KL-250 medical ultrasonic coupling agent (Hangzhou Keppler Medical Materials Co., Ltd, China). (6) Propofol injection: Batch No. H20130504 (Corden Pharma S.P.A. Viale dell' Industria 3, Caponago, Italy). (7) Butorphanol tartrate injection: Batch No. H20020454 (Jiangsu Hengrui Medicine Co., Ltd., China). (8) 2% Chlorhexidine gluconate: Hangzhou Xizi Sterilizing Facilities Co., Ltd., China. (9) Alcohol: Hangzhou Outuopu Biotech Co., Ltd., China. (10. 0.9% Sodium chloride injection: Shanghai Baxter Healthcare Corporation, China.

Patients and grouping

This prospective study was approved by the Ethics Committee of the hospital (Approval ID: 2015-k-015-01), and all the patients or their family members signed the written informed consent.

Using the inclusion criteria, 88 shock patients, aged 16–85 years, in the ICU were successively selected between May 2014 and December 2014.

Exclusion criteria: Patients having a history of forearm surgery, local infection, local artery embolism, and abnormal results in a quantitative SaO_2-Allen trial (negative).

The patients were divided into a palpation group (control group) and an ultrasound group (experimental group) using a random number table developed by the Clinical Assessment Center. Each group contained 44 patients.

Operational methods

Preparation

The patients' arms were externally rotated in extension; the wrists were in dorsiflexion as much as possible, and the medial side of the palms and arms was faced upward to expose the forearm. Then, the patients were given a continuous intravenous injection of butorphanol tartrate for analgesia and an intravenous

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injection of propofol for sedation, in which the analgesia score (Critical-Care Pain Observation Tool) was maintained at 0–2 points and the sedation score (Richmond Agitation-Sedation Scale) was maintained at –1 to 0 points. The same puncture materials were used in both the groups, and the puncture was performed by the same group of medical staff, which contained 4 members, including 1 specialized nurse and 3 nurse-in-charge leaders with more than 10 years of experience in artery blind cannulation. The group members received unified training by the cannulation team of the hospital, and had 3 months of experience in ultrasound-guided cannulation; they did not show any difference in operation by consistency analysis.

Operational procedures

Palpation group

The operator palpated the strongest radial artery pulsation from the superior part of the transverse crease of the wrist to the heart along the radial part of the forearm to assess the suitability of puncture. Then, a small pillow was blocked under the wrist, sterile towels were placed under the forearm, the arm was fixed, and the puncture area was disinfected twice using 2% chlorhexidine gluconate. Wearing sterile gloves, the operator palpated and fixed the strongest pulsation part of the radial artery with the ventral surface of the left index finger, and inserted the needle into the radial artery with an angle of 15–45° using the right hand. After reflux blood was seen from the sheathed needle, the needle tail was compressed and pushed 2–3 mm forward. Then, the external trocar was inserted, the needle was retracted, and a pressure transducer was connected, followed by disinfection and fixation after normal waveforms were seen. Inserting the needle once was referred to as 1 puncture, and repuncture after the needle was retracted was referred to as the second puncture. A successful puncture meant that the artery waveforms were shown on the monitor after the pressure transducer was connected. If the puncture was unsuccessful 3 times in the patients, it was termed as puncture failure, in which case the patients were switched to ultrasound-guided puncture.

Ultrasound group

The out-of-plane technique was first used to observe the diameter, depth, trajectory, and surrounding tissues of the radial artery within 15 cm above the transverse crease of the wrist to assess the presence of deformity and suitability of cannulation. Then, a small pillow was blocked under the anterior one-third of the forearm, a sterile towel was placed under the forearm, and the arm was fixed. After that, the in-plane technique was used to select a 5-cm segment with a thick diameter and a smooth inner wall at 5 cm above the transverse crease of the wrist. The superior part of the radial artery at the 2 ends of this segment was labeled with a marker using the out-of-plane

Figure 1. Site of each point on the surface.

technique (the proximal end was denoted as A, and the distal end was denoted as B), whereas a mark (denoted as C) was made near the wrist and on the extension of these 2 marks where the length of extension was >3 cm (Figure 1). Then, the puncture area was disinfected with 2% chlorhexidine gluconate, the coupling agent was applied to the probe surface, and the probe was covered with a sterile sleeve and tightened with a rubber band. Wearing sterile gloves, the operator sat at the trailing end of the puncture arm, with the face perpendicular to the arm of the patient. Alcohol was applied to the skin as a coupling agent, and the position of each point was confirmed again using the cross-sectional surface. Then, the probe was longitudinally placed at the AB segment above the radial artery using the left hand, and the needle was quickly inserted into the skin at a point on the extension with the right hand, followed by superficially inserting the needle toward the B point in the subcutaneous tissues above the radial artery with a small angle (without puncturing the radial artery). Then, the angle was increased after the puncture needle entered the ultrasound vision, which was inserted into the radial artery through the anterior wall of the radial artery under ultrasound guidance. When reflux blood was seen, the needle tail was lowered, the needle was pushed forward 2–3 mm, the external trocar was inserted, the needle was retracted, and a pressure transducer was connected, followed by disinfection and fixation. The puncture point was selected at 2–3 cm away from the probe, which was adjusted according to the depth of the radial artery, where the puncture point was selected at a farther location with a deeper radial artery. If no reflux blood was found in the vessels using ultrasound, the observation needle at the probe was gently deviated and part of the needle was retracted, followed by angle adjustment and repuncture, where the puncture site was changed after 3 unsuccessful punctures.

Outcomes and data acquisition

The main outcome was the success rate of the first puncture, and the rest were secondary outcomes.

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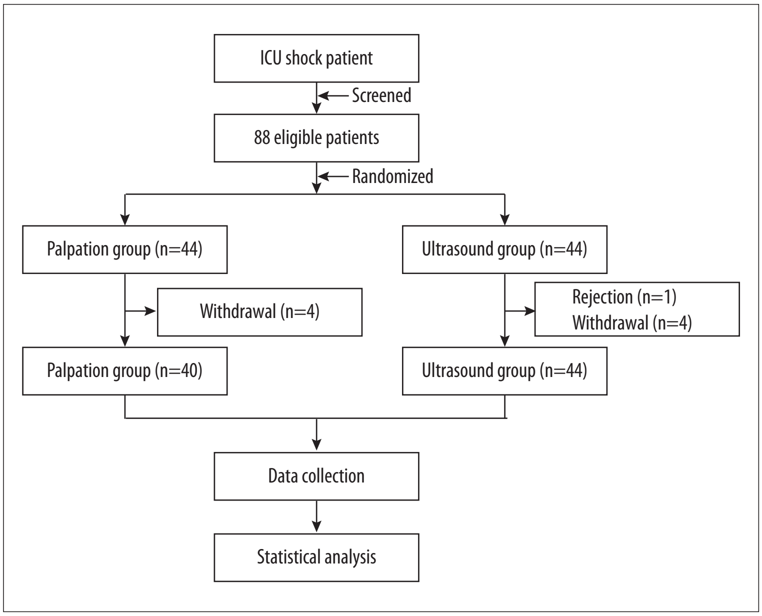

Figure 2. Flowchart for randomized controlled trial.

(1) The success rate of the first puncture referred to the proportion of patients with successful cannulation at first puncture. (2) The failure rate of the puncture referred to the proportion of patients with puncture failure, which was defined as 3 unsuccessful punctures at one site. (3) Puncture duration referred to the time from inserting the puncture needle into the skin to successfully inserting the trocar, which was calculated using a stopwatch.

(4) The incidence of hematoma referred to the proportion of patients in whom local swelling occurred during the puncture or within 3 days after the puncture. (5) The incidence of staxis around stoma referred to the proportion of patients in whom a small amount of staxis occurred around stoma continuously within 3 days after cannulation. (6) Time to achieve early goal-directed therapy (EGDT) referred to the time from the transfer of shock patients into the ICU to EGDT after treatment, in which they promptly received radial artery cannulation after entering the ICU. Physicians and nurses were blinded to the observation and recording of this indicator because it was affected by a variety of factors. (7) Overall duration referred to the time from the beginning of the assessment to the appearance of arterial waveform on the monitor, where it started from assessing radial arterial pulsation in the palpation group and the radial artery of the forearm using the ultrasound technique in the ultrasound group.

Statistical analysis

Statistical analyses were performed using SPSS 17.0 software. Measurement data in accordance with normal distribution were expressed as mean ± standard deviation ($\overline{\chi}$±sd). The comparisons were performed using the independent-samples *t* test, whereas count data were compared using the χ^2 test. A difference with $P<0.05$ was considered statistically significant.

Results

Rejection and withdrawal

Four withdrawal cases existed in the palpation group, of which 2 died within 3 days and 2 cases were discharged against medical advice within 3 days. One rejection case and 3 withdrawal cases existed in the ultrasound group, of which 1 case was excluded due to flexion and stenosis of bilateral radial arteries, 1 case died within 3 days, and 2 cases were discharged against medical advice (Figure 2).

Comparison of general information

Age, type of shock, prothrombin time, activated partial thromboplastin time, blood platelet count, critical illness score (APACHE-II score), depth of radial artery at 5 cm above the transverse crease of the wrist, amount of norepinephrine, and mean arterial pressure did not show significant differences between the 2 groups ($P>0.05$) (Table 1).

Comparison of outcomes

Outcomes (Table 2)

Main outcome

The success rate of the first puncture was significantly higher in the ultrasound group than in the palpation group ($P<0.05$).

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Table 1. Comparison of general information between the two groups.

	Palpation group	Ultrasound group	*P* value
Gender (M/F)	26/14	27/13	1.000
Age (year)	64.08±12.43	61.9±14.24	0.469
Type of shock			0.954
Hypovolemic shock (n)	6 (15.0%)	7 (17.5%)	
Septic shock (n)	30 (75.0%)	29 (72.5%)	
Cardiogenic shock (n)	4 (10.0%)	4 (10.0%)	
PT (SCE)	13.342±1.05	13.67±0.80	0.124
APTT (SCE)	45.13±10.234	41.03±9.901	0.072
PLT (10^9)	111.85±35.121	113.58±31.014	0.400
APACHE-II score (point)	22.38±3.112	22.1±2.772	0.682
Depth of radial artery (mm)	3.59±0.94	3.66±0.85	0.700
Amount of norepinephrine (µ/kg·min)	0.64±0.17	0.61±0.20	0.370
MAP (mmHg)	58.10±4.82	58.05±5.12	0.964

Comparison between the two groups, *P*>0.05. PT – prothrombintime; APTT – activated partial thromboplastin time; PLT – blood platelet; APACHE-II – Acute Physiology and Chronic Health Evaluation; MAP – mean arterial pressure.

Table 2. Outcomes for the two groups.

	Palpation group	Ultrasound group	*P* value
Success rate for the first puncture (%)	42% (17/40)	80% (32/40)	0.010*
Failure rate of puncture (%)	17.5% (7/40)	2.5% (1/40)	0.018*
Puncture duration (s)	28.±26.33	8.77±6.33	<0.001*
Hematoma (%)	20% (8/40)	2.5% (1/40)	0.029*
Staxis around stoma (%)	32.5% (13/40)	5% (2/40)	0.040*
Time to reach EGDT (min)	356.75±40.97	306.73±39.98	<0.001*
Overall puncture duration (s)	192.67±27.95	186.87±14.57	0.289

* *P*<0.05; EGDT – the early goal directed therapy.

Secondary outcomes

The failure rate of puncture, puncture duration, and time to achieve EGDT were significantly shorter in the ultrasound group than in the palpation group (*P*<0.05), while the overall puncture duration did not show any significant difference between the 2 groups (*P*>0.05).

Adverse reactions

Incidences of hematoma and staxis around stoma were significantly lower in the ultrasound group than in the palpation group (*P*<0.05).

Imaging of ultrasound-guided puncture

(1) Imaging before the needle started to pass through the anterior wall of the radial artery (Figure 3). (2) Imaging after the needle entered the radial artery (Figure 4).

Discussion

The ultrasonic technique has been widely clinically used in various vascular punctures due to visualization and security, and has become the "third eye" of physicians, leading to reduced complications and thus attracting more and more attention in clinics. In recent years, with the emergence of high-frequency high-resolution ultrasonic apparatus and improvement in ultrasonic probes, the use of ultrasound-guided radial artery

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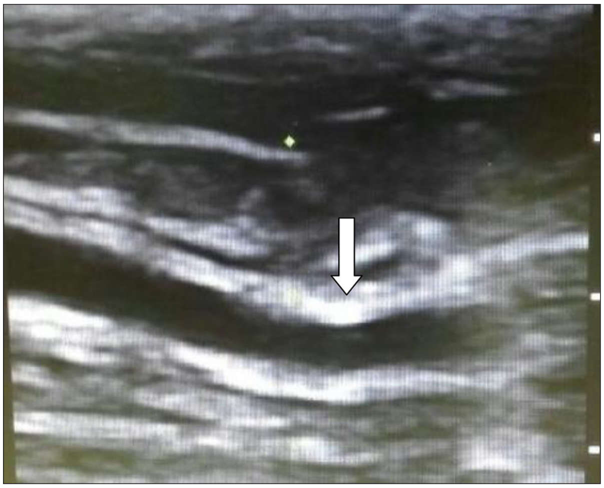

Figure 3. Image of the needle penetrating the anterior wall of the radial artery.

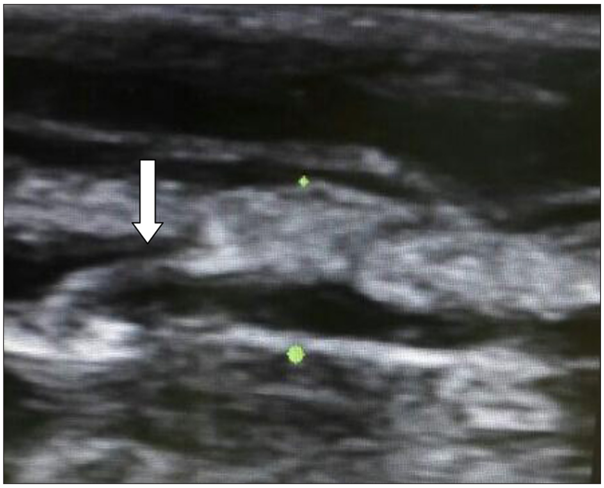

Figure 4. Image of the needle after entering the radial artery.

cannulation in rescue and treatment intervention of patients with emergency and severe illness has increased. Because artery puncture may lead to more severe complications compared with the venous puncture, the current study focused on ways to minimize puncture-related complications. Among these, the ultrasound technique has been confirmed to have many advantages in radial artery cannulation compared with the traditional palpation method. Shiloh et al. [3] retrospectively analyzed 334 patients undergoing ultrasound-guided radial artery cannulation and found that high-frequency ultrasound guidance improves the success rate for the first puncture. In terms of puncture duration, Shiver et al. [4] revealed that the time for successful cannulation was shorter in the ultrasound group than in the traditional palpation group. Tokumine et al. [5] confirmed that the ultrasound tended to guide the radial artery puncture effectively in patients with difficulty in radial artery palpation. Furthermore, Velasco et al. [6] reported that the ultrasound technique enabled clinicians to find and avoid puncture at various points for patients with radial artery variation.

The ultrasound guidance has 2 modes: cross-sectional (out-of-plane technique) and vertical-sectional (in-plane technique) approaches, both of which have their own advantages and disadvantages. The out-of-plane technique is prone to intercept the cross-sectional images of the vascular lumen and identify the vascular location, and also intuitively determines the relationship between sternal angle and vascular lumen. However, its disadvantage is that it can only capture local and vague images of the needle, failing to visualize the needle tip location and leading to a high penetration rate. The in-plane ultrasound guidance reveals the overall path of the needle and clearly displays the needle tip location, and also maintains the needle tip at the radial artery level, preventing the needle from penetrating the posterior wall of the vessels and resulting in a low penetration rate. However, due to the thickness of the ultrasound beam, when the needle travels outside the vessels while still in the section range of the ultrasound probe, overlapping images of the vessels and needle may appear, resulting in an illusion that the needle is inside the vessels. Berk et al. [7] found that the in-plane technique had shorter operation time, higher success rate for the first puncture, and lower incidence of posterior wall penetration compared with the out-of-plane technique. Cannulation time was shorter in the in-plane technique group (24±17 s) than in the out-of-plane technique group (47±34 s) ($P<0.05$). The artery cannulation by the in-plane approach increased the success rate of cannula insertion at the first attempt (76%) compared with the out-of-plane approach (51%). Posterior wall damage during artery cannulation was found in 30 patients in the out-of-plane group (56%) and 11 patients in the in-plane group (20%), ($P<0.05$). In their study, the use of in-plane approach during ultrasound-guided radial artery cannulation had a higher success rate at first insertion. They also found that the in-plane approach resulted in shorter cannulation time and decreased the incidence of complications. Mahler et al. [8] used in-plane and out-of-plane guidance separately in patients having difficulty in peripheral venous cannulation, and found that the puncture duration was shorter in patients with in-plane guidance. In cannulation under the guidance of in-plane technique, the probe position must be fixed using the left hand because even a slight shift may miss the puncture plane. Therefore, the in-plane technique is more difficult than the out-of-plane technique, and most beginners favor the latter. Ball et al. [9] believed that although the in-plane guidance was more difficult, it tended to achieve clearer luminal images, prevented the needle from damaging the vessels, and was safer in clinical use. Michael et al. [10] also confirmed that the in-plane guidance tended to achieve a better and clearer observation of the needle tip, avoiding the damage of the contralateral vascular wall and surrounding tissues.

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For cannulation of thin vessels, a larger sternal angle of the out-of-plane technique tended to induce a larger compression in puncturing the anterior wall of the vessels, which was likely to compress the vessels and reduce the vascular lumen, causing difficulty in observing the needle tip location and increasing the likelihood of penetrating the posterior wall of the vessels and inducing hematoma. However, a smaller sternal angle of the in-plane technique tends to induce less compression in puncturing the anterior wall of the vessels, leading to smaller changes in the vascular lumen. Furthermore, this technique enabled the operator to locate the needle in the whole puncture process, avoiding penetration of the posterior wall. Therefore, the superiority of the in-plane technique is even more prominent in treating shock patients. Also, shock patients often have coagulation disorders, and are prone to hematoma and difficulty in hemostasis once the arteries are penetrated. Thus, the in-plane guidance was favored for conducting radial artery cannulation in shock patients in this study. Based on this, to clearly determine the inserting direction and avoid artifacts caused by section thickness to the greatest extent, this study used out-of-plane orientation to visualize the projection of the radial artery at the puncture segment on the body surface, fully utilizing the advantages of the out-of-plane and in-plane techniques.

In this study, the success rate of the first puncture was up to 80%, which was higher than that obtained in selected patients with the in-plane guidance alone reported by Berk et al. [7]. The incidence of posterior wall damage in this study was also lower. Therefore, radial artery cannulation with out-of-plane orientation and in-plane guidance tended to combine the advantages of the 2 methods, which could significantly improve the success rate for the first puncture and reduce the incidence of hematoma and other complications [10]. The improvement in the success rate of the first puncture tended to reduce the cannulation time, allowing physicians to quickly obtain accurate and dynamic invasive pressure data, which is important in rescuing shock patients.

The puncture duration was significantly shorter in the ultrasound group than in the palpation group, which could shorten the duration of suffering in patients, alleviate the pain stimulation in puncture, and reduce the incidence of infection. In patients with shock, the body tissues are in a state of hypoxia, where pain and other adverse stimuli tend to aggravate oxygen consumption, deteriorating the condition. Shorter puncture duration may also alleviate the arterial spasm.

The failure rate was significantly higher in the palpation group than in the ultrasound group, leading to postponed establishment of ambulatory blood pressure. Although the overall puncture duration did not have any difference between the 2 groups, the time to achieve EGDT was different, which might be associated with the difference in the puncture failure rate. Also, patients in the palpation group in which the puncture was unsuccessful 3 times were successfully punctured after they were switched to the ultrasound-guided puncture.

The incidence of hemorrhage around stoma was significantly lower in the ultrasound group than in the palpation group, which might be due to the following reasons: (1) The success rate of the first puncture was higher in the ultrasound group, leading to fewer punctures. (2) In this study, the puncture point in the ultrasound group was 3 cm above the transverse crease of the wrist, facilitating fixation and avoiding the effect of wrist activities. However, the puncture point in the palpation group was selected below the part with most significant radial arterial pulsation, that is, 0.5–2 cm above the transverse crease of the wrist, which is unfavorable for fixation and prone to be affected by the wrist activity, leading to displacement of the catheter. (3) In the ultrasound group, the puncture needle tended to first travel 2.5–3.5 cm in the subcutaneous tissues before it entered the radial artery, hence allowing sufficient soft tissues between the parts for the catheter to enter the radial artery and the skin puncture point, so as to fill in the space between the catheter and muscles. This played an important role in fixing the catheter and reducing the chances of infection. Furthermore, the catheter was inserted into 1.5–2.5 cm of radial artery, reducing the incidence of catheter-related thrombosis and arterial inflammation.

The following aspects should be noted during the operation: (1) Full sedation and analgesia should be applied before puncture. Since most of the ICU shock patients were in severe conditions, they were normally given mechanical ventilation through endotracheal intubation. Thus, the patients could and must keep continuous sedation and analgesia to alleviate the pain and discomfort caused by various channels and operations, reducing the oxygen consumption. For patients who were particularly sensitive to pain might be given a quick injection of 2–4 mg propofol before puncture, so as to prevent the displacement of the arm during the puncture. (2) The A, B, and C sites for surface positioning must be marked accurately and clearly. Since the inner diameter of the radial artery is very thin in shock patients, the A and B sites for positioning in the out-of-plane technique must be marked above the center of the radial artery, and A, B, and C sites must be in a straight line, ensuring that the puncture trajectory is coplanar with and above the radial artery. (3) The operator must sit at the trailing end of the puncture arm, with face perpendicular to the patients' arm, which allows the puncture needle to travel along the defined straight line (surface projection of the radial artery at the puncture segment) and decrease deviation. Furthermore, the left elbow of the operator must lean on a special fixture to hold the probe. (4) The A and B sites must be confirmed again to be above the radial artery using the cross-section, and the

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C site must be at the extension of A and B, so as to prevent the deviation of puncture direction due to changes in their locations. (5) In the ultrasound group, a small pillow should be blocked under the posterior one-third of the forearm, which avoids affecting the insertion angle. A small pillow should be blocked below the wrist in the palpation group, where the different blocking positions of the small pillows in the 2 methods are due to different puncture point locations.

Although this study enrolled only shock patients, this method is applicable to all patients undergoing radial artery cannulation, and presents an even higher success rate in patients with normal hemodynamics and good angiosclerosis. Also, this method is preferable for patients undergoing surgical intervention through radial artery puncture and venous cannulation.

Conclusions

Radial artery cannulation with out-of-plane orientation and in-plane guidance in shock patients can improve the success rate for the first puncture, shorten puncture duration, and reduce related complications. Hence, it is a quick and secure cannulation method and is appropriate for use in clinics. With the development of scientific techniques, the multifunctional, multiprobe, and multidimensional ultrasound apparatus plays a significant role in clinics.

Limitations

1. The study did not assess radial artery cannulation under the guidance of a single approach in shock patients.
2. The inner diameter and blood flow of the radial artery in shock patients were not measured accurately.
3. The patients' body weight and BMI were not measured due to the limitation of body weight-measuring instruments.
4. The sample size was small; each group consisted of only 40 cases. Therefore, further large-sample studies are needed to confirm the clinical significance of this approach.

Conclusions

1. Radial artery cannulation with out-of-plane orientation and in-plane guidance in shock patients tended to obtain a high success rate for the first puncture, and short puncture duration.
2. Radial artery cannulation with out-of-plane orientation and in-plane guidance in shock patients tended to achieve a lower incidence of complications compared with the traditional palpation method.
3. Radial artery cannulation with out-of-plane orientation and in-plane guidance in shock patients reduced the time to achieve EGDT compared with the traditional palpation method.

Conflict of interest

The authors declare that they have no actual or potential conflicts of interest.

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