Effects of ultrasound-guided radial artery catheterization: an updated meta-analysis

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A B S T R A C T

Background: Previous meta-analyses have shown that ultrasound guidance is an effective technique for radial artery catheterization. However, these reports neglected to include several non–English language studies. Therefore, an updated meta-analysis including more eligible studies was performed to assess the effectiveness of ultrasound-guided radial artery catheterization.

Methods: Eligible studies were identified by systematically searching PubMed, EMBASE, Wanfang, and China National Knowledge Infrastructure literature databases. The outcome measure was the rate of first-attempt success. Two investigators identified the randomized controlled trials (RCTs) for inclusion and independently extracted data from these RCTs. The quality of the included studies was evaluated using the Jadad score. The relative risk (RR) for dichotomous outcomes and the 95% confidence intervals (CIs) were calculated and pooled using a random-effects model.

Results: Eleven RCTs involving 803 patients met the inclusion criteria. Ultrasound-guided radial artery catheterization was generally associated with a 47% improvement, as compared with the palpation technique, in terms of the rate of first-attempt success (RR, 1.47; 95% CI, 1.22-1.76; P < .0001). Specifically, the ultrasound-guided technique significantly improved the rate of first-attempt success for adult (RR, 1.39; 95% CI, 1.13-1.72; P = .002) and pediatric (RR, 1.68; 95% CI, 1.15-2.47; P = .008) patients.

Conclusions: Adult and pediatric patients benefited from ultrasound-guided radial artery catheterization in terms of the rate of first-attempt success. Given the potential bias and significant heterogeneity of the available data in the present study, further investigation is required to confirm the present findings and to identify other effects of the ultrasound-guided technique.

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1. Introduction

Radial artery catheterization is a well-established procedure that enables accurate hemodynamic monitoring and frequent arterial blood sampling. The procedure is widely used in the operating room, intensive care unit, and the emergency department. To date, 2 main techniques are used in radial arterial catheterization or puncture. The traditional technique relies on external landmarks and uses pulse palpation to guide the radial artery catheterization. However, the palpitation technique has been associated with a low rate of first-attempt success [1].

The development of ultrasound applications in medicine has led to the use of ultrasound guidance as a tool for central vein catheterization; the ultrasound-guided technique has increased success rates and decreased the rates of complications, as compared with the traditional palpation technique [2-4]. The American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists recommend ultrasound as an effective rescue technique for arterial access; ultrasound can likewise identify the location and patency of suitable arteries for cannulation or procedural access [5].

Previously reported systematic reviews and meta-analyses [6,7] were based on aggregate data from randomized controlled trials (RCTs); their findings suggested that ultrasound-guided radial artery catheterization is superior to traditional palpation in terms of an improved rate of first-attempt success. However, the previous reviews included RCTs that were exclusively written in English and mainly conducted in the United States and Europe. These previous meta-analyses neglected non–English language RCTs, especially those published in Chinese; the excluded RCTs could add to the existing knowledge base. Therefore, we conducted an updated meta-analysis that incorporated...
all relevant studies, including the original research from China, to critically assess the rate of first-attempt success of ultrasound-guided radial artery catheterization.

2. Methods

2.1. Data sources and literature search

A comprehensive literature search for original research articles (dated up to June 2014) was conducted in PubMed, EMBASE, Wanfang (www.wanfangdata.com.cn), and China National Knowledge Infrastructure (www.cnki.net) databases using the following keywords: [(Doppler OR ultrasound OR ultrasonography) AND (radial artery catheterization OR radial arterial puncture)]. The search was restricted to human subjects and RCTs, but no language restrictions were imposed. Additional manual searches were made to identify all potentially relevant studies from the references of the search results as well as the recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists [5].

2.2. Study selection

The following selection criteria were applied: (i) population: only adult and pediatric patients with radial artery catheters or punctures were included; (ii) intervention vs control: the study compared 2-dimensional ultrasound guidance against traditional palpation; (iii) outcome measures: the rate of first-attempt success was reported; and (iv) study design: RCT was used.

2.3. Data extraction and outcome measurement

We recorded the first author, year of publication, sample size, study population (setting), operator, and the catheter specifications for each included RCT. To evaluate the eligibility of these studies, the analytical data and trial quality information were independently extracted by 2 authors. The extracted information were entered into a standardized Excel file by one author and subsequently checked by another author. Any discrepancies were discussed until a consensus was achieved. The analytical data to be included in our meta-analysis but was missing from the original published studies were sought from their authors. The rate of first-attempt success was defined as the outcome measure.

2.4. Quality and risk-of-bias assessment

The methodological quality of each included study was evaluated using the Jadad scale [8]. This scale is composed of 3 items that described the randomization (0-2 points), blinding (0-2 points), and the dropouts and withdrawals (0-1 points) in the RCTs. A score of 1 is awarded for each of the abovementioned points. An additional point is given when the appropriate method of randomization and/or blinding is specified. A score of 2 or lower indicates low quality, whereas a score of 3 or higher indicates high quality [9]. The risk of bias was measured using the Cochrane Handbook for Systematic Reviews of Interventions (Revman version 5.1.0, The Cochrane Collaboration 2011).

2.5. Statistical analysis

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement was followed during the analysis [10]. Significant differences between RCTs were reported in terms of the relative risk (RR), with 95% confidence intervals (CIs) for dichotomous outcomes; results were pooled across studies using a random-effects model [11]. The heterogeneity across studies was tested using the \( I^2 \) statistic, a quantitative measure of inconsistency across studies. The heterogeneity of each study was classified as either low (\( I^2 = 25\%-50\% \)), moderate (\( I^2 = 50\%-75\% \)), or high (\( I^2 > 75\% \)) [12]. If \( I^2 > 50\% \), the potential sources of heterogeneity were identified using sensitivity analyses conducted by sequentially excluding each study and investigating the influence of a single study on the overall pooled estimate. A subgroup analysis was performed based on differences among studies in terms of the patient age (\( \geq 18 \) years vs \(< 18 \) years), sample size (\( \geq 100 \) vs \(< 100 \)), and methodological quality (\( \geq 3 \) vs \(< 3 \)). The publication bias was assessed using Begg funnel plot and Egger test [13]. A value of \( P < 0.05 \) was considered significant. The analysis of publication bias was conducted using Stata version 12.0 (Stata Corporation LP, College Station, TX). Other data and statistical analyses were combined and performed using Revman. 5.1.0 (The Cochrane Collaboration, Oxford, UK).

Fig. 1. Search strategy and flowchart of the meta-analysis.
Table 1
Main characteristics of RCTs included in the meta-analysis

<table>
<thead>
<tr>
<th>Study/Country</th>
<th>No. of patients (ultrasound/palpation)</th>
<th>Study population</th>
<th>Operator</th>
<th>Catheters</th>
<th>Study design/Jadad score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levin et al</td>
<td>69 (34/35)</td>
<td>Adult (cardiothoracic, abdominal, neuro- and vascular surgery)</td>
<td>Anesthesia attending physicians and residents with USG central venous catheter placement experience</td>
<td>20-G intravenous catheters (Venflon; Becton Dickinson, Helsingborg, Sweden)</td>
<td>RCT/3</td>
</tr>
<tr>
<td>Shiver et al</td>
<td>60 (30/30)</td>
<td>≥18 y (from the emergency department)</td>
<td>Attending physicians with experience of US-guided peripheral and central venous lines, but without US-guided arterial catheters</td>
<td>20-G Arrow radial-artery catheterization kit (Arrow International Inc, Reading, PA)</td>
<td>RCT/3</td>
</tr>
<tr>
<td>Schwemmer et al</td>
<td>30 (15/15)</td>
<td>≥6-mo children (for neurosurgery)</td>
<td>Anesthesiologists with experience of ≥20 pediatric arterial catheterizations</td>
<td>24-G cannulas (Becton Dickinson, Helsingborg, Sweden)</td>
<td>RCT/2</td>
</tr>
<tr>
<td>Ganesh et al</td>
<td>152 (72/80)</td>
<td>&lt;18 y children (abdominal, craniofacial, neuro-, orthopedic, and thoracic surgery)</td>
<td>Pediatric subspecialty trainee anesthesiologists who had performed &lt;10 US-guided arterial cannulations before the study</td>
<td>NA</td>
<td>RCT/2</td>
</tr>
<tr>
<td>Mei et al</td>
<td>40 (20/20)</td>
<td>32- to 62-year-old patients (with traumatic injury)</td>
<td>Anesthesiologists with experience more than 5 y of clinical work, and more than 5 mo of US-guided vascular puncture</td>
<td>20-G or 22-G intravenous catheters (Insyte WTM; Becton Dickinson, Franklin Lakes, NJ)</td>
<td>RCT/2</td>
</tr>
<tr>
<td>Bobbia et al</td>
<td>72 (37/35)</td>
<td>Adult patients with general anesthesia</td>
<td>One board-certified anesthesiologist who had been trained in the ultrasound technique in 20 patients before the study</td>
<td>NA</td>
<td>RCT/3</td>
</tr>
<tr>
<td>Ishii et al</td>
<td>59 (59/59)</td>
<td>Pediatric patients scheduled to undergo elective cardiac surgery for congenital heart disease</td>
<td>Trainees in anesthesiology with experience of ≥3 y of clinical training and with US-guided central venous catheterization</td>
<td>24-G JELCO cannulas (Smiths Medical, Dublin, OH)</td>
<td>Crossover RCT/3</td>
</tr>
<tr>
<td>Liu et al</td>
<td>60 (30/30)</td>
<td>1–3 y children with elective surgery</td>
<td>Anesthesia attending physicians with experience ≥4 y of US-guided radial artery and deep vein puncture</td>
<td>22-G intravenous catheters (Insyte WTM; Becton Dickinson, Singapore)</td>
<td>RCT/3</td>
</tr>
<tr>
<td>Ma et al</td>
<td>61 (30/31)</td>
<td>16- to 75-year-old patients needing to monitor arterial blood pressure and blood gas analysis</td>
<td>Anesthesia attending physicians with experience of ≥5 years of clinical training and with US-guided central venous catheterization</td>
<td>20-G catheters (Terumo, Japan)</td>
<td>RCT/2</td>
</tr>
<tr>
<td>Hansen et al</td>
<td>40 (40/40)</td>
<td>≥18-year-old patients scheduled for elective cardiac surgery</td>
<td>Anesthesiologists with experience of 20 y in transesophageal and transthoracic ultrasonography and of 1 y in ultrasonography dynamic needle tip positioning, but without US-guided nerve blocks</td>
<td>20-G radial-artery catheterization kit (Becton Dickinson Critical Care Systems, Franklin Lakes, NJ)</td>
<td>Blinded crossover RCT/5</td>
</tr>
<tr>
<td>Quan et al</td>
<td>160 (80/80)</td>
<td>28- to 78-year-old patients scheduled for hepatectomy and splenectomy</td>
<td>Anesthesia attending physicians with experience of ≥4 y of US-guided artery and venous catheterization</td>
<td>NA</td>
<td>RCT/2</td>
</tr>
</tbody>
</table>

US, ultrasound; USG, ultrasound guidance; NA, not applied.

* Matched data (the radial arteries are matched as they belong to the same patient).

3. Results

3.1. Eligible studies and studies of characteristics

The initial search yielded 185 potential articles; 174 of these articles were excluded based on their titles and abstracts because they were duplicate studies or because of other reasons (Fig. 1). A final list of 11 full-text RCTs were selected for the meta-analysis [14–24]. Seven of the RCTs were published in English [14–20], and the remaining 4 were in Chinese [21–24]. The principal characteristics of the selected articles are provided in Table 1. The selected RCTs involved a total of 803 patients; these studies were published between 2003 and 2014. The sample sizes of these RCTs varied from 30 to 160. Among the 11 RCTs, 7 involved adult patients [14,16,18,20,22–24] and 4 involved pediatric patients [15,17,19,21]. Eight RCTs adopted 20-24 G catheters [15–18,20–23], whereas the remaining RCTs did not report the catheter type or size [14,19,24]. In addition, all the included RCTs reported training or experience with both forms of arterial puncture.

3.2. Quality and risk-of-bias assessment

The 2 authors agreed on every item of the Jadad scores. The mean (SD) Jadad score was 2.7 (0.9). The risk-of-bias analysis showed that only one study was both double blinded and described the method used to conceal allocation of patients [20]. Fig. 2 presents the risk-of-bias of the individual RCTs.

3.3. Meta-analysis of outcome measure

All the selected RCTs reported the rate of first-attempt success [14–24]. The aggregated results of these studies suggested that ultrasound-guided radial artery catheterization was associated with a significant improvement in terms of the rate of first-attempt success, as compared with the palpation technique (RR, 1.47; 95% CI, 1.22–1.76; P < .0001; Fig. 3). Significant heterogeneity was observed among the selected studies (P = .005 for heterogeneity; I² = 60%). We subsequently performed sensitivity analyses to explore potential sources of heterogeneity. Further exclusion of each study did not alter the combined RR value.
However, it did cause the CI to change the width with a range from 1.41 (95% CI, 1.17-1.68; \( P = .0002 \)) to 1.54 (95% CI, 1.37-1.74; \( P = .0001 \)). Furthermore, we performed subgroup analyses for the rate of first-attempt success; this step aimed to examine the effect of various exclusion criteria according to the patient age, patient sample size, and the methodological quality of the combined estimates (Table 2). These exclusion criteria did not significantly alter the overall combined RR, which ranged from 1.32 (95% CI, 1.12-1.55; \( P = .001 \)) to 1.73 (95% CI, 1.35-2.21; \( P < .0001 \)).

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**Fig. 2.** Risk-of-bias assessment.

**Fig. 3.** Forest plot of the meta-analysis of RCTs. Ultrasound guidance techniques are compared with traditional palpation techniques in terms of the rate of first-attempt success. Each block represents a study, and the area of each block is proportional to the precision of the mean treatment effect in that particular study. The horizontal line represents the 95% CI for the treatment effect in a study. The center of the diamond represents the average treatment effect across studies. The width of the diamond denotes its 95% CI. US, ultrasound.
The present analysis only focused on the rate of first-attempt success because it was the most tangible outcome. This rate is the most convincing indicator that can represent the effectiveness of ultrasound-guided radial artery catheterization. This point was similarly highlighted by the authors of a previous meta-analysis [6]. Multiple discrete clinical end points were previously assessed by the RCTs and included in our meta-analysis. These end points are, namely, the number of catheters used, overall success, mean attempts or time to success, and the incidence of complications like hematoma. Given that the included RCTs did not use uniform criteria to define these end points, we could not formally combine the said end points in the present study. However, these clinical end points provide more compelling evidence of the tangible benefits for clinicians than simply increasing first-pass success [26]. Future studies should clearly define these important points, as previously reported by the prior research. In addition, we believe that first-attempt success may not be equal to the minimum clinically important difference despite the fact that any amount of change greater than the minimum clinically important difference threshold is generally considered meaningful or important [28].

Several limitations of the present meta-analysis should be taken into consideration. First, the 11 included RCTs have a high variation of patient populations. Overestimation of the treatment effect usually occurs in smaller trials compared with larger samples. Second, considerable heterogeneity was observed among the included RCTs. The targeted population, the experience level of the operators, catheter specifications, and study design differed among these RCTs. The above-mentioned factors may cause heterogeneity and potentially influence the meta-analysis results. Furthermore, differences in ultrasonic instruments used in the RCTs may have affected the present results. Finally, the exclusion of missing and unpublished data from the RCTs may have led to selection bias.

3.4. Publication bias

The results of the Begg and Egger tests suggested that there was no significant publication bias for the rate of first-attempt success among the included RCTs (Begg test, \( P = .533 \); Egger test, \( P = .340 \); Fig. 4).

4. Discussion

The primary purpose of the present meta-analysis was to update and critically evaluate the effects of ultrasound-guided arterial catheterization on patients. Our results suggested that ultrasound guidance, as compared with traditional palpation, was associated with significant improvements in adult and pediatric patients in terms of the rate of first-attempt success.

To the best of our knowledge, reviews and meta-analyses on ultrasound-guided arterial catheterization have been previously published [6,7,25,26]. One such meta-analysis was performed and published in 2011 by Shiloh et al [6]. Their study involved a total of 311 patients and included 4 RCTs. Their meta-analysis showed that ultrasound-guided radial artery catheterization improved the likelihood of a first-attempt success rate by 71%, as compared with traditional palpation techniques. The most recent systematic review and meta-analysis included 7 RCTs and enrolled 546 patients; this review was conducted by Gu et al [26] and published in 2014. Their analysis suggested that ultrasound-guided radial artery catheterization is an effective and safe technique for patients. The meta-analysis of the present study suggested that ultrasound-guided radial artery catheterization dramatically increased the rate of first-attempt success in both adult and pediatric patients. Thus, our results are apparently similar to the previously reported by the prior research. In addition, we believe that these clinical end points provide more compelling evidence of the tangible benefits for clinicians than that from the United States and Europe. Therefore, we set rigorous inclusion criteria to produce robust results and included additional RCTs (involving a total of 361 patients) to increase the sample size and to improve the test performance.

The present analysis only focused on the rate of first-attempt success because it was the most tangible outcome. This rate is the most convincing indicator that can represent the effectiveness of ultrasound-guided radial artery catheterization. This point was similarly highlighted by the authors of a previous meta-analysis [6]. Multiple discrete clinical end points were previously assessed by the RCTs and included in our meta-analysis. These end points are, namely, the number of catheters used, overall success, mean attempts or time to success, and the incidence of complications like hematoma. Given that the included RCTs did not use uniform criteria to define these end points, we could not formally combine the said end points in the present study. However, these clinical end points provide more compelling evidence of the tangible benefits for clinicians than simply increasing first-pass success [26]. Future studies should clearly define these important points, as previously reported by the prior research. In addition, we believe that first-attempt success may not be equal to the minimum clinically important difference despite the fact that any amount of change greater than the minimum clinically important difference threshold is generally considered meaningful or important [28].

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### Table 2

<table>
<thead>
<tr>
<th>Outcome</th>
<th>n (N)</th>
<th>Ultrasound</th>
<th>Palpation</th>
<th>RR (95% CI)</th>
<th>P</th>
<th>F (%)</th>
<th>Heterogeneity P</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>All included trials [14–24]</td>
<td>803 (11)</td>
<td>306/447(^a)</td>
<td>210/455(^a)</td>
<td>1.46 (1.31-1.63)</td>
<td>&lt;.0001</td>
<td>60</td>
<td>.0005</td>
<td>Fixed-effects</td>
</tr>
<tr>
<td>High-quality trials (Jadad score ≥ 3) [14–16,18,20,21]</td>
<td>360 (6)</td>
<td>171/230(^a)</td>
<td>113/229(^a)</td>
<td>1.47 (1.08-2.00)</td>
<td>.02</td>
<td>76</td>
<td>.0009</td>
<td>Random-effects</td>
</tr>
<tr>
<td>Low-quality trials (Jadad score &lt; 3) [17,19,22–24]</td>
<td>443 (5)</td>
<td>135/217</td>
<td>97/226</td>
<td>1.39 (1.21-1.59)</td>
<td>&lt;.0001</td>
<td>0</td>
<td>.43</td>
<td>Random-effects</td>
</tr>
<tr>
<td>Large-scale trials (number &gt; 100) [19,24]</td>
<td>312 (2)</td>
<td>82/152</td>
<td>65/160</td>
<td>1.32 (1.12-1.55)</td>
<td>.001</td>
<td>0</td>
<td>.45</td>
<td>Random-effects</td>
</tr>
<tr>
<td>Modest small-scale trials (number ≤ 100) [14–18,20–23]</td>
<td>492 (9)</td>
<td>224/295(^a)</td>
<td>145/295(^a)</td>
<td>1.52 (1.22-1.91)</td>
<td>.0003</td>
<td>65</td>
<td>.004</td>
<td>Random-effects</td>
</tr>
<tr>
<td>Adult patients [14,16,18,20,22–24]</td>
<td>502 (7)</td>
<td>216/271(^a)</td>
<td>157/271(^a)</td>
<td>1.38 (1.22-1.55)</td>
<td>&lt;.0001</td>
<td>65</td>
<td>.008</td>
<td>Fixed-effects</td>
</tr>
<tr>
<td>Pediatric patients [15,17,19,21]</td>
<td>301 (4)</td>
<td>90/176(^a)</td>
<td>53/184(^a)</td>
<td>1.73 (1.35-2.21)</td>
<td>&lt;.0001</td>
<td>51</td>
<td>.11</td>
<td>Fixed-effects</td>
</tr>
</tbody>
</table>

\( \text{n, number of patients; N, number of trials.} \)

\(^a\) Matched data (the radial arteries are matched as they belong to the same patient).
5. Conclusions

To date, evidence in the literature implies that both adult and pediatric patients have benefited from ultrasound-guided radial artery catheterization in terms of the rate of first-attempt success. However, the selected data for inclusion in the present meta-analysis have potential bias and significant heterogeneity. Therefore, large-scale studies with improved designs should be conducted in the future to further confirm the current findings and to investigate other effects of the ultrasound-guided technique.

Acknowledgments

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References