Use of Ultrasound to Place Central Lines

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Context: **Placement of central venous catheters (CVCs) is an integral part of care for the critically ill patient but is associated with significant morbidity when using the traditional landmark method. The use of real-time ultrasound to guide line placement has been developed in hopes of avoiding this morbidity.**
Objective: **The objectives of this article are 2-fold. The first is to determine the relative effectiveness of the use of real-time ultrasound to place CVCs compared with the use of landmarks alone. The second is to discuss the merits of future study to increase the use of this technology.**
Data Sources: **Medline from 1966 to 2001, personal files, 2 prior systematic reviews, and reference lists of selected articles.**
Study Selection: **Studies were included if: (1) study design was a controlled trial, (2) patients required placement of a CVC, (3) the interventions were real-time ultrasound versus standard landmark-guided line placement, and (4) outcomes included at least 1 of failure to place catheter, success of first attempt, number of attempts, time to catheter placement, or complication rate.**
Data Synthesis: **Eighteen trials were identified. Pooled results showed a significant reduction in failure rate (risk difference, −.12, 95% confidence interval [CI], −.18 to −.06), number of attempts (risk reduction, 1.41, 95% CI, 1.15–1.67), and arterial puncture rate (risk difference, −.07, 95% CI, −.10 to −.03). The number of successful venous cannulations on first attempt were higher using ultrasound (risk difference, .24, 95% CI, .08–.39). No difference was found in time to insertion. Significant heterogeneity of study results was found for most analyses. Subgroup analyses suggested that ultrasound improved outcomes most convincingly using external probes, for internal jugular vein cannulation, and when used by clinicians less experienced at line placement.**
Conclusions: **Adoption of real-time ultrasound to guide CVC placement has the potential to improve successful line placement and minimized complications. It can improve patient safety. However, there are significant cost concerns and the reported adverse events are generally minor and easy to treat. Before creating study protocols to increase usage of this technology, both current usage and cost effectiveness should be determined.**
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CENTRAL VENOUS catheters (CVCs) have become an integral part of care for critically ill patients. They allow the administration of inotropic or vasopressor support, total parenteral nutrition (TPN), venous access in patients with poor peripheral access, and monitoring of central venous pressures. In the noncritically ill, they are used for the administration of chemotherapy, long-term antibiotic therapy, and TPN. Despite the necessity for CVCs in the care of critically ill patients, placement of these catheters has been associated with significant morbidity, including arterial puncture, pneumothorax, hemothorax, chylothorax, hematoma, brachial plexus injury, air embolus, catheter malposition, catheter knotting, and dysrhythmia.[1-3] At times, several attempts are required to place CVCs and several sites may be tried before achieving success. This may lead to delayed administration of necessary vasopressor support. The traditional method of catheter placement uses landmarks to locate the central vein of interest. An increasingly popular alternative is the use of ultrasound to guide placement of these catheters. First described in 1984,[4] ultrasound has been used to either locate the vessel initially followed by attempted catheter placement, or continuously during the actual attempt to place the CVC (real-time ultrasound guidance). The former approach has not been consistently shown to be more effective than use of landmarks alone.[2] Real-time ultrasound may be provided through either the external application of an ultrasound probe to visualize the vessels or through the use of Doppler ultrasound guidance of the needle into the vein.

OBJECTIVES

The objectives of this article are 2-fold. The first objective is to update prior excellent reviews[5,6] on the relative effectiveness and safety of the use of real-time ultrasound to place CVCs compared with the use of landmarks alone. The second is to use the results of this review to suggest a potential research agenda on the use of these catheters.

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SYSTEMATIC REVIEW OF THE LITERATURE

Data Sources and Settings

To identify relevant studies, Medline was searched from 1966 to 2001 using keywords *central venous catheter* OR *internal jugular vein* OR *subclavian vein* OR *femoral vein* with the restriction of *controlled clinical trial.* In addition, the references of selected studies were reviewed and 2 former systematic reviews were identified and references reviewed. Finally, for selected studies the option of *related articles* was also used to identify further trials of interest.

Study Design

The clinical question that guided the review of the literature was as follows: What is the relative effectiveness and morbidity of real-time ultrasound compared with the traditional landmark techniques in patients requiring a central vein catheter? Effectiveness was measured by using several potential outcomes including successful catheter placement, cannulation of vein on first attempt, time to cannulation, and number of attempts at cannulation. All complications were recorded from the literature but the one of primary interest was arterial puncture.

The selection criteria for included studies were: (1) population—any patient group that required placement of a CVC, (2) intervention—use of real-time ultrasound (either using an external probe or Doppler ultrasound), (3) outcomes—may include any of the following: time to catheter placement, number of attempts, successful on first attempt, failure to place catheter, and (4) study design—randomized controlled trial or quasirandomized controlled trial.

Data Collection Methods

Data was abstracted to assess both methodologic quality of the selected trials and to summarize the trial results. Criteria used to assess methodologic quality were adapted from those of Randolph et al[5] and are found in Table 1. In addition, we included

Table 1. Methodologic Quality

Study	Allocation (Random/ Blinded)	Patient Selection	Patient Characteristics	Insertion Method Standardized	Explicit Description of Outcome	Postrandomization Exclusions	Intention-to-Treat Analysis
Scherhag et al,[18] 1989	Random/unknown	Not specified	Specified	Yes	Yes	No	Yes
Mallory et al,[16] 1990	Random/unknown	Consecutive patients	Not specified	Yes	Yes	No	Yes
Troianos et al,[21] 1991	Random/unknown	Not specified	Specified	Yes	Yes	No	Yes
Denys et al,[10] 1993	Quasirandom/not blinded	Not specified	Not specified	Yes	Yes	No	Yes
Vucevic et al,[24] 1994	Random/unknown	Not specified	Not specified	Yes	Yes	No	Yes
Gratz et al,[12] 1994	Random/unknown	Not specified	Specified	Yes	Yes	Yes (1/41 in Doppler group)	No
Branger et al,[8] 1994	Random/unknown	Not specified	Not specified	Yes	Yes	No	Yes
Branger et al,[9] 1995	Random/unknown	Specified	Specified	Yes	No	Yes (2/50 in Doppler group)	No
Gilbert et al,[11] 1995	Random/unknown	Consecutive patients	Specified	Yes	Yes	No	Yes
Gualtierie et al,[13] 1995	Random/unknown	Not specified	Not specified	Yes	Yes	Yes (1/53)	No
Hilty et al,[14] 1997	Random/unknown	Selected patients	Specified	Yes	Yes	No	Yes
Teichgraber et al,[20] 1997	Random/unknown	Not specified	Not specified	Yes	No	No	Yes
Slama et al,[19] 1997	Random/unknown	Not specified	Specified	Yes	No	No	Yes
Nadig et al,[17] 1998	Random/unknown	Not specified	Not specified	Yes	Yes	No	Yes
Bold et al,[7] 1998	Random/unknown	Not specified	Specified	Yes	Yes	No	Yes
Lefrant et al,[15] 1998	Random/unknown	Selected patients	Specified	Yes	No	No	Yes
Verghese et al,[22] 1999	Random/unknown	Not specified	Specified	Yes	Yes	No	Yes
Verghese et al,[23] 2000	Random/unknown	Consecutive patients	Specified	Yes	Yes	No	Yes

the date of publication, population studied, the site of vein being cannulated, ultrasound method used (external probe versus Doppler ultrasound needle probe), operator experience, and all outcomes recorded.

Results of the individual trials were summarized in tabular format. In addition, failure rate for catheter placement, successful placement of the catheter on first attempt, and the rate of arterial puncture were all reported by using individual study risk differences and their respective 95% confidence intervals (CIs). By using a random effects model, we calculated a summary risk difference and 95% CIs for these 3 outcomes using Review Manager computer program version 4.1 for Windows (RevMan; The Cochrane Collaboration, Oxford, England). For the outcomes of time to catheter placement and number of attempts at catheter placement, those trials reporting mean and standard deviations for respective groups had their results pooled using the weighted mean difference. For trials presenting time to catheter placement or number of attempts at venous cannulation as median rather than mean, individual study results were reported but were not pooled with other studies. Heterogeneity of study results were assessed both visually and by using the test for heterogeneity χ^2 from RevMan.

A priori, the decision was made to examine the following subgroups: cannulation vein (internal jugular vein versus subclavian vein), ultrasound method used (external probe versus Doppler ultrasound needle probe), operator experience, and patient population (intensive care unit [ICU] patients vs non-ICU patients).

RESULTS

After applying the selection criteria to those studies identified by the search strategy, 18 trials were identified for further evaluation,[7-24] 17 nonblinded, randomized, controlled trials[7-9,11-24] and 1 quasirandomized trial[10] conducted in a cardiac catheterization laboratory that allocated the intervention on an alternate week basis. This last trial was accepted because it was felt that selection bias would be relatively low in this setting. Of these 18 studies, the population of interest were ICU patients in 6 studies,[11,13,15,16,19,24] medical-surgical patients in 2,[8,18] adult cardiothoracic surgery patients in 2,[12,21] pediatric cardiac surgery in 2,[22,23] dialysis, apheresis, or TPN patients in 2,[9,17] cardiac catheterization patients in 1,[10] chemotherapy patients in 1,[7] post–cardiac arrest patients in the emergency room in 1,[14] and the final study did not clearly specify their population (Table 2).[20] Within the 6 trials on ICU patients, 1 trial excluded high-risk patients (those with obesity, coagulopathy, or prior catheter placement or surgery to area the catheter was to be placed),[15] another actually restricted their study population to patients at higher risk (obesity or coagulopathy),[11] whereas the rest did not specify any specific inclusion or exclusion criteria.[13,16,19,24]

The vein cannulized included the internal jugular vein in 12 studies,[10-12,16-24] the subclavian vein in 3 trials,[7,13,15] either internal jugular or subclavian vein in 2 trials,[8,9] and the femoral vein in 1 trial.[14] Nine trials examined the relative effectiveness of Doppler ultrasound by using a small probe that passed through the needle.[7-9,11,12,15,18,23,24] The needle, with the probe inside, entered the skin and then was moved toward the vein, guided by the characteristic sound on Doppler ultrasound. Eleven trials used an external ultrasound probe to locate the vein and artery and guide the passage of the needle into the vein[10,13,14,16-23] (2 trials studied both technologies[18,23]). Operator experience was not described in 3 trials[12,18,21] and ranged from junior residents to senior staff in one.[9] Of the remainder, in 5 trials junior house staff were involved in catheter placement,[8,11,13,14,19] senior house staff or fellows placed catheters in 5 trials,[7,10,16,22,23] and consultant staff placed catheters in the remaining 4 trials (Table 2).[14,17,19,22]

The methodologic qualities of trials varied and are summarized in Table 1. In all trials operators and adjudicators of outcomes were nonblinded and none made reference to whether allocation was blinded or not. Only 4 trials were clearly conducted on consecutive patients[9,11,16,23] and 11 clearly specified patient population[7,9,11,12,14,15,18,19,21-23] (including at least age, height, and weight). All trials specified the method of insertion and 14 had explicit outcomes. Only 3 trials had patients excluded postrandomization,[9,12,13] 2 patients in 1 trial[9] and 1 patient each in the other 2.[12,13] By strict definition, these 3 trials did not use intention-to-treat analysis.

Failure rate was reported in 17 trials but the definition varied considerably, ranging from "inability to cannulate vein in 2 attempts"[7] to hybrid definitions including "arterial puncture and inability to cannulate the vein after 15 attempts"[23] (see Table

Table 2. Study Characteristics

Study	Population	Site	Ultrasound Method	Operator Experience	Outcomes
Doppler ultrasound					
Scherhag et al,[18] 1989	Mixed medical and surgical	IJV	Needle Doppler ultrasound External ultrasound	Not described	Failure rate (not defined) Time to placement Complications
Vucevic et al,[24] 1994	ICU patients or cardiac surgery patients	IJV	Needle Doppler ultrasound	2 consultant anesthetists with experience	Failure rate (inability to cannulate) Time (to successful insertion of wire) Number of attempts Complications
Branger et al,[8] 1994	Low-risk medical-surgical patients	IJV/SCV	Needle Doppler ultrasound (fingertip pulsed doppler/ needle guide)	Junior and senior residents	Failure (line not placed after 30 min) Success of cross-over Complications
Gratz et al,[12] 1994	Cardiothoracic or major vascular surgery	IJV	Needle Doppler ultrasound	Not specified	Failure rate (inability to cannulate) Time (from injection of local anesthetic to insertion of cannula in IJV) Number of attempts Carotid puncture
Branger et al,[9] 1995	Dialysis, apheresis, or TPN patients Exclusions: thoracic abnormalities, obesity, respiratory distress, restlessness	IJV/SCV	Needle Doppler ultrasound (4 MHz)	Residents and senior staff	Failure rate (unable to cannulate in 4 attempts or after 30 min) Success on cross-over Time (not specified) Number of attempts Complications
Gilbert et al,[11] 1995	Patients with obesity or coagulopathy in ICU or operating room	IJV	Needle Doppler ultrasound	Junior housestaff with supervision by attending staff	Failure (failure after 3 attempts) Success on cross-over Time (skin puncture to wire placement or failure)
Bold et al,[7] 1998	Chemotherapy patients with risk factors (XRT, surgery to site, or obesity	SCV	Needle Doppler ultrasound	Experienced Fellows 18 physicians	Failure (unable to cannulate in 2 attempts) Success on cross-over Number of attempts Complications
Lefrant et al,[15] 1998	ICU patients Exclusions: prior surgery to area or line, coagulopathy, emergency line	SCV	Needle Doppler ultrasound (4 MHz)	All by same physician experienced	Failure rate (not specified) Time to insertion (first puncture or search for Doppler signal to guide wire) Success on first pass Number of attempts Complication rate
Verghese et al,[23] 2000	Infants scheduled for cardiac surgery (<12 mo and 10 kg)	IJV	External ultrasound Needle Doppler ultrasound	Pediatric anesthesia Fellows supervised by Staff	Failure rate (carotid/hematoma, >5 attempts) Time (initial needle stick to easy aspiration of venous blood from distal catheter) Number of attempts Complications
External ultrasound					
Scherhag et al,[18] 1989	Mixed medical and surgical	IJV	Needle Doppler ultrasound External ultrasound	Not described	Failure rate (not defined) Time to placement Complications
Mallory et al,[16] 1990	ICU patients requiring urgent or urgent-elective IJV line	IJV	External ultrasound	Senior ICU staff or ICU Fellows with at least 6 mo	Failure rate (failure after 5 attempts)
Troianos et al,[21] 1991	Cardiothoracic surgery patients	IJV	External ultrasound	Not specified but same for both	Failure rate (>15 attempts or arterial puncture and >6 attempts—retrospective definition?) Time (from injection of local until entry of IJV) Number of attempts Complications
Denys et al,[10] 1993	Cardiac catheter patients	IJV	External ultrasound	Experienced staff or fellows	Failure rate (inability to cannulate) Time (skin puncture to aspiration) Number of attempts Complications
Gualtierie et al,[13] 1995	Critically ill patients	SCV	External ultrasound	Junior housestaff with <30 lines supervised	Failure rate (failure after 3 attempts) Success on cross-over Number of attempts Complications

Table 2. Study Characteristics (Cont'd)

Study	Population	Site	Ultrasound Method	Operator Experience	Outcomes
Hilty et al,[14] 1997	Cardiac arrest patients in emergency room	FV	External ultrasound	2 emergency medicine residents)	Failure rate (arterial puncture, failure after 15 attempts) Time (from ultrasound by bedside to flash of blood) Number of attempts Complications
Teichgraber et al,[20] 1997	Not specified routine catherization	IJV	External ultrasound	Variable 3.8 ± 3.1 yrs for ultrasound vs 6.9 ± 3.2 yrs for landmarks	Time to successful venipuncture Successful on first attempt Complications
Slama et al,[19] 1997	ICU patients	IJV	External ultrasound	Junior housestaff supervised by senior physician	Failure rate (not specified) Time (first skin puncture to aspiration of blood) Successful on first attempt Access time <3 min Carotid artery puncture
Nadig et al,[17] 1998	Dialysis patients Department of Medicine awake	IJV	External ultrasound	1 to 7 y (5 physicians)	Failure rate (not clearly specified but declared unsuccessful after 3–7 attempts). Unsuccessful attempts (any withdrawal of the needle with a consecutive forward motion) Time (to successful venipuncture)
Verghese et al,[22] 1999	Infants scheduled for cardiac surgery (<12 mo and 10 kg)	IJV	External ultrasound	Board-eligible pediatric anesthesia Fellows supervised by Staff	Failure rate (carotid/hematoma, >7 >45 min) Time (initial needle stick to easy aspiration of venous blood from distal catheter) Number of attempts Complications
Verghese et al,[23] 2000	Infants scheduled for cardiac surgery (<12 mo and 10 kg)	IJV	External ultrasound Needle Doppler ultrasound	Pediatric anesthesia Fellows supervised by Staff	Failure rate (carotid/hematoma, >5 attempts) Time (initial needle stick to easy aspiration of venous blood from distal catheter) Number of attempts Complications

Abbreviations: IJV, internal jugular vein; SCV, subclavian vein; FV, femoral vein.

2). No definition was provided in 3 trials.[15,18,19] By using the definition for failure applied by the trialists, 6 trials individually found a statistically significant reduction in failure rate (see Fig 1).[10,11,13,16,19,22] When the results of the 17 trials were pooled, there was significant reduction in failure rate of 16% (95% CI, 9%–23%). Of the 8 trials reporting data on successful cannulation of the central vein on first attempt,[10-12,15,16,19,20,21] 5 trials individually statistically favored real-time ultrasound over use of landmarks alone (Fig 2).[10-12,20,21] The pooled risk reduction was 24% (95% CI, 8%–39%). Six of the 13 trials reporting rate of arterial puncture showed a statistically significant reduction in the ultrasound group,[10,11,16,20-22] the pooled risk reduction being 7% (95% CI, 3%–10%) (Fig 3). Of the 11 trials reporting on time to insertion,[9-12,14,17-19,21-23] 2 were excluded[22,23] (see Table 3) because the average time was almost a factor of 10 higher than the rest (both trials on infants undergoing cardiac surgery). Of the remaining 9 trials,[9-12,14,17-19,21] 4 reported a significantly shorter time to cannulation using ultrasound,[10,17,19,21] whereas 2 reported a significantly longer time to cannulation.[9,18] The pooled estimate was not significant, a reduction by 6.56 seconds (95% CI, ranged from a reduction by 44.02 sec to an increase by 57.14 sec). Although only 6 trials reported mean number of attempts at cannulation,[9,10,12,14,21,22] all found a significant reduction in favor of real-time ultrasound, risk reduction of 0.81 (95% CI, .64–.97). Another 6 trials reported information on a number of attempts as either median, with or without range, or mean without standard deviation (see Tables 3 and 4).[11,13,15,16,23,24] In all trials, the number of attempts was lower in the ultrasound group.

Although all pooled estimates, except time to insertion, favored the use of real-time ultrasound,

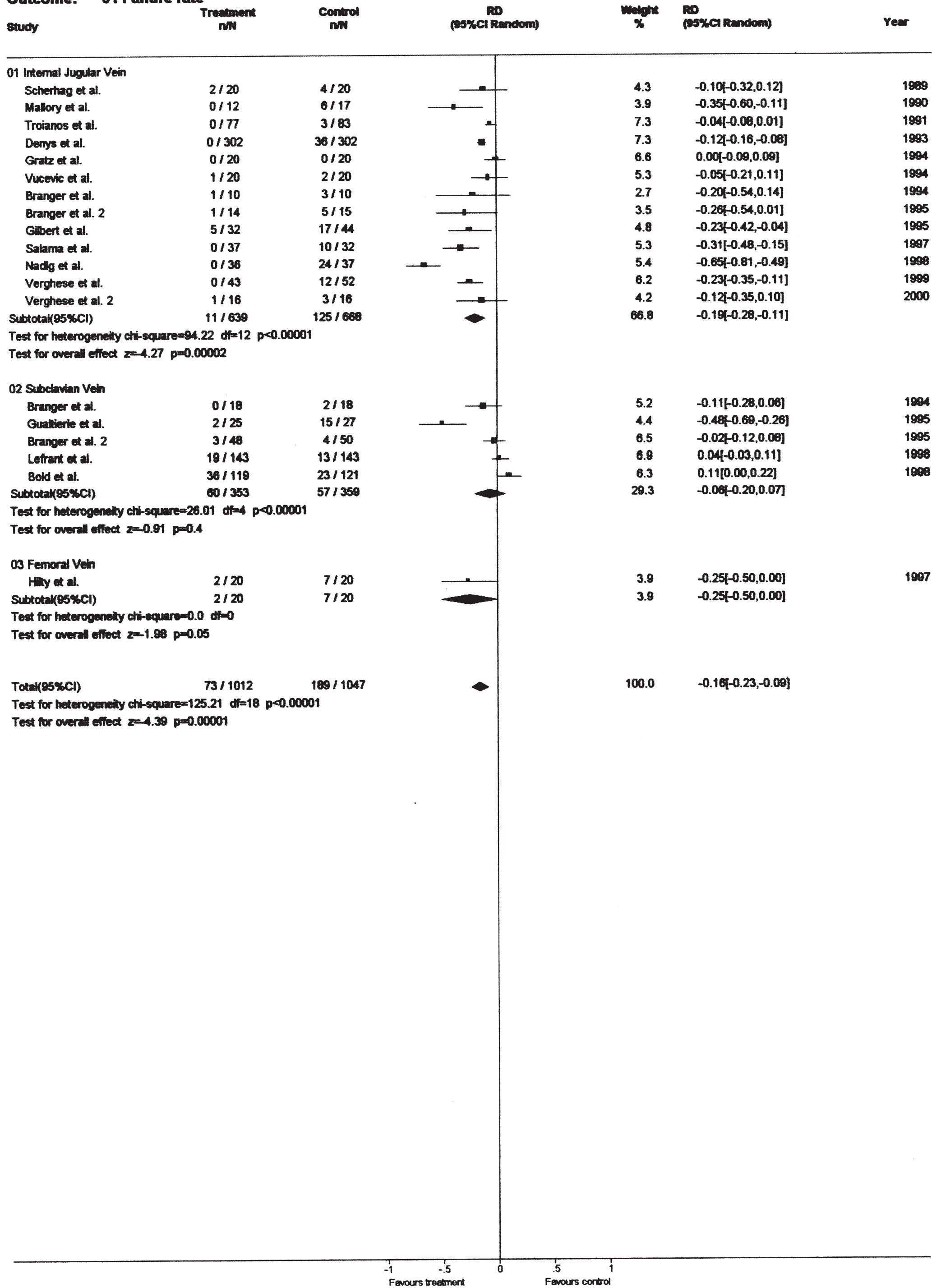

Fig 1. Forest plot of individual trials and their pooled results that included failure rate as an outcome. Studies are grouped by ultrasound method used. Results are reported as risk differences and 95% CIs.

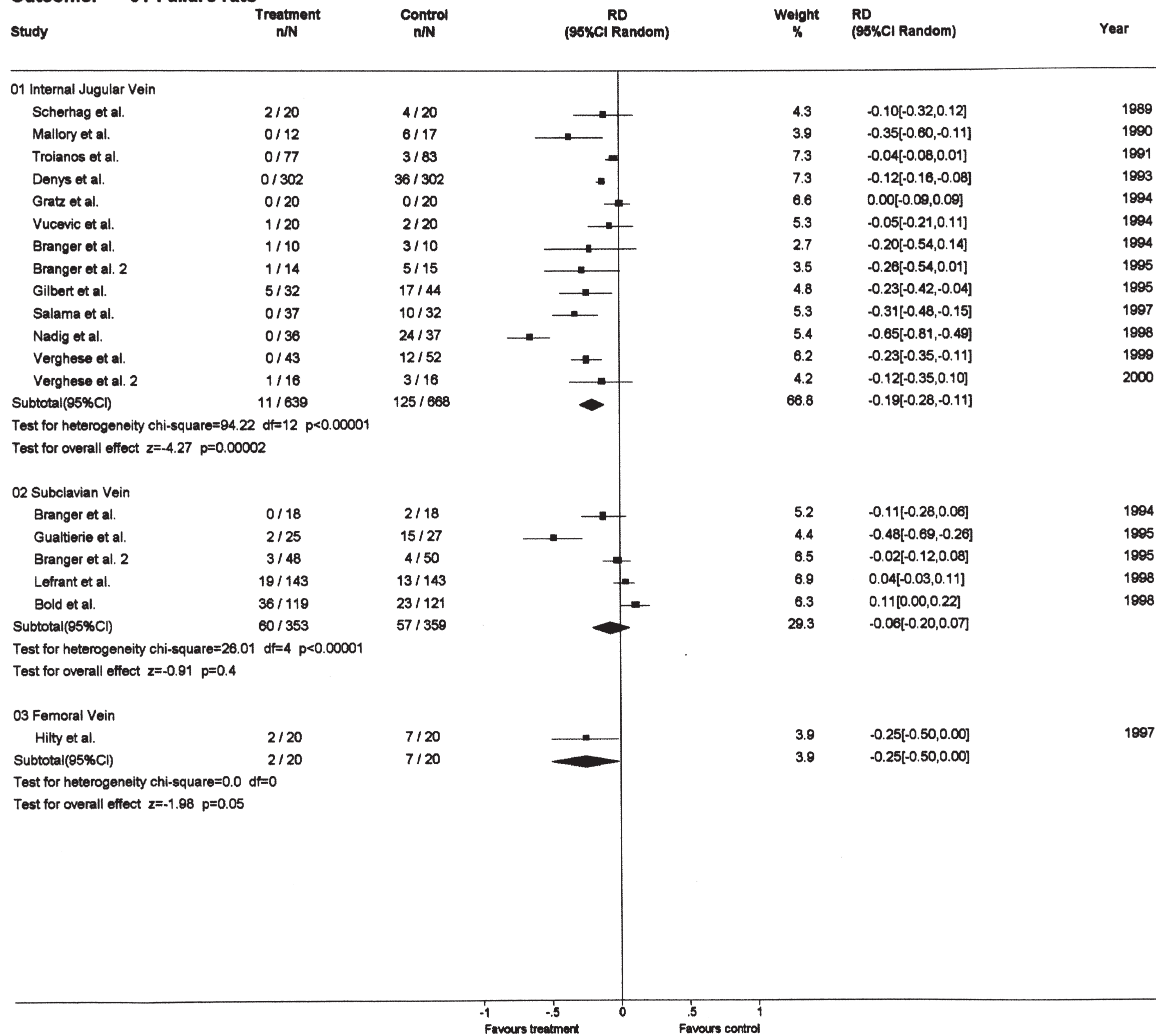

Fig 2. Forest plot of individual trials and their pooled results that included successful cannulation on initial attempt as an outcome. Studies are grouped by ultrasound method used. Results are reported as risk differences and 95% CIs.

there were marked heterogeneity of study results by both visual inspection of the Forest plots and by statistical testing ($P < .00001$ for failure rate, success on first attempt, and time to insertion, and $P = .0002$ for arterial puncture rate) for all but number of attempts at venous cannulation. Subgroup analysis suggested some explanation for this heterogeneity. From Table 5 it is apparent that failure rate was only significantly reduced in the pooled results when external ultrasound was used, operators were less experienced, and the internal jugular vein was the vessel approached. When the studies on ICU patients were compared with non-ICU patients, there was no obvious difference. However, the ICU populations studied were still clearly heterogeneous. For example, of the 2 studies on ICU populations that did not favor use of ultrasound, both were conducted by consultant staff[15,24] and 1 excluded all high-risk patients.[15] In summary, though subgroup analysis explains some of the heterogeneity found, other variables likely exist that contribute to this finding.

COST IMPLICATIONS

There is an added cost to using either form of ultrasound to guide line placement. For Doppler ul-

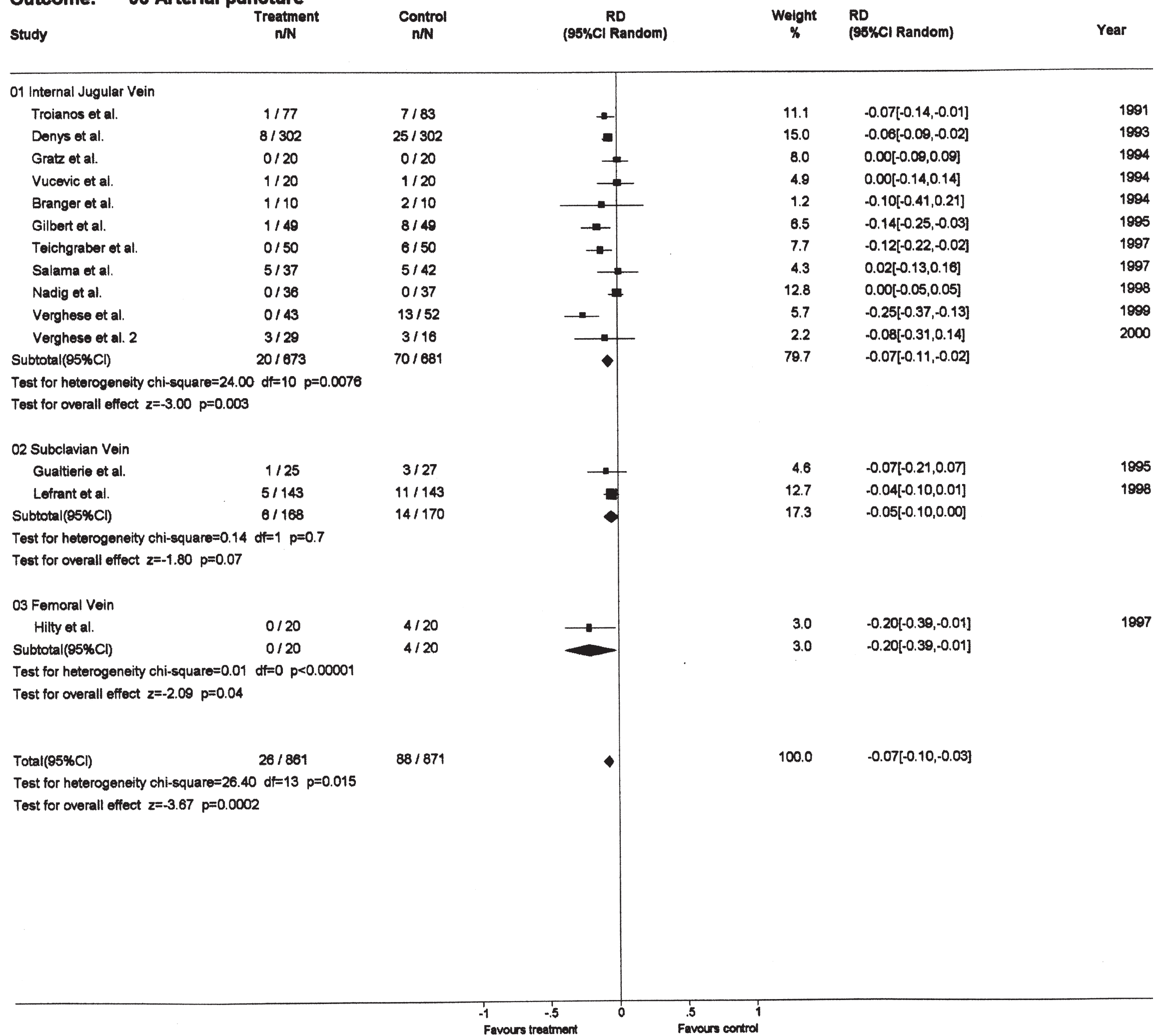

Fig 3. Forest plot of individual trials and their pooled results that included arterial puncture as an outcome. Studies are grouped by ultrasound method used. Results are reported as risk differences and 95% CIs.

trasound there is the cost of the Doppler unit that is in the range of $800 US. In addition, it requires special needles to allow the probe to be positioned within them. In the study by Bold et al,[7] these needles were priced at $40 to $70 US compared with the standard needles at $3 to $5. Portable ultrasound machines with external probes cost approximately $13,000 US. The external probes need to be covered to maintain a sterile field. Specific sterile sheaths are available at a cost of $13 US for a box of 10. Alternatively, sterile gloves have been used ($13 US for a box of 25). Training of personnel is also a potential cost but should not be much different than training for landmarks. The potential benefit of faster line insertion in high-risk patients and reduced complications has not been specifically valued. There also remains a theoretic potential for increased line infection because of the presence of an ultrasound probe in the field, however, this may be offset by a reduction in number of attempts at catheterization and duration of the procedure.

SUMMARY OF LITERATURE REVIEW

In summary, the use of ultrasound guidance for placement of CVCs has been extensively studied in

Table 3. Study Outcome—Internal Jugular Vein

Study	Method (No)	Time	Number of Attempts	Successful on First Attempt	Number of Unsuccessful Attempts	Failures	Cross-Over	Complications
Scherhag et al,[18] 1989	Landmarks (20)	112.1 ± 48 s				4/20		
	Doppler (20)	155.8 ± 77 s				2/20		
	Ultrasound (20)	167.1 ± 74 s				2/20		
Mallory et al,[16] 1990	Landmarks (17)		3.12	7/17		6/17	6/6 cross-over successful	
	Ultrasound (12)		1.75	7/12		0/12		
Troianos et al,[21] 1991	Landmarks (83)	117.1 ± 136 s	2.8 ± 3	45/83		3/83		7/83 carotid
	Ultrasound (77)	61 ± 46 s	1.4 ± 0.7	56/77		0/77		1/77 carotid
Denys et al,[10] 1993	Landmarks (302)	44.5 ± 129.5 s	2.5 ± 2.7	116/302		36/302		25/302 carotid 5 brachial plexus 10 hematoma
	Ultrasound (302)	10.3 ± 11.6 s	1.2 ± 0.5	248/302		0/302		8/302 carotid 1 brachial plexus 0 hematoma
				all $P < .001$				
Branger et al,[8] 1994	Landmarks (10)					3/10	1/3 success on cross-over	3/10: 2 carotid, 1 hematoma
	Doppler (10)					1/10		1/10: 1 carotid
Vucevic et al,[24] 1994	Landmarks							
	Easy (10)	59.2 (20.5–97.9) s	10	10/10		0/10		1/20 carotid
	Difficult (10)	322.6 (148.7–496.5) s	31			1/10		
	Doppler	95% CI						
	Easy (10)	91.8 (53.1–130.5) s	11	9/10		0/10		1/20 carotid
	Difficult (10)	167.6 (77.2–258) s	23			2/10		
Gratz et al,[12] 1994	Landmarks (20)	226 ± 332	2.8 ± 2.8	11/20		0/20		0/20 carotid
	Doppler (20)	109 ± 139 s	1.35 ± 0.9	17/20		0/20		0/20 carotid
Gilbert et al,[11] 1995	Landmarks (44)	188.5 ± 193.3 s	1.7	13/44		17/44	2/5 success	8/49 carotid 5/49 hematoma
	Doppler (32)	283.5 ± 227.7 s	1.4	18/32 $P < .05$		5/32 $P < .05$	12/17 success	1/49 carotid 2/49 hematoma Either: 13 vs 3 ($P < .01$)
Branger et al,[9] 1995	Landmarks (15)	187 ± 73 s	2.4 ± 0.6			5/15		N/A
	Doppler (14)	401 ± 380 s	2.3 ± 0.4			1/14	3/5 success	
Slama et al,[19] 1997	Landmarks (42)	235 ± 408 s >3 min: 19/42		11/42		10/32		5/42 carotid
	Ultrasound (37)	95 ± 174 s >3 min: 5/37 $P = .06$		16/37		0/37 $P < .01$		5/37 carotid
Teichgraber et al,[20] 1997	Landmarks (50)	51.4 (3–820) s		26/50				5/50 hematoma 6/50 carotid 3/50 plexus irritation
	Ultrasound (50)	15.2 (8–76) s $P = .001$		48/50 $P = .002$				1/50 hematoma 0/50 carotid 2/50 plexus irritation
Nadig et al,[17] 1998	Site marked (37)	4.8 ± 2.2 min			87	13/37		0/37 carotid
	Ultrasound (36)	3.4 ± 0.9 min $P < .01$			10 $P < .01$	0/36 $P < .01$	10/13 success	0/36 carotid
Verghese et al,[22] 1999	Landmarks (52)	14 ± 15.1 m	3.3 ± 2.8			12/52	NA	13/52 carotid 6 hematomas 1 hematomas 2 kinking/threading
	Ultrasound (43)	4.2 ± 2.8 m	1.3 ± 0.6			0/43	3/12 success	0/43 carotid 6 kinking/threading
Verghese et al,[23] 2000	Landmarks (16)	6.6 ± 5.3 m	2 (median)			3/16		3/16 carotid
	Doppler (13)	8.9 ± 6.1 m	2 (median)			2/13		2/13 carotid
	Ultrasound (16)	4.5 ± 3.7 m	1 (median)			1/16		1/16 carotid

Table 4. Study Outcome—Subclavian Vein/Femoral Vein

Study	Method (No)	Time	Number of Attempts	Successful on First Attempt	Number of Unsuccessful Attempts	Failures	Cross-Over	Complications
Branger et al,[8] 1994	Landmarks (10)					2/18	2/2 success on cross-over	3/18: 1 pneumothorax, 1 hematoma, 1 nerve
	Doppler (10)					0/18		0/18
Gualtieri et al,[13] 1995	Landmarks (27)		2.5			15/27		3/27 artery 5 hematoma 3 malposition
	Ultrasound (25)		1.4			2/25 $P = .003$	12/15 success	1/25 artery
Branger et al,[9] 1995	Landmarks (50	153 ± 56 s	1.9 ± 0.7			4/50		Not applicable
	Doppler (48)	362 ± 105 s	1.5 ± 0.3			3/48	2/4	
Bold et al,[7] 1998	Landmarks (121)	Longer time for SMART				23/121	27/34	1 hemothorax
	Doppler (119)	needle				36/119 $P = .04$	18/21	1 hematoma
Lefrant et al,[15] 1998	Landmarks (143)	27 (15–240) s	1 (1–4)	94/143		13/143		11/143 artery 3 pneumothorax 11 malposition
	Doppler (143)	300 (94–900) s	1 (1–3)	92/143		19/143		5/143 artery 2 pneumothorax 1 malposition
Hilty et al,[14] 1997	Landmarks (20)	124.2 ± 69 s	5.0 ± 5			7/20		4/20 artery
	Ultrasound (20)	121.0 ± 60 s	2.3 ± 3			2/20		0/20 artery

the literature but the studies themselves have some methodologic flaws that may bias results (lack of blinding, varying definition of failure). The heterogeneity of results found makes one more cautious in drawing strong inferences from pooled results. However, taking into account the various subgroup analyses, it appears that the use of external ultrasound probes increases the successful placement of internal jugular vein catheters, and decreases complications in the hands of less experienced operators. Less work is available to be confident of the benefit of Doppler ultrasound and the use of either technology for placement of subclavian or femoral lines.

For the readers of the *Journal of Critical Care,* the patient group of primary interest is those in the ICU. Although one has to be careful not to overinterpret the results, the studies on ICU patients showed that external ultrasound was at least as effective, and perhaps more so, as in non-ICU patients. This was not consistent for all studies on ICU patients. The 2 studies that did not show much benefit were both conducted by experienced operators[15,24] and 1 excluded patients that they consid-

Table 5. Subgroup Analyses—Failure Rate

Subgroup	Number of Studies	Total No. of Patients	Risk Difference (95% CI)	Test of Heterogeneity
Ultrasound method				
External ultrasound	10	1194	−0.22 (−0.31 to −0.13)	$P < .00001$
Doppler ultrasound	9	898	−0.02 (−0.09 to 0.04)	$P = .063$
Operator experience				
Junior housestaff	5	293	−0.26 (−0.36 to −0.17)	$P = .26$
Senior housestaff	5	1013	−0.12 (−0.26 to 0.02)	$P < .00001$
Consultant staff	3	398	−0.19 (−0.62 to 0.24)	$P < .00001$
Vein cannulated				
Internal jugular	13	1307	−0.19 (−0.28 to −0.11)	$P < .00001$
Subclavian	4	712	−0.06 (−0.20 to 0.07)	$P < .00001$
Femoral	1	20	−0.25 (−0.50 to 0.00)	Not applicable
Patient population				
ICU patients	6	552	−0.20 (−0.39 to −0.01)	$P < .00001$
Non-ICU patients	11	1484	−0.13 (−0.22 to −0.05)	$P < .00001$

ered to be at higher risk for complications (obese or coagulopathy).[15] Although we do not yet have adequate evidence to be certain, it is possible that the greatest benefit of external ultrasound would be found in the ICU population, who have a higher proportion of patients with coagulopathy and are more prone to be edematous. In addition, the added benefit of being able to visualize the course of the vein and artery (not available with Doppler ultrasound) will allow detection of thrombosed or scarred veins before attempted placement.

Although there appears to be potential benefit in adopting external ultrasound, at least for placement of internal jugular vein catheters, arguments can be made against this decision. There is the concern that training physicians to insert lines with this technology alone may result in their inability to place a line should the technology not be available. Others would suggest that the use of ultrasound may actually facilitate training of the landmark technique. We do not have evidence to support either of these opinions. It does appear, however, that physicians who are well trained in the use of both approaches are less likely to benefit from the addition of ultrasound. Another concern about adopting this technology is appreciable added costs. It is not clear that these costs are balanced by the complications avoided that are rarely more than minor problems and easily treatable. No studies have shown an effect on survival or length of stay.

FUTURE STUDY

Ultrasound guidance of central line placement is a technology that clearly improves patient safety. However, it is not clear from this systematic review that the added costs of adopting this technology are justified. For those of us working in the ICU, the decision to use this technology requires better evidence that can only be derived from a large, multicenter, randomized, controlled trial of the use of external ultrasound versus landmarks for insertion of CVCs in high-risk ICU patients with an associated economic evaluation. The outcomes of primary interest to clinicians, survival, future quality of life, and duration of ICU and hospital stay have never been studied, leaving estimates of differences difficult to determine. We do have data on complication rates. This review of the literature, including 2,159 patients, found that the incidence of more significant complications such as hematomas and pneumothoraces, with or without hemothoraces, were low (1.2% and 0.37%, respectively). The proportion of these complications were less in the real-time ultrasound group (4 vs 23 for hematoma and 2 vs 6 for pneumothoraces [all but 1 of the latter occurring during attempted subclavian vein cannulation]). These numbers are consistent with the literature[2,25] and again highlight the apparently real but proportionately small number of patients that will experience fewer significant complications. Although there will be challenges to both designing and implementing such a trial, it remains the preferred approach to providing us with the necessary evidence.

An alternative, but less satisfactory, approach to conducting an economic evaluation is using retrospective modeling. The challenges here would include determining the appropriate value of the potential benefits (shorter insertion time, fewer complications) and harms (theoretical risk for infection). However, the use of extensive sensitivity analyses would allow us to vary these unknown variables over a range of plausible values and to vary population risk for complications to simulate different patient populations within an ICU (stable, short-stay postoperative patient, to patient with multiple organ dysfunction with a coagulopathy and prior catheter placements). This study design is not the preferred option.

A complementary study would be a survey to determine the current use of, and satisfaction with, this technology. However, only after we have valid evidence that suggests that the added costs are balanced by the potential benefits should efforts be made to increase implementation of this technology. This may not be the case.

REFERENCES

1. Bernard RW, Stahl WM: Subclavian vein catheterizations: A prospective study. I. Non-infectious complications. Ann Surg 173:184-190, 1971

2. Mansfield PF, Hohn DC, Fornage BD, et al: Complications and failures of subclavian-vein catheterization. N Engl J Med 331:1745-1748, 1994

3. Sznajder JI, Zveibil RR, Bitterman H, et al: Central vein catheterization: Failure and complication rates by three percutaneous approaches. Arch Intern Med 146:259-261, 1986

4. Legler D, Nugent M: Doppler localization of the internal jugular vein facilitates central venous cannulation. Anesthesiology 60:481-482, 1984

5. Randolph AG, Cook DJ, Gonzales CA, et al: Ultrasound guidance for placement of central venous catheters: A meta-

analysis of the literature. Crit Care Med 24:2053-2058, 1996

6. Rothschild JM: Ultrasound Guidance of Central Vein Catheterization, in Markowitz AJ (ed): Making Health Care Safer: A Critical Analysis of Patient Safety Practices. Agency for Healthcare Research and Quality, 2001, pp 244-252

7. Bold RJ, Winchester DJ, Madary AR, et al: Prospective, randomized trial of Doppler-assisted subclavian vein catheterization. Arch Surg 133:1089-1093, 1998

8. Branger B, Sabadani B, Vecina F, et al: Continuous guidance for venous punctures using a new pulsed Doppler probe: Efficiency, safety. Nephrologie 1:137-140, 1994

9. Branger B, Dauzat M, Sabadani B, et al: Pulsed Doppler sonography for guidance of vein puncture: A prospective study. Artif Organs 19:933-954, 1995

10. Denys BG, Uretsky BF, Reddy PS: Ultrasound-assisted cannulation of the internal jugular vein: A prospective comparison to the external landmark-guided technique. Circulation 87:1557-1562, 1993

11. Gilbert TB, Seneff MC, Becker RB: Facilitation of internal jugular venous cannulation using an audio-guided Doppler ultrasound vascular access device: Results from a prospective, dual-center, randomized, crossover clinical study. Crit Care Med 23:60-65, 1995

12. Gratz I, Afshar M, Kidwell P, et al: Doppler-guided cannulation of the internal jugular vein: A prospective, randomized trial. J Clin Monit Comput 10:185-188, 1994

13. Gualtieri E, Deppe S, Sipperly ME, et al: Subclavian venous catheterization: Greater success rate for less experienced operators using ultrasound guidance. Crit Care Med 23:692-697, 1995

14. Hilty WM, Hudson PA, Levitt MA, et al: Real-time ultrasound-guided femoral vein catheterization during cardiopulmonary resuscitation. Ann Emerg Med 29:331-336, 1997

15. Lefrant JY, Cuvillon P, Benezet JF, et al: Pulsed Doppler ultrasonography guidance for catheterization of the subclavian vein. Anesthesiology 88:1195-1201, 1998

16. Mallory DL, McGee WT, Shawker TH, et al: Ultrasound guidance improves the success rate of internal jugular vein cannulation: A prospective, randomized trial. Chest 98:157-160, 1990

17. Nadig C, Leidig M, Schmiedeke T, et al: The use of ultrasound for the placement of dialysis catheters. Nephrol Dial Transplant 13:978-981, 1998

18. Scherhag A, Klein A, Jantzen JP: Cannulation of the internal jugular vein aided by two ultrasound methods. Anaesthesist 38:633-638, 1989

19. Slama M, Novara A, Safavian A, et al: Improvement of internal jugular vein cannulation using an ultrasound-guided technique. Intensive Care Med 23:916-919, 1997

20. Teichgraber UKM, Benter T, Gebel M, et al: A sonographically guided technique for central venous access. AJR Am J Roentgenol 169:731-733, 1997

21. Troianos CA, Jobes DR, Ellison N: Ultrasound-guided cannulation of the internal jugular vein: A prospective, randomized trial. Anesth Analg 72:823-826, 1991

22. Verghese ST, McGill WA, Patel RI, et al: Ultrasound-guided internal jugular venous cannulation in infants. Anesthesiology 91:71-77, 1999

23. Verghese ST, McGill WA, Patel RI, et al: Comparison of three techniques for internal jugular vein cannulation in infants. Paediatr Anaesth 10:505-511, 2000

24. Vueivic M, Tehan B, Gamlin F, et al: The SMART needle: A new Doppler ultrasound-guided vascular access needle. Anaesthesia 49:889-891, 1994

25. Polderman KH, Girbes ARJ: Central venous catheter use. Part 1: Mechanical complications. Intensive Care Med 28:1-17, 2002