



Ultrasound-Guided Catheterization of the Radial Artery

A Systematic Review and Meta-analysis of Randomized Controlled Trials

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Background: Ultrasound guidance commonly is used for the placement of central venous catheters (CVCs). The Agency for Healthcare Research and Quality recommends the use of ultrasound for CVC placement as one of its 11 practices to improve patient care. Despite increased access to portable ultrasound machines and comfort with ultrasound-guided CVC access, fewer clinicians are familiar with ultrasound-guided techniques of arterial catheterization. The goal of this systematic review and meta-analysis was to determine the utility of real-time two-dimensional ultrasound guidance for radial artery catheterization.

Methods: A comprehensive literature search of Medline, Excerpta Medica Database, and the Cochrane Central Register of Controlled Trials by two independent reviewers identified prospective, randomized controlled trials comparing ultrasound guidance with traditional palpation techniques of radial artery catheterization. Data were extracted on study design, study size, operator and patient characteristics, and the rate of first-attempt success. A meta-analysis was constructed to analyze the data.

Results: Four trials with a total of 311 subjects were included in the review, with 152 subjects included in the palpation group and 159 in the ultrasound-guided group. Compared with the palpation method, ultrasound guidance for arterial catheterization was associated with a 71% improvement in the likelihood of first-attempt success (relative risk, 1.71; 95% CI, 1.25-2.32).

Conclusions: The use of real-time two-dimensional ultrasound guidance for radial artery catheterization improved first-pass success rate. *CHEST* 2011; 139(3):524-529

Abbreviations: 2-D = two-dimensional; CVC = central venous catheter; RCT = randomized controlled trial

Arterial catheterization is a commonly performed minimally invasive procedure in the ICU that enables accurate hemodynamic monitoring and frequent blood sampling.¹ The insertion, especially in patients with hypotension, edema, and obesity, often is difficult and may require multiple attempts. Repeated attempts

at catheterization may become progressively more difficult due to arterial spasm. Although generally it is a safe procedure, mechanical, infectious, and thromboembolic complications occur in 1% to 5% of cases.^{1,2} The radial artery is the most common site for arterial catheterization because of its superficial course and dual arterial supply to the hand by the ulnar artery.^{2,3}

Ultrasound guidance is commonly used for the placement of central venous catheters (CVCs). Numerous randomized controlled trials (RCTs) and meta-analyses have associated ultrasound use with

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considerable reductions in complications and increased first-attempt success when compared with traditional landmark techniques.^{4,6} The Agency for Healthcare Research and Quality recommends the use of ultrasound for CVC placement as one of its 11 practices to improve patient care.⁷

Despite increased access to ultrasound machines and comfort with ultrasound-guided CVC access, fewer clinicians are familiar with ultrasound-guided techniques of arterial catheterization. The radial artery is easily visualized as an echo-free pulsatile circle. Ultrasound-guided arterial catheterization is easily learned if the operator has familiarity with other ultrasound-guided procedures. The objective of this meta-analysis was to determine the effectiveness of using two-dimensional (2-D) ultrasound guidance for radial artery catheterization and its effect on first-attempt success.

MATERIALS AND METHODS

Medline, Excerpta Medica Database (EMBASE), and the Cochrane Central Register of Controlled Trials (CENTRAL) were searched from inception through February 23, 2010, using appropriately broad medical subject headings and Emtree terms for arterial catheterization and ultrasonography. Conference proceedings (2005-2009) of the American Thoracic Society, the Society of Critical Care Medicine, the American Association of Respiratory Care, the European Society of Intensive Care Medicine, the American College of Chest Physicians, and the International Symposium on Intensive Care and Emergency Medicine were searched for relevant abstracts. Experts in the field were contacted to seek additional articles, and the reference lists of identified titles were searched. There were no language restrictions. Guidelines established by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Group were followed.⁸ The search strategy is shown in Table 1.

Selection

Prospective RCTs comparing radial artery catheterization using real-time 2-D ultrasound guidance techniques with traditional palpation techniques were included in the review. Trials evaluating the use of Doppler ultrasonography, marking techniques (without using real-time guidance), or catheterization of other arteries were excluded. Adult and pediatric populations were included. Two reviewers independently evaluated the identified titles, confirmed eligibility for use, and extracted data. Discrepancies were resolved by consensus.

Validity Appraisal

The methodologic quality of selected trials was appraised by two independent reviewers using the Jadad criteria.⁹ The following criteria were assessed: randomization of subjects, the use of blinding, and the completeness of subject follow-up.

Statistical Analysis

Analysis of the combined data was conducted using RevMan version 5.0 software (The Nordic Cochrane Centre; Copenhagen,

Denmark). A random effects model was used to estimate the relative risk of dichotomous outcomes and associated 95% CIs. Heterogeneity was assessed visually by forest plot and by formal statistical tests for heterogeneity. The χ^2 test was used to assess whether observed differences in results were compatible with chance alone. $P < .10$ provided evidence of heterogeneity of intervention effects. In addition, the I^2 statistic was used to describe the percentage of the variability in effect estimates due to heterogeneity rather than to chance. Heterogeneity was considered significant if the I^2 statistic exceeded 50%.¹⁰

RESULTS

Selection

Three hundred titles were identified by the search strategy. The flow diagram (Fig 1) summarizes the steps followed to identify the RCTs meeting the inclusion criteria. Seven RCTs were identified, of which three trials were excluded for using Doppler ultrasound,^{11,12} marking techniques,¹² or catheterization of an artery other than the radial artery.¹³

Included Trial Characteristics

Four trials were included in the review, all of which compared real-time 2-D ultrasound guidance techniques to traditional palpation techniques for radial artery catheterization.¹⁴⁻¹⁷ A total of 311 pediatric and adult patients were randomized. Table 2 details the characteristics of the individual trials.

Validity Appraisal

All selected trials were randomized. Given the nature of the intervention studied, blinding was not possible. All subjects studied were reported in the final results of the trials. The individual Jadad scores can be found in Table 2.

Results of Statistical Analysis

A total of 159 subjects underwent arterial catheterization using an ultrasound guidance technique, of which 43% had first-attempt success, and 152 subjects were catheterized using palpation techniques, of which 27% had first-attempt success. The pooled relative risk for ultrasound-guided techniques was 1.71 (95% CI, 1.25-2.32). The χ^2 test and the I^2 statistic for heterogeneity were not significant ($P = 3.36$; $I^2 = 11\%$). The corresponding forest plot is seen in Figure 2 with data provided in Table 3.

DISCUSSION

According to our findings, the use of ultrasound guidance for arterial catheterization improved the likelihood of a first-pass success rate by 71% compared with traditional palpation techniques. Many robust

Table 1—Search Strategy

Database	Search Terms
Medline	1. (ultrasound or ultrasonic or Doppler) 2. catheterization, peripheral/methods 3. 1 and 2
EMBASE	4. (artery catheterization or catheterization or blood vessel catheterization) 5. (ultrasonography or Doppler) 6. 4 and 5
CENTRAL	7. (ultrasound or ultrasonic or Doppler) 8. catheterization, peripheral/methods

CENTRAL = Cochrane Central Register of Controlled Trials; EMBASE = Excerpta Medica Database.

RCTs and meta-analyses have concluded that the use of ultrasound reduces complications and improves success rates for CVC placement. The few trials on ultrasound-guided arterial catheterization involved relatively small patient populations. Our meta-analysis pooled these populations to allow an adequate sample size for determining the effectiveness of using 2-D ultrasound guidance for radial artery catheterization.

Multiple different outcomes were assessed by the trials, including overall success, number of attempts, number of catheters used, and time to catheterization. Because the trials did not use uniform criteria to define these outcomes, they could not be combined formally in our meta-analysis. Our analysis focused on first-pass success rate because this was the most objective outcome and the least likely to be

influenced by the inability to blind the study participants. Overall, the trials tended to show that the use of ultrasound guidance resulted in a higher success rate, a reduced number of attempts, a reduced number of catheters used, and a faster time to catheterization than palpation.

The trial by Ganesh et al¹⁷ was the only one that did not show any benefit when implementing ultrasound guidance. As explained by the authors, this finding was likely due to the lack of training and inexperience of the operators at ultrasound-guided catheterization. Notably, their most-experienced operator in ultrasound-guided catheterization was successful with the technique in three cases when the initial operator failed at the palpation technique. In addition, when compared with the other trials, Ganesh et al had the lowest first-pass success rates in both the ultrasound (13.8%) and the palpation (13.9%) groups.

Standard arterial catheterization relies on anatomic landmarks and the palpation of a pulse. Frequently, obesity, edema, and shock states limit the ability to successfully palpate and catheterize a vessel. External landmarks can be unreliable in predicting underlying anatomy and can be particularly poor if aberrant anatomy exists. The inguinal crease, a common puncture site for femoral artery catheterization, has been shown by Lechner et al¹⁸ to be an inaccurate predictor of femoral vasculature. In 65% of cases, a portion of the common femoral artery overlaps the common femoral vein.¹⁹ Although less aberration occurs at the distal forearm (the most frequent site of arterial catheterization), up to 30% of individuals have variation in the origin and course of the radial artery.²⁰

Although the evidence is not strong, direct arterial visualization would likely reduce complications besides failure to place, which occur more frequently when repeated attempts are made. Shiver et al¹⁶ compared the complication rate between the ultrasound-guided and palpation groups. They demonstrated a 43% reduction in the development of a hematoma at the puncture site (ultrasound, 7%; palpation, 50%). The arterial catheter, as a potential source of sepsis, should be accorded the same degree of importance as the CVC.²¹ As such, ultrasound guidance may be indicated as a way to decrease risk of infection, as was demonstrated in an RCT of CVC placement where ultrasound guidance decreased infection rates compared with landmark techniques.²² Furthermore, although not formally evaluated, it is very likely that patient pain and discomfort would be reduced when first-pass success is increased.

Although direct 2-D ultrasound seems to have significant benefit for arterial catheterization, alternative uses of ultrasound have not been proven to be as beneficial. When using two-way Doppler ultrasound to mark a puncture site for radial artery

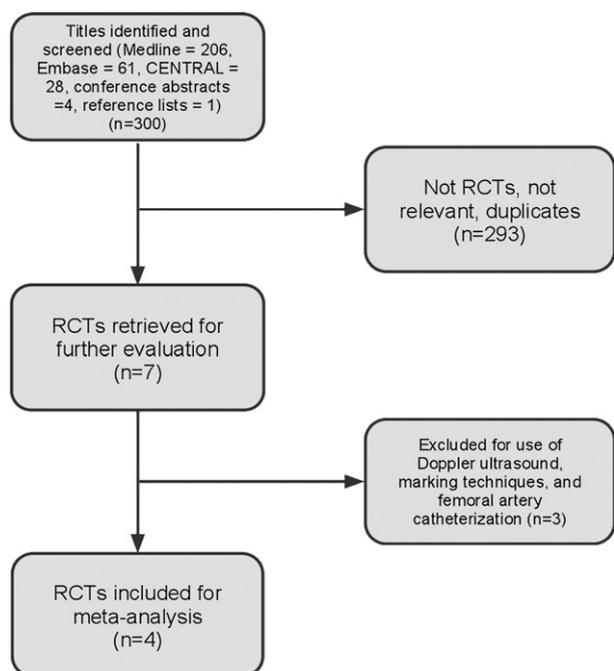


FIGURE 1. Flow diagram of study identification, inclusion, and exclusion. CENTRAL = Cochrane Central Register of Controlled Trials; Embase = Excerpta Medica Database; RCT = randomized controlled trial.

Table 2—Summary of RCTs of Ultrasound-Guided Arterial Catheterization

Author	Sample Size	Population	Operator	First-Attempt Success ^a		Jadad Score	P Value
				USG	Palpation		
Levin et al ¹⁴	69	Adult cardiothoracic, abdominal, neuro-, and vascular surgery	Anesthesia attending physicians and residents with USG CVC placement experience but with minimal USG arterial catheterization experience	62% (21/34)	34% (12/35)	3	.03
Schwemmer et al ¹⁵	30	Infant neurosurgery	Anesthesiologists with experience in >20 pediatric arterial catheterizations in both palpation and USG	67% (10/15)	20% (3/15)	3	<.05
Shiver et al ¹⁶	60	Adult ED	Attending emergency physicians without USG arterial catheterization experience; all had extensive USG CVC and peripheral venous catheterization experience	87% (26/30)	50% (15/30)	3	.005
Ganesh et al ¹⁷	152	Pediatric abdominal, craniofacial, neuro-, orthopedic, and thoracic surgery	Pediatric trainee and consultant anesthesiologists, 94% with <5 USG arterial catheterization experience	13.8% (11/80)	13.9% (10/72)	3	1

CVC = central venous catheter; RCT = randomized controlled trial; USG = ultrasound guidance.

^aFor all studies, the intervention was real-time two-dimensional ultrasound guidance to visualize the radial artery and direct arterial catheterization, and the control was palpation of the radial artery.

catheterization, Tada et al^{12,23} did not find benefit over palpation techniques, although there was benefit in select cases of hemorrhagic shock. An abstract by Puig et al¹¹ demonstrated a 19.6% reduction in failure in a trial of radial artery catheterization using Doppler ultrasound guidance. We excluded trials that used Doppler ultrasound or marking techniques from our meta-analysis because both are considered inferior to the use of 2-D real-time visual guidance for the analogous procedure of CVC placement.^{5,24-27}

Ultrasound requirements for arterial and venous catheterization are similar. Costs include the purchase of the machine, sterile ultrasound sheaths, staff training, and machine maintenance. The potential reductions in complications, numbers of catheter sets required, and time of the procedure for both CVC

and arterial catheterization may assist in offsetting the cost of machinery and supplies. Randolph et al⁴ showed that ultrasound guidance would be required in five patients to prevent more than one attempt at CVC insertion. Comparably, by calculating the number needed to treat (based on the absolute risk reduction of 16%), ultrasound guidance would be required for approximately six arterial catheter placements to prevent more than one attempt at insertion. In a cost-effectiveness analysis of ultrasound-guided CVC placement, Calvert et al²⁸ concluded that cost savings were relatively sensitive to the assumed average number of procedures per machine per week and the average number of ultrasound procedures per week undertaken by each trained operator. Because the ultrasound placement techniques for arterial and venous catheters are relatively similar, in our experience, little additional cost or time would be required to train clinicians in ultrasound-guided arterial catheterization. It is not a requirement that ultrasound machines be state of the art to facilitate vascular access; whereas current devices may be smaller and highly portable, older devices are able to provide more-than-adequate and highly cost-effective bedside ultrasound visualization.^{29,30}

Although we formally evaluated the radial artery, ultrasound can be used to assist in catheterization of multiple arterial sites, including the femoral, axillary, and dorsalis pedis.³⁰ Reports of ultrasound-guided brachial and transpectoral axillary artery catheterization

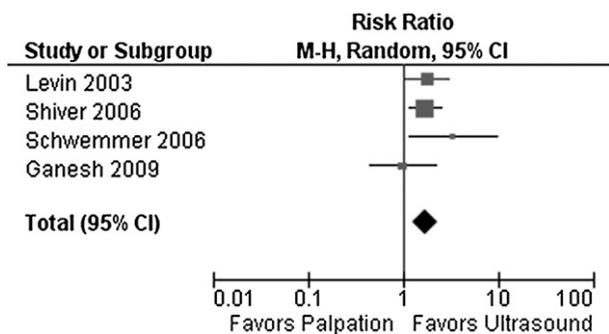


FIGURE 2. Effect of ultrasound-guided catheterization on first-attempt success. M-H = Mantel-Haenszel test.

Table 3—Effect of Ultrasound-Guided Catheterization on First-Attempt Success

Study/Year	USG		Palpation		Weight, %	Risk Ratio M-H, Random (95% CI)
	Events	Total	Events	Total		
Levin et al ¹⁴ /2003	21	34	12	35	29.1	1.80 (1.06-3.06)
Shiver et al ¹⁶ /2006	26	30	15	30	49.1	1.73 (1.18-2.55)
Schwemmer et al ¹⁵ /2006	10	15	3	15	7.9	3.33 (1.14-9.75)
Ganesh ¹⁷ /2009	11	80	10	72	14.0	0.99 (0.45-2.19)
Total	68	159	40	152	100.0	1.71 (1.25-2.32)

Heterogeneity: $\tau = 0.01$; $\chi^2 = 3.36$; df (degrees of freedom) = 3 ($P = .34$); $I^2 = 11\%$. Test for overall effect: $z = 3.41$ ($P = .0007$). M-H = Mantel-Haenszel test. See Table 2 legend for expansion of other abbreviation.

have been described.^{31,32} When using ultrasound for the assistance of interventional procedures requiring a femoral artery puncture, case series have demonstrated rapid procedure times, decreased radiation exposure (fluoroscopy time), and reduced complication rates (pseudoaneurysm formation).³³⁻³⁵

CONCLUSION

Our meta-analysis clearly demonstrated a 71% increase in the likelihood of first-attempt success when using ultrasound guidance for radial artery catheterization. The strengths of our review include a thorough, comprehensive, and minimally restrictive literature search, with the inclusion of both adult and pediatric populations in different clinical scenarios. Although there could be theoretical concern regarding trial heterogeneity in our study, our rigorous meta-analysis (I^2 statistic and χ^2 test) revealed minimal heterogeneity and did not prevent formal analysis. The limitations include the inherent lack of blinding when conducting ultrasound studies and the relatively small number of trials and patients available for analysis. In addition, the training and experience of the operators varied in the included trials. Although further research is required to demonstrate cost-effectiveness and reduction in complication rates, the use of ultrasound guidance is beneficial for radial artery catheterization.

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Author contributions: *Dr Shiloh:* contributed to concept, data collection, statistical analysis, primary authorship and composition of manuscript, and final review of the submitted manuscript. He takes responsibility for the integrity of the data and the accuracy of the data analysis.

Dr Savel: contributed to statistical analysis, crucial review, editing, and final review of the submitted manuscript.

Dr Paulin: contributed to data collection, crucial review, editing, and final review of the submitted manuscript.

Dr Eisen: contributed to concept, crucial review, editing, and final review of the submitted manuscript.

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