Critical Care Medicine
Issue: Volume 24(12), December 1996, pp 2053-2058

Publication Type: [Special Article]
ISSN: 0090-3493
Accession: 00003246-199612000-00020

[Special Article]

Ultrasound guidance for placement of central venous catheters: A meta-analysis of the literature

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Supported, in part, by National Research Service Award F32 HS00 106-01 from the Agency for Health Care Policy and Research (Dr. Randolph).

Abstract

Objective: To evaluate the effect of real-time ultrasound guidance using a regular or Doppler ultrasound technique for placement of central venous catheters.

Data Sources: We searched for published and unpublished research using MEDLINE, citation review of relevant primary and review articles, conference abstracts, personal files, and contact with expert informants.

Study Selection: From a pool of 208 randomized, controlled trials of venous and arterial catheter management, eight published randomized, controlled trials were identified.

Data Extraction: In duplicate, independently, we abstracted data on the population, intervention, outcome, and methodologic quality.

Data Synthesis: Ultrasound guidance significantly decreases internal jugular and subclavian catheter placement failure (relative risk 0.32; 95% confidence interval 0.18 to 0.55), decreases complications during catheter placement (relative risk 0.22; 95% confidence interval 0.10 to 0.45), and decreases the need for multiple catheter placement attempts (relative risk 0.60; 95% confidence interval 0.45 to 0.79) when compared with the standard landmark placement technique.

Conclusions: When used for vessel location and catheter placement real-time, ultrasound guidance or Doppler ultrasound guidance improves success rates and decreases the complications associated with internal jugular and subclavian venous catheter placement. (Crit Care Med 1996; 24:2053-2058)

Key Words: ultrasound guidance; central venous catheter; catheterization, complications; Doppler ultrasound; meta-analysis; resuscitation; internal jugular vein; critical illness; subclavian vein

Central venous cannulation is useful for volume resuscitation, hemodynamic monitoring, vasopressor administration, frequent blood sampling, parenteral nutritional support, and the administration of long-term chemotherapy. However, placement of central venous catheters is not without risk. Major and minor mechanical complication rates have been reported as high as 10%, depending on operator experience as well as patient body habitus and coagulation status [1,2]. These complications related to catheter insertion include arterial puncture, hematoma, nerve injury, pneumothorax, and catheter malposition. An inability to cannulate the vessel may occur in >19% of cases [2].

The standard technique for placement of central venous catheters is by use of anatomical landmarks, which may not correlate with vessel location [3]. The use of Doppler ultrasound to assist with catheter placement was first reported in 1984 [4]. Ultrasonography for vessel location with subsequent catheter placement by landmark technique was later shown to have no effect on the complication or success rate of subclavian catheterization [5]. It was unclear at that time, however, whether real-time ultrasound guidance used for vessel location and catheter placement would be beneficial. Ultrasound guidance for central venous catheter placement is currently uncommon. The expense of echo devices may be prohibitive unless the impact on patient outcomes is favorable and clinically important.

The objective of this review was to more precisely estimate the effect of real-time ultrasound guidance on the placement of central venous catheters. We used scientific methods to search for, select, critically appraise, and synthesize the data from primary articles. The outcomes assessed were the rapidity of placement, the number of attempts before successful placement, the success of placement, the rate of complications, and the rate of success after failure by the landmark method.

MATERIALS AND METHODS

Study Identification.

Trials included in the analysis were identified from a larger subset of all identified randomized trials of central venous catheter-related complications. This larger pool of trials was identified by cross-referencing the following medical subject heading terms using MEDLINE from 1966 to October, 1995-catheterization, central venous and catheterization, Swan-Ganz and catheters, indwelling-with the following medical subject heading terms-randomization, random allocation, randomized controlled trial(s), randomized response technique, and (controlled) clinical trials, randomized. In addition, every citation for catheterization, central venous, and catheterization, Swan-Ganz was scanned from January 1985 to October 1995 and the abstracts of potentially relevant citations were reviewed on line. After examining the full manuscripts of all abstracts deemed potentially relevant, we reviewed the reference lists of each retrieved article and obtained the manuscript of any reference deemed to be a potential randomized, controlled trial. This approach was done iteratively until no new potential randomized, controlled trial citations were found on review of the reference lists of retrieved articles. Package inserts from catheter kits were also searched for references regarding published and unpublished data. The proceedings of the 1994 and 1995 Infectious Disease Society of America, and the 1986 through 1995 American Society for Microbiology Interscience Conference on Antimicrobial Agents and Chemotherapy annual meetings were also searched.

Study Selection.

The following selection criteria were used to identify published studies for inclusion in this analysis: a) Study Design: Randomized clinical trial; b) Population: Adult or pediatric patients; c) Intervention: Real-time ultrasound or real-time Doppler ultrasound guidance for placement of central venous catheters; and d) Outcomes: Rapidity of placement, number of attempts before successful placement, rate of successful placement, complication rate, and rate of success after failure by the alternate method.

Data Abstraction.

Data abstraction was conducted by two investigators; disagreement was resolved by consensus. Data on the number of catheters and/or the numbers of patients were abstracted the way they were reported. Catheters were the unit of analysis when data were pooled. We asked the primary investigators to provide further information when the data necessary for critical appraisal and/or analysis were missing or unclear.

Definitions.

Mechanical complications were defined as arterial puncture, hematoma, nerve injury, pneumothorax, and catheter malposition.

Assessment of Methodologic Quality.

Two investigators independently applied the methodologic quality assessment system presented in Table 1 to critically appraise each of the primary studies. When the information was not reported in the study, we attempted to contact the primary authors for clarification. We calculated the percentage of agreement between reviewers across quality items. Disagreements between reviewers were resolved by a third author.

Author, Yr (Ref.)	Pt. Selection[a]	Pt. Characteristics[b]	Insertion Method Standardized	Randomization Method	Explicit Description of Outcome	Post-Randomization Exclusions	Intention-To-Treat Analysis
Scherhag et al., 1989 (14)	Unknown	4	Yes	Not reported	Yes	No	Yes
Mallory et al., 1990 (9)	Eligible	0	Yes	Not reported	Yes	No	Yes
Troianos et al., 1991 (16)	Unknown	4	Yes	Not reported	Yes	No	Yes
Vucevic et al., 1994 (15)	Selected	1	Yes	Not reported	Yes	No	Yes
Branger et al., 1994 (13)	Unknown	0	Yes	Not reported	Yes	No	Yes
Gratz et al., 1994 (10)	Selected	4	Yes	Not reported	Yes	1/41[c]	No
Gilbert et al., 1995 (12)	Eligible	4	Yes	Not reported	Yes	No	Yes
Gualtieri et al., 1995 (11)	Eligible	0	Yes	Random number	Yes	1/53[d]	No

Pt., patient; Yr (Ref.), year of study (reference number).
[a]Patient selection: Unknown, not reported; Eligible, consecutive consenting patients or random series with no exceptions; selected, patients selected; [b]patient characteristics measured were age, sex, diagnoses, coagulopathy, body surface area (or height and weight); 4, four of five characteristics specified, 1, one of five characteristics specified, etc.; [c]patient dropped because of user error in connecting the Doppler needle to the transducer; [d]patient dropped because patient was extremely uncooperative.

Table 1. Methodologic quality characteristics of included trials of ultrasound guidance

Data Analysis.

We combined data to estimate the relative risk and associated 95% confidence limits across studies using the random effects model [6]. A priori, we decided that when the p value was > .05, differences in relative risk of >or=to20% would represent a trend, and differences in relative risk of <20% would represent no difference between strategies.

We tested for heterogeneity (major differences in the apparent effect of the interventions across studies) using the method proposed by Fleiss [6]. Using the null hypothesis that the relative risks were the same across studies, a p > .05 for the test of homogeneity is consistent with the assumption that differences in study results are due to the play of chance.

RESULTS

Study Identification and Selection.

From a pool of 208 randomized, controlled trials of venous and arterial catheters management, 12 randomized, controlled trials of ultrasound guidance or Doppler ultrasound guidance for placement of central venous or pulmonary artery occlusion pressure catheters in adult patients were identified. We excluded one quasi-randomized trial using alternate assignment of patients every other week [7], two trials in which ultrasound guidance was used only for vessel localization but not catheter placement (not real-time) [4,5], and one trial for which only a published abstract was available [8]. Eight published trials [9-16] were included in the meta-analysis, with six trials reporting outcomes for internal jugular, one trial reporting outcomes for subclavian, and one trial describing both internal jugular and subclavian vein catheter placement. The patient populations, the number and experience level of operators who participated, and the methods of ultrasound guidance used in the trials we appraised and pooled are described in Table 2. The Doppler ultrasound guidance methods used included: a 4-MHz Doppler transducer (Licance Delalande, Dyna Electronique, France) [14], a SMART[R] Needle Doppler with the probe in the needle (Peripheral Systems Group, Mountain View, CA) [10,12,15], and fingertip pulsed Doppler [13]. Non-Doppler real-time ultrasound modalities included: 2D ultrasound without needle guidance (7702A, Hewlett-Packard, Andover, MA) [9], Echo-kamera without a needle guide (Echokamera SSD-210DX[R], Hellige, Freiberg, Germany) [14], 7.5-MHz ultrasound transducers with [11] and without [16] needle guides (SiteRite[R], Dymax Corporation, Pittsburgh, PA), and a 5.0-MHz ultrasound transducer without a needle guide (Sonos 500, Hewlett-Packard).

Author, Yr (Ref.)	Site/Side	Pt. Population	Operator No./ Experience	Ultrasound Guidance Method	No. Placements/ No. Patients
Scherhag et al., 1989 (14)	Internal jugular/ Right side	Mixed medical and surgical	Not described	Doppler ultrasound Echo-kamera	60/60
Mallory et al., 1990 (9)	Internal jugular Side not reported	Critically ill adult ICU	No. not reported Mean 6 yrs exp.	2D ultrasound without needle guide	27/27
Troianos et al., 1991 (16)	Internal jugular Right side	Cardiothoracic Surgical	Not described	7.5 & 5 MHz transducer without needle guide	160/160
Vucevic et al., 1994 (15)	Internal jugular Right side	Adult ICU or cardiac surgery	2 consultant anesthetists	Needle Doppler Probe in needle	40/40

Branger et al., 1994 (13)	Internal jugular Subclavian Side not reported	"Low risk" medical/surgical	No. not reported Residents	Fingertip pulsed Doppler with needle guide	57/57
Gratz et al., 1994 (10)	Internal jugular Side not reported	Cardiovascular Surgical	No. not reported Anesthesia staff	Needle Doppler Probe in needle	40/40
Gilbert et al., 1995 (12)	Internal jugular Side not reported	Obese or coagulopathy	No. not reported Junior housestaff	Needle Doppler Probe in needle	76/76
Gualtieri et al., 1995 (11)	Subclavian Both sides	Critically ill adult ICU	18 operators with <30 procedures	7.5 MHz transducer with needle guide	53/33

Pt., patient; No., number; Yr (Ref.), year of study (reference number); ICU, intensive care unit; exp., experience; MHz, megahertz.

Table 2. Study characteristics of controlled trials of ultrasound guidance

Definitions of placement failure varied among the studies. Failure was defined as inability to place the catheter after five attempts in one trial [9], four attempts in another [10], and three attempts in two trials [11,12]. Another trial set a 30-min time limit for placement [13]. In the remaining three trials, the definition of placement failure was not defined [14,15], although one trial reported that one patient had 15 insertion attempts and two other patients had six and ten attempts, respectively, before stopping due to arterial puncture [16].

Methodologic Quality Assessment.

Design features and methodologic quality of the eight published studies included in this review are described in Table 1. The percentage agreement on each quality assessment item (method of randomization, blinding of caregiver and outcome assessor, description of outcome, follow-up, and intention-to-treat analysis) was very good (range 0.75 to 1.00).

Tests of Homogeneity.

The tests for homogeneity were nonsignificant in all analyses except among trials comparing time to catheter placement.

Number of Failures.

Ultrasound guidance significantly decreases the relative risk of catheter placement failure. As shown in Figure 1, eight of nine comparisons showed a lower placement failure rate using ultrasound guidance yielding an overall relative risk of 0.32 (95% confidence interval 0.18 to 0.55) in comparison with landmark placement. The significant improvement in successful placement rates using ultrasound guidance is true whether catheters were placed in the internal jugular vein (relative risk 0.38, 95% confidence interval 0.21 to 0.71) or the subclavian vein (relative risk 0.15; 95% confidence interval 0.04 to 0.53.

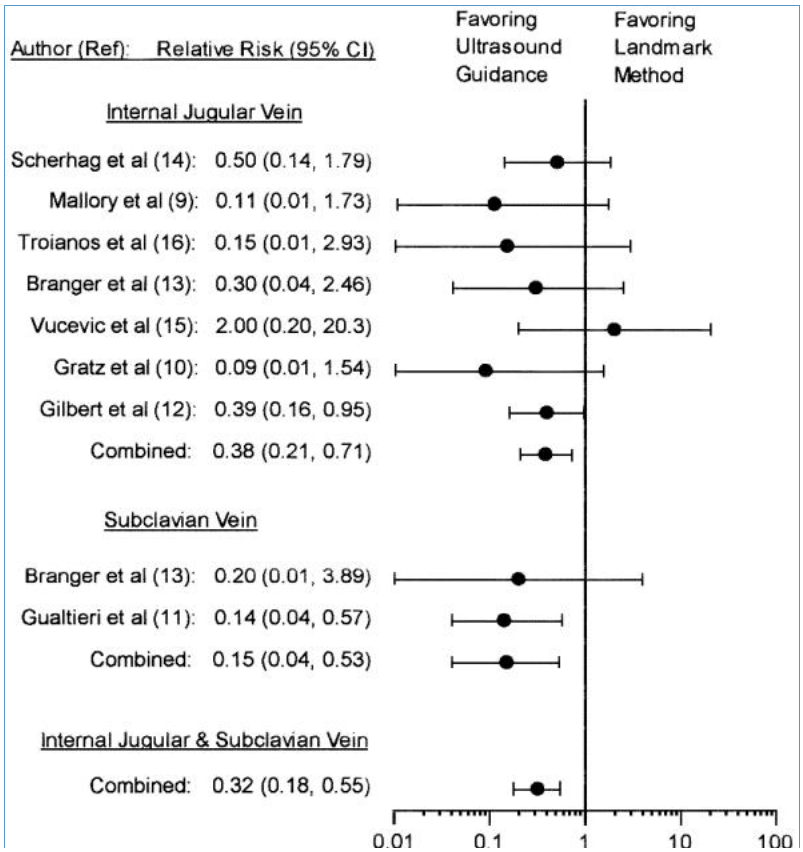


Figure 1. Effect of ultrasound guidance on number of failed catheter placements. CI, confidence interval.

Complications During Placement.

As shown in Figure 2, six of seven trials showed a lower placement complication rate using ultrasound guidance. The frequency rate of complications during catheter placement is significantly decreased using ultrasound guidance (relative risk 0.22; 95% confidence interval 0.10 to 0.45). This finding holds true for catheters placed with ultrasound guidance in the internal jugular vein (relative risk 0.26; 95% confidence interval 0.11 to 0.58) or the subclavian vein (relative risk 0.11; 95% confidence interval 0.02 to 0.56).

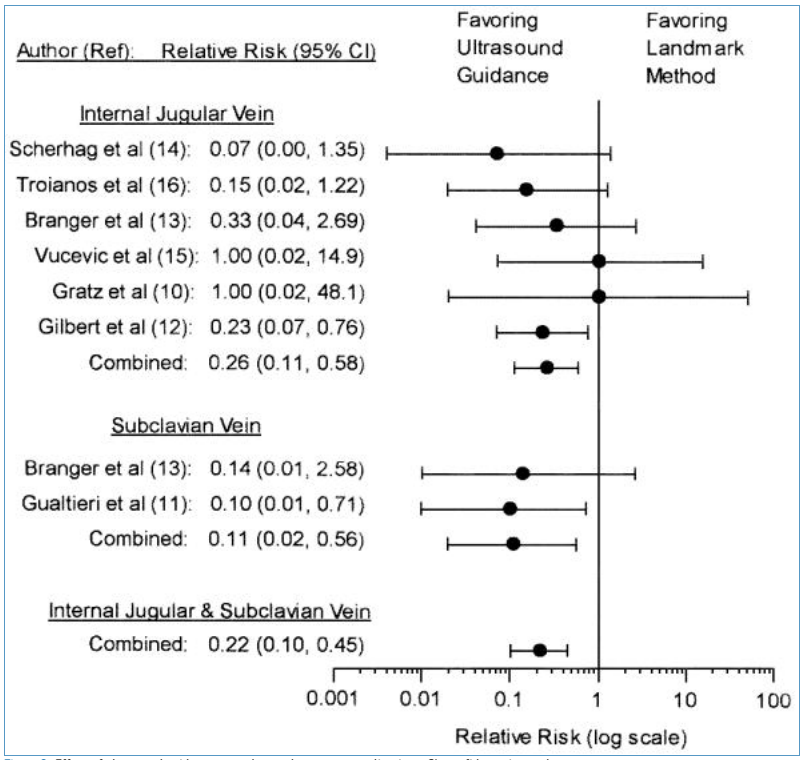
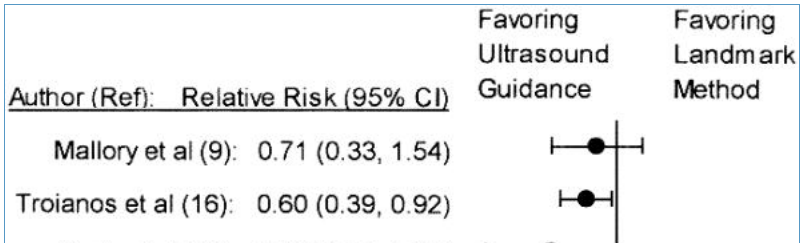


Figure 2. Effect of ultrasound guidance on catheter placement complications. CI, confidence interval.

Number of Attempts Before Success.

As shown in Figure 3, ultrasound guidance significantly decreases the requirement of multiple placement attempts with all four trials showing a reduced risk. The overall relative risk for ultrasound guidance was 0.60 (95% confidence interval 0.45 to 0.79).



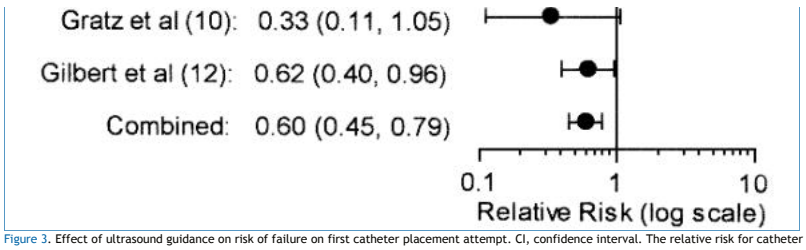


Figure 3. Effect of ultrasound guidance on risk of failure on first catheter placement attempt. CI, confidence interval. The relative risk for catheter placement using ultrasound guidance vs. the landmark method is represented for each study. The combined relative risk is the pooled estimate for all studies. A relative risk of 1 represents no difference between the two techniques.

Time to Success.

Trial results comparing the number of seconds needed for successful catheter placement using ultrasound guidance vs. landmark technique were heterogeneous (p value for test of homogeneity: <.0001). Three trials found that less time was needed for catheter placement via ultrasound guidance [10,15,16], while two trials showed that more time was required [12,14]. The mean difference in the number of seconds until successful catheter placement using ultrasound guidance vs. the landmark technique was 9 secs (95% confidence interval -80.1 to 62.2).

Success after Failure by Alternate Method.

As shown in Table 3, six trials reported success rates ranging from 33% to 100% with ultrasound guidance following failure by the landmark method. Only three trials planned to compare success rates for the landmark method after failure by ultrasound guidance. One trial had no ultrasound guidance failures to cross over, one trial had no successes in the two patients who were crossed over to landmark placement, and one trial had 12/17 successes.

Author, Yr (Ref.)	Method	No. Failures	No. Attempts To Success	Complications	Secs (± SD) To Success	No. USG Success Post LM Failure	No. Successes on First Attempt
Internal Jugular Vein							
Scherhag et al., 1989 (14)	LM	4/20		3/20	112.1 ± 48		
	USG-RT	2/20		0/20	167.1 ± 74		
	DUSG-RT	2/20		0/20	155.8 ± 77		
Mallory et al., 1990 (9)	LM	6/17	3.1			6/6	7/17
	USG-RT	0/12	1.8				7/12
Troianos et al., 1991 (16)	LM	3/83	2.8 ± 3.0	7/83	117 ± 136		45/83
	USG-RT	0/77	1.4 ± 0.7	1/77	61 ± 46		56/77
Branger et al., 1994 (13)	LM	3/10		3/10		1/3	
	USG-RT	1/11		1/10			
Vucevic et al., 1994 (15)	LM	1/20	20.5	1/20		1/1	
	DUSG-RT	2/20	17.0	1/20		(LM) 0/2	
Gratz et al., 1994 (10)	LM	5/20	2.8 ± 2.9	0/20	226.0 ± 332		11/20
	DUSG-RT	0/20	1.4 ± 0.9	0/20	283.5 ± 228		17/20
Gilbert et al., 1995 (12)	LM	17/44	1.7	13/49	188.5 ± 193	12/17	13/44
	DUSG-RT	5/32	1.4	3/49	283.5 ± 228	(LM) 12/21	18/32
Subclavian Vein							
Branger et al., 1994 (13)	LM	2/18		3/18		2/2	
	DUSG-RT	0/18		0/18			
Gualtieri et al., 1995 (11)	LM	15/27	2.5	11/27		12/15	
	USG-RT	2/25	1.4	1/25			

No., number; Yr (Ref.), year of study (reference number); RT, real time; DUSG, Doppler ultrasound guidance.

Table 3. Summary of outcomes of real time (RT) ultrasound guidance (USG) vs. landmark (LM) placement

DISCUSSION

The purpose of this systematic review was to provide a more precise estimate of the effect of real-time or Doppler ultrasound guidance for placement of central venous catheters than that which can be determined by any single trial. We found that compared with the landmark technique for placement of internal jugular and subclavian central venous catheters, ultrasound guidance significantly increases the probability of successful catheter placement, significantly reduces the number of complications encountered during catheter placement, and significantly decreases the need for multiple catheter placement attempts. However, the time it takes to successfully place a catheter may not be reduced using ultrasound guidance.

Ultrasound-guided placement costs include purchase of the technology, staff training, and maintenance of the machine. It is therefore important that the benefit conferred by ultrasound-guided placement be clinically important. By calculating the difference between the absolute risks of landmark vs. ultrasound guidance over all trials in this review, we can calculate the absolute risk reduction. The inverse of this number yields the number of patients it is necessary to treat with ultrasound guidance to prevent one negative outcome using the landmark method [16]. For example, we would need to use ultrasound guidance instead of the landmark method in seven patients to prevent one placement complication, and in five patients to prevent more than one attempt at catheter insertion. Although the number of patients in which ultrasound guidance needs to be used to confer benefit is quite low, the technology is not inexpensive and a formal cost-effectiveness analysis is needed to accurately assess the added cost or savings of ultrasound guidance when used for central venous catheter placement.

The benefits seen for ultrasound guidance were shown across a number of operators with varying levels of experience in central venous catheter placement and patients with both high and low catheter placement complication risks. Three studies [11-13] enrolled inexperienced operators (junior and senior residents or those clinicians with experience of <30 catheter placements). Two studies [9,10] reported a benefit with use of ultrasound guidance for experienced operators (consultant anesthetists or those clinicians with >6 yrs experience). One randomized, controlled trial [17] of ultrasound guidance in infants showed a reduced number of attempts to success. Due to their smaller vessel size, this technology may be beneficial for children and warrants further investigation under controlled settings.

One threat to the validity of these studies is that all trials were unblinded and investigators may have been biased in assessing outcomes in patients undergoing ultrasound guidance. Another limitation of the inferences from this review is the variable definition of failed catheter placement across individual studies and possibly within the same study. When studies did not report an a priori definition of placement failure, it is possible in these unblinded trials that more attempts could have been allowed with the ultrasound method. However, ultrasound guidance increased the success rate on the first attempt, which lends strength to the conclusion that this technology is of benefit.

All trials in this review used real-time ultrasound guidance for both vessel localization and throughout catheter placement. A prospective, randomized trial of 821 patients by Mansfield and colleagues [5], not included in this review, demonstrated that ultrasound guidance used solely for subclavian vessel localization (not real-time localization and placement) did not improve subsequent catheter placement success rates or decrease complications. However, another trial [4] of 43 patients of Doppler ultrasound guidance for localization of the internal jugular vessel before catheter placement (not real-time) did show a significantly increased rate of success on first attempt using ultrasound guidance. Although the conclusions regarding the benefit of real-time ultrasound guidance used for vessel localization and placement via Doppler or non-Doppler ultrasonography are sound, further studies would be needed to see whether ultrasound guidance used for internal jugular vessel localization alone (not real-time) is beneficial.

We conclude that use of real-time ultrasound or Doppler ultrasound guidance for placement of internal jugular and subclavian central venous catheters in adult patients increases the probability of successful catheter placement, and reduces the risk of complications and the need for multiple catheter placement attempts. However, ultrasound equipment and additional personnel costs are expenses not often incurred for central venous catheter placement. Whether more widespread use of real-time ultrasound guidance for vessel location and catheter placement is both practical and cost-effective warrants further study.

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IMAGE GALLERY

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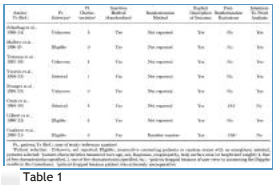

Table 1

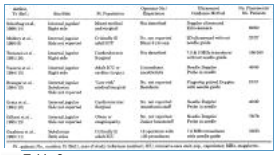

Table 2

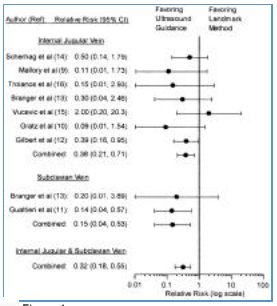

Figure 1

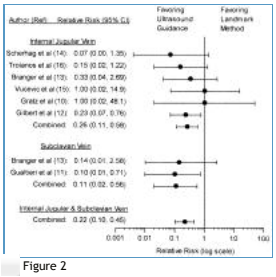

Figure 2

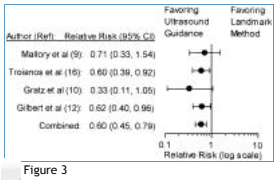

Figure 3

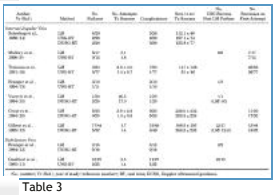

Table 3

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