Ultrasound Guidance and Risk for Central Venous Catheter–Related Infections in the Intensive Care Unit: A Post Hoc Analysis of Individual Data of 3 Multicenter Randomized Trials

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Background. Ultrasound (US) guidance is frequently used in critically ill patients for central venous catheter (CVC) insertion. The effect of US on infectious risk remains controversial, and randomized controlled trials (RCTs) have assessed mainly noninfectious complications. This study assessed infectious risk associated with catheters inserted with US guidance vs use of anatomical landmarks.

Methods. We used individual data from 3 large RCTs for which a prospective, high-quality data collection was performed. Adult patients were recruited in various intensive care units (ICUs) in France as soon as they required short-term CVC insertion. We applied marginal Cox models with inverse probability weighting to estimate the effect of US-guided insertion on catheter-related bloodstream infections (CRBSIs, primary outcome) and major catheter-related infections (MCRIs, secondary outcome). We also evaluated insertion site colonization at catheter removal.

Results. Our post hoc analysis included 4636 patients and 5502 catheters inserted in 2088 jugular, 1733 femoral, and 1681 subclavian veins, in 19 ICUs. US guidance was used for 2147 catheter insertions. Among jugular and femoral CVCs and after weighting, we found an association between US and CRBSI (hazard ratio [HR], 2.21 [95% confidence interval {CI}, 1.17–4.16]; *P* = .014) and between US and MCRI (HR, 1.55 [95% CI, 1.01–2.38]; *P* = .045). Catheter insertion site colonization at removal was more common in the US-guided group (*P* = .0045) among jugular and femoral CVCs in situ for ≤7 days (n = 606).

Conclusions. In prospectively collected data in which catheters were not randomized to insertion by US or anatomical landmarks, US guidance was associated with increased risk of infection.

Keywords. ultrasound guidance; anatomical landmarks; intravascular catheter; catheter-related infection; catheter-related bloodstream infection.

Short-term central venous catheters (CVCs) are essential in the care of critically ill patients to aid the intravenous administration of fluid resuscitation, allow safe intravenous administration of medications, and help in the monitoring of hemodynamic parameters. In European intensive care units (ICUs), the CVC utilization rate was on average 70 CVC days per 100 patient-days, and ICU bloodstream infections were catheter-related in 44% of cases [1]. Intravascular catheter–related infections are associated with increased mortality and morbidity, and many are preventable [2].

Anatomical landmarks (ALs) were traditionally used to determine the correct place in which to insert CVCs. Ultrasound (US) guidance is now available and frequently used by intensivists and hospitalists [3]. Among jugular catheters, insertion using ALs is associated with (1) an increased number of attempts needed for successful cannulation, (2) a decreased chance of success at the first attempt, (3) an augmented chance of hematoma formation, and (4) an increased time to successful cannulation compared to US guidance

[4]. Among femoral and subclavian catheter insertions, US guidance offers gains in safety and quality when compared with insertion using AL [5]. Interestingly, the impact of US-guided insertion on infectious risk remains controversial, and most randomized controlled trials (RCTs) have assessed only noninfectious complications [4, 5]. However, US-guided insertion may have its own infectious risk. We used the data gathered for 3 large RCTs [6–8] to determine the association between US-guided or AL CVC insertion and catheter-related bloodstream infections (CRBSIs). Since experience with US-guided subclavian insertion remains low, as well as the low infectious risk involving catheters inserted in the subclavian vein [9], we focused on the jugular and femoral insertion sites.

METHODS

Study Design
We used the databases from 3 large RCTs (DRESSING2, CLEAN, and 3SITES) that investigated various prevention strategies, and for which prospective high-quality data collection was performed [6–8]. The similarities among all these RCTs with regard to definitions and inclusion criteria allowed us to merge the 3 databases. The objectives of the 3 studies were similar: to evaluate the effect of specific prevention measures on the risk of intravascular catheter complications. The DRESSING2 study assessed the effect of chlorhexidine-gluconate (CHG) dressing and highly adhesive dressing for preventing catheter-related infections and catheter colonization [6]. The impact of skin antisepsis with CHG compared to povidone iodine-alcohol on intravascular catheter–related infections was investigated in the CLEAN study [7]. The 3SITES study evaluated differences in mechanical and infectious complications between the subclavian, jugular, and femoral insertion sites [8]. CHG dressing, CHG skin antisepsis, and the subclavian vein insertion site decreased the risk of infection [6–8]. The study interventions were neither blinded to the investigators nor to the ICU staff, but they were blinded to the adjudication committee and to the microbiologists who processed the samples of skin, blood, and catheter cultures [6–8]. Details on the merging process and missing data are provided in the Supplementary Data. The current analysis complied with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for observational studies [10].

Study Patients
Adult patients (≥18 years of age) were recruited from 2010 to 2014 in ICUs in France as soon as they required CVC insertion [8], or a peripheral arterial catheter (AC) or short-term dialysis catheter (DC) insertion [6, 7]. For the current study only, patients from ICUs that performed >10% of catheter insertions with US were included. The characteristics of patients were similar across studies [6–8]. Patients underwent follow-up until ICU discharge [8], 48 hours after ICU discharge [6, 7], or death [6–8].

Study Catheters
This post hoc analysis evaluated data from patients with short-term CVCs included in the 3 studies. ACs and DCs were excluded. As CHG dressings were tested only in the DRESSING2 study, and their use demonstrated a reduced infection rate, catheters with CHG dressing were excluded from the analysis. Moreover, a catheter was excluded from the analysis if it was inserted in another site after a primary insertion failure. All catheters were managed in the same way and complied with the French recommendations for catheter insertion and care [11], which are similar to Centers for Disease Control and Prevention guidelines [12] (Supplementary Data). Of note, prevention strategies did not change since then. Importantly, US guidance was used at the discretion of the attending physician, and this variable was routinely collected in all studies. A transducer with a sterile sheath was used to perform vascular access procedures. Sterile gel was used. Decisions to remove catheters were made independently by the physicians caring for each patient.

Definitions and Outcomes
According to American and French recommendations, we used the following definitions [13, 14]. Catheter colonization was defined as a quantitative catheter tip culture yielding ≥1000 colony-forming units/mL [15]. A CRBSI (primary outcome) was a combination of (1) 1 or more positive peripheral blood cultures sampled after at least 48 hours of catheterization or 48 hours after catheter removal; (2) the isolation of the same phenotypic microorganism from the colonized catheter, or a blood culture differential time to positivity [6, 7] of ≥2 hours [16]; and (3) no apparent source of bloodstream infection other than the catheter. Catheter-related clinical sepsis without bloodstream infection was a combination of catheter colonization, body temperature, pus at the insertion site, or resolution of clinical sepsis after catheter removal, and the absence of any other infectious focus. Major catheter-related infection (MCRI, secondary outcome) was defined as either a CRBSI, or a catheter-related clinical sepsis without bloodstream infection. If a patient had a positive blood culture for coagulase-negative staphylococci, the same pulsotype from the strains recovered from the catheter tip and blood culture was required for a diagnosis of a CRBSI [6]. Alternatively, 2 separate peripheral blood cultures had to grow the same microorganism that colonized the catheter tip [7, 8]. All suspected cases of intravascular catheter–related infections were reviewed by blinded independent assessors based on detailed preestablished definitions. Insertion site colonization at the time of catheter removal was evaluated in 2 studies [6, 7] using semi-quantitative insertion-site cultures; the insertion site was sampled immediately before catheter

removal. As previously analyzed [17], and because the size of the insertion site cultured was different across studies, we created a semi-quantitative variable with sterile, low-grade colonization, and high-grade colonization according to the median of quantitative cultures obtained in each study. We performed an additional analysis for insertion variables, mechanical complications at insertion, and symptomatic thrombosis, which were routinely collected in the 3SITES study.

Statistical Analysis

Characteristics of patients and catheters were described as count (percentage) or median (interquartile range [IQR]) for qualitative and quantitative variables, respectively.

Because the use of US guidance was not randomized, we developed a propensity score aimed to predict the conditional probability that a given catheter would be inserted using US guidance, using variables recorded before and at the time of catheter insertion. We included confounding covariates (those related to US guidance and infection) and prognostic covariates (ie, only related to infection) [18–20]. Then, we developed different propensity scores according to the insertion site (ie, jugular and femoral, jugular, femoral and subclavian) using nonparsimonious logistic regression models. The following clinically relevant covariates were included: age, experience of the operator (<50 procedures vs ≥50 procedures), antibiotics at insertion, skin antisepsis, anticoagulation at insertion, time from ICU admission to catheter insertion, and mechanical ventilation at insertion. The distribution of propensity scores was checked graphically between the US and the AL groups (Supplementary Figure 1). An inverse probability of treatment weighting (IPTW) based on the propensity score was computed to create a pseudopopulation in which the probability to use US guidance or AL will be equal (Supplementary Data). Then, the effect of US on CRBSI and MCRI was estimated using a marginal Cox model for clustered data, weighted by IPTW and stratified by ICU and study. Data were censored at 28 days since catheter insertion. Hazard ratios (HRs) were derived: An HR >1 indicated an increased risk for the US-inserted catheters. This model considers the intracluster dependency (ie, >1 catheter per patient), using robust sandwich covariance estimates (PROC PHREG procedure of SAS) [21]. The proportionality of hazard risk for US was tested using Martingale residuals. To confirm our results, we performed additional analyses using univariate and multivariate marginal Cox models (Supplementary Data). Differences in insertion site skin colonization, variables at insertion (number of attempts needed, time for insertion, time between venipuncture and dressing, and mechanical complications) and symptomatic thrombosis between the US and AL groups were tested using χ^2, Fisher, and Wilcoxon tests, respectively (Supplementary Data). Tests were 2-tailed, with $P < .05$ being considered significant, without adjustement for multiple comparisons. All analyses were performed using SAS (version 9.4) and R (version 3.5.3) software.

RESULTS

Patients and Catheters

Between May 2010 and June 2014, a total of 4636 patients and 5502 catheters were inserted in 19 different ICUs (Figure 1). We observed 2088 jugular, 1733 femoral, and 1681 subclavian CVC insertions. Characteristics of patients and catheters were described in Table 1. Median age of patients was 64 (IQR, 52.7–75) years and 2991 (64.5%) patients were male. Diabetes mellitus was present at admission in 720 (15.5%) patients, and the median Simplified Acute Physiology Score II (SAPS II) was 54 (IQR, 41–68). Junior operators (<50 procedures) placed 3777 (68.6%) catheters, and CHG for skin disinfection was used for skin disinfection in 2498 (45.4%) catheters. Among the US-guided group (n = 2147), 1493 (69.5%) and 479 (22.3%) catheters were inserted in the jugular and in the femoral vein, respectively. Among the AL group (n = 3355), 1466 (43.7) and 1254 (37.4) catheters were inserted in the subclavian and femoral vein, respectively. We observed 17 (0.5%) CRBSIs and 38 (1.1%) MCRIs in the AL group, whereas in the US group, CRBSI and MCRIs were observed in 35 (1.6%) and 57 (2.7%), respectively. The proportionality of hazard was respected for MCRI and for CRBSI in all different subsets analyzed.

Jugular and Femoral Catheters

A total of 3821 catheters were inserted in the jugular (n = 2088) or in the femoral (n = 1733) vein. In the US group, 34 (1.76%) CRBSIs and 55 (2.85%) MCRIs occurred during the study period, whereas 14 (0.74%) CRBSIs and 34 (1.80%) MCRIs were observed in the AL group.

In the unweighted Cox model analysis, the CRBSI risk was similar for the US group compared to the AL group (HR, 1.58 [95% confidence interval {CI}, .83–3.01]; $P = .17$; Supplementary Figure 2). After IPTW for this specific subset, we found an association between US and CRBSI (HR, 2.21 [95% CI, 1.17–4.16]; $P = .014$; Figure 2). A confirmatory analysis using multivariate marginal Cox models showed that US was associated with an increased risk for CRBSI compared to AL (HR, 2.23 [95% CI, 1.16–4.28]; $P = .016$; Supplementary Figure 2).

After IPTW, we found an association between US and MCRI (HR, 1.55 [95% CI, 1.01–2.38]; $P = .045$; Figure 2). A confirmatory analysis using multivariate marginal Cox models showed similar results (Supplementary Figure 2).

Skin Colonization of the Jugular and Femoral Catheter Insertion Sites

The catheter insertion site (variable available for 941 catheters) tended to be more frequently colonized in the US group

compared to the AL group ($P = .10$; Table 2). Considering only catheters with ≤7 days of maintenance (n = 606), this difference became significant, with catheters in the US group being more often colonized than those in the AL group ($P = .0045$).

Microorganisms

The distribution of microorganisms associated with CRBSI (0.57) and MCRI ($P = .22$) was similar between the US and the AL groups (Supplementary Table 1).

Variables at Insertion, Mechanical Complications, and Symptomatic Thrombosis

In the subset including jugular and femoral catheters (n = 3821), the variables at insertion were available in 2359 observations. The US reduced the number of attempts needed for successful cannulation ($P = .0044$) and tended to decrease arterial puncture ($P = .094$; Supplementary Table 2). Clinical symptomatic deep vein thrombosis was significantly reduced in the US group ($P = .035$). The US increased significantly the time from first puncture to the completed dressing (13 vs 11 minutes for AL; $P < .0001$).

Jugular Catheters

After IPTW, US guidance increased the risk for CRBSI (HR, 2.52 [95% CI, .85–7.41]; $P = .094$; Figure 2). A confirmatory analysis using multivariate marginal Cox models showed that US guidance was associated with an increased risk for CRBSI compared to AL (HR, 2.81 [95% CI, .99–7.96]; $P = .052$; Supplementary Figure 2).

After IPTW, US guidance increased the risk for MCRI (HR, 1.99 [95% CI, .96–4.13]; $P = .064$; Figure 2).

Femoral Catheters

After IPTW, the CRBSI US risk was increased compared with the CRBSI AL risk (HR, 2.57 [95% CI, 1.13–5.84]; $P = .024$; Figure 2).

After IPTW, the MCRI US risk was not statistically increased compared to MCRI AL risk (HR, 1.53 [95% CI, .82–2.85]; $P = .18$; Figure 2).

Subclavian Catheters

In the CRBSI analysis, no significant increased risk for US was observed in the unweighted Cox model (HR, 0.95 [95% CI,
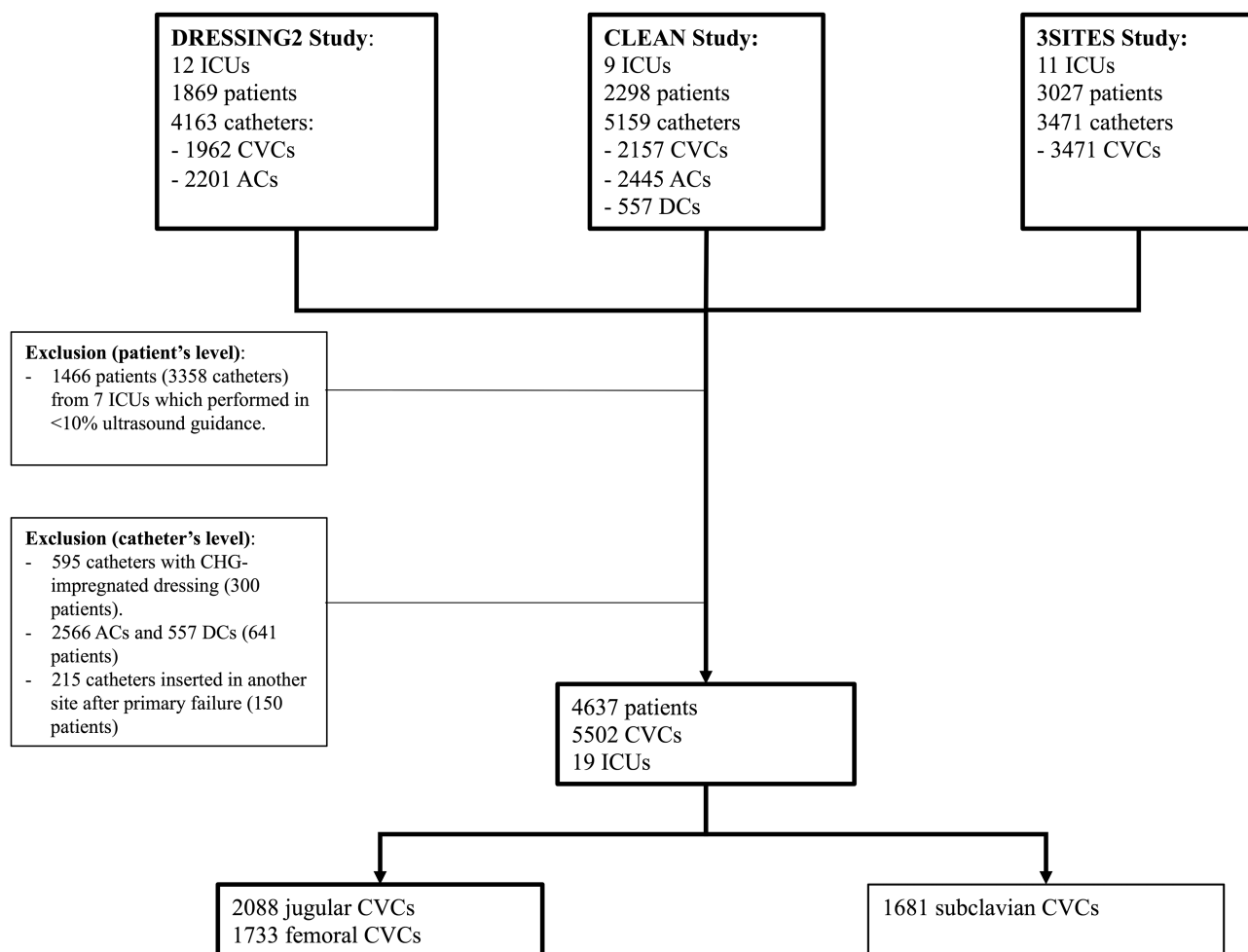

Figure 1. Study flowchart. Abbreviations: AC, arterial catheter; CHG, chlorhexidine-gluconate; CVC, central venous catheter; DC, short-term dialysis catheter; ICU, intensive care unit.

Table 1. Patient and Catheter Characteristics

Characteristic	All	AL	US
	(n = 4637)	(n = 2885)	(n = 1752)
Patient characteristics			
Sex			
Female	1646 (35.5)	1022 (35.4)	624 (35.6)
Male	2991 (64.5)	1863 (64.6)	1128 (64.4)
Age, y, median (IQR)	64 (52.7–75)	64 (51.9–74.4)	64 (54–75.9)
Chronic renal failure	328 (7.1)	210 (7.3)	118 (6.7)
Diabetes mellitus	720 (15.5)	440 (15.3)	280 (16)
Chronic respiratory failure	465 (10)	267 (9.3)	198 (11.3)
Neoplasia	482 (10.4)	301 (10.4)	181 (10.3)
Immunosuppression	882 (19)	545 (18.9)	337 (19.2)
SAPS II, median (IQR)	54 (41–68)	55 (42–69)	53 (41–67.5)
Catheter-related variables	All (n = 5502)	AL (n = 3355)	US (n = 2147)
Catheter-days, median (IQR)	6 (3–10)	6 (3–10)	6 (3–10)
Time from ICU admission to catheter insertion, median (IQR)	1 (1–4)	1 (1–5)	1 (1–4)
Experience of the operator			
<50 procedures	3777 (68.6)	2284 (68.1)	1493 (69.5)
≥50 procedures	1725 (31.4)	1071 (31.9)	654 (30.5)
Insertion site			
Jugular	2088 (37.9)	635 (18.9)	1453 (677)
Subclavian	1681 (30.6)	1466 (43.7)	215 (10)
Femoral	1733 (31.5)	1254 (37.4)	479 (22.3)
Right side jugular	1470 (70.4)	463 (72.9)	1007 (69.3)
Right side femoral	1037 (59.8)	754 (60.1)	283 (59.1)
Skin antisepsis			
Non-CHG	3004 (54.6)	1879 (56)	1125 (52.4)
CHG	2498 (45.4)	1476 (44)	1022 (476)
Mechanical ventilation at insertion	4341 (78.9)	2684 (80)	1657 (772)
Vasopressor at insertion	3340 (60.7)	1986 (59.2)	1354 (63.1)
Antibiotics at insertion	3234 (58.8)	1938 (57.8)	1296 (60.4)
Heparin	2715 (49.3)	1648 (49.1)	1067 (49.7)
Lipids	1197 (21.8)	738 (22)	459 (21.4)
Catheter removal because no longer needed	2343 (42.6)	1425 (42.5)	918 (42.8)
Catheter removal for suspected infection	765 (13.9)	473 (14.1)	292 (13.6)
Catheter removal for death	1192 (21.7)	717 (21.4)	475 (22.1)
Catheter tip colonization	491 (8.9)	274 (8.2)	217 (10.1)
CRBSI	52 (0.9)	17 (0.5)	35 (1.6)
MCRI	95 (1.7)	38 (1.1)	57 (2.7)

Data are presented as No. (%) unless otherwise indicated.

Abbreviations: AL, anatomical landmark. CHG, chlorhexidine-gluconate; CRBSI, catheter-related bloodstream infection; ICU, intensive care unit; IQR, interquartile range; MCRI, major catheter-related infection; SAPS, Simplified Acute Physiology Score II; US, ultrasound.
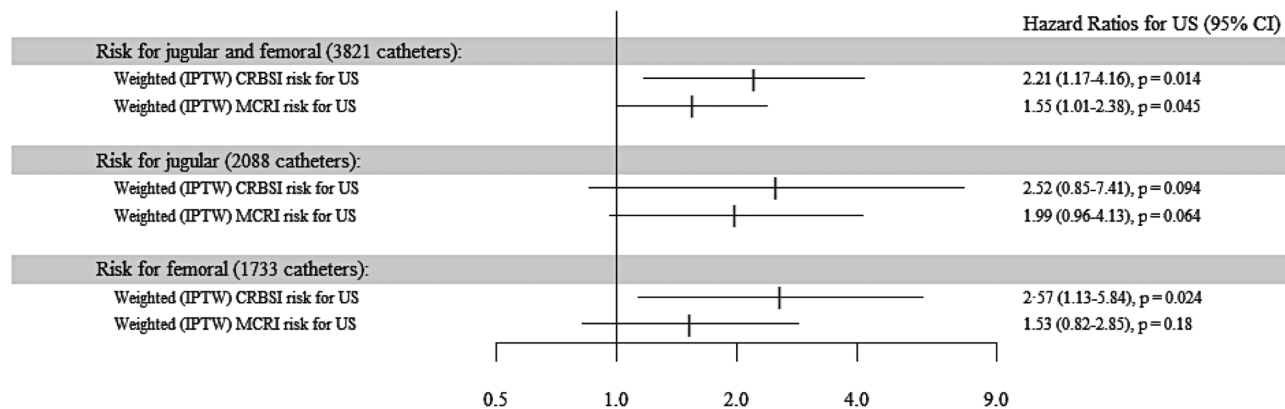
Figure 2. Association between ultrasound guidance and the risk of intravascular catheter infection using inverse probability treatment weighting in jugular and femoral catheters. Abbreviations: CI, confidence interval. CRBSI, catheter-related bloodstream infection; IPTW, inverse probability treatment weighting; MCRI, major catheter-related infection; US, ultrasound guidance.

.12–7.29]; *P* = .96; Supplementary Data) or after IPTW (HR, 1.00 [95% CI, .16–6.12]; *P* = .99).

DISCUSSION

Using high-quality data from 3 RCTs and using 2 different robust statistical methods, this post hoc analysis suggested that the daily hazard rate of MCRI and CRBSI for jugular and femoral catheters inserted with US guidance was higher than using AL.

Data in the literature about the infection risk for intravascular catheters according to US use are scarce, especially regarding RCTs. In 2015, 2 Cochrane systematic reviews and meta-analyses concluded that US guidance offered gains in safety and quality compared with an AL technique [4, 5]. However, assessing infection rates associated with the use of US-guided insertion was not investigated as a primary outcome in any of the reviewed studies, and only 2 studies reported rates of intravascular catheter infections [4, 5, 22, 23]. To do an exhaustive literature search, we used Medline to perform a systematic review of articles published before 1 January 2020

with similar search strategies used in the previous Cochrane systematic reviews (see details in the Supplementary Data and Supplementary Table 3) [4, 5] and we found only 2 additional studies reporting data on intravascular catheter infections [24, 25]. Overall, the impact of US guidance on infection rate was not the focus of many studies. Among jugular site insertion, only 4 RCTs assessed the infection rate. The first showed that CRBSI was increased for AL compared with US-guided insertion (16% vs 10%; *P* < .001) [22]. Of note, this study reported elevated CRBSI rates, which may reflect clinical practices prior to routine implementation of prevention bundles. The second study showed a higher infection rate for the AL group (10% vs 2%; *P* < .05). This study was performed by a single operator and also found disproportionately high infectious and mechanical complications (29%) in the AL group [23]. In 2 additional small RCTs, no intravascular catheter infections were observed [24, 25]. Among femoral catheter insertion, to our knowledge, no RCT investigated infectious complications with US-guided insertion. Similarly, few data from observational

Table 2. Skin Colonization at Removal for Jugular and Femoral Catheters

Colonization	AL	US	*P* Value[a]
Skin colonization at removal (n = 941)			
High colonization	183 (43.3)	253 (48.8)	.10
Low colonization	159 (37.6)	161 (31.1)	
Sterile	81 (19.1)	104 (20.1)	
Skin colonization at removal for ≤7 catheter-days (n = 606)			
High colonization	106 (37.3)	150 (46.6)	.0045
Low colonization	120 (42.3)	95 (29.5)	
Sterile	58 (20.4)	77 (23.9)	
Skin colonization at removal for >7 catheter-days (n = 335)			
High colonization	77 (55.4)	103 (52.6)	.51
Low colonization	39 (28.1)	66 (33.7)	
Sterile	23 (16.5)	27 (13.8)	

Legend. AL, anatomical landmark; US, ultrasound.

[a]χ² test.

studies are available. Other investigators found that US guidance had no effect on CVC-associated bloodstream infections [26]. A recent study showed that the cumulative incidence of CRBSI at 100 days was slightly higher for the US-guided group (31% vs 25%; $P = .09$) [27]. In an environment of consistent catheter care representing the largest dataset ever assembled, we found that US guidance was associated with an increased risk of MCRI and CRBSI compared to AL, in both jugular and femoral catheter insertions. Moreover, the skin at catheter removal was more frequently colonized for the US group in the first 7 days of catheterization, thus suggesting extraluminal contamination.

The use of a US transducer may complicate catheter insertion, leading to breaches in aseptic technique. Of note, all the above-noted RCTs were conducted during a time when US guidance was not routinely used among all intensivists: meanwhile, it is conceivable that knowledge on US aseptic insertion technique has improved since then. Evidence-based recommendations on the use of US guidance for CVC insertion in adult patients have been only recently published [28]. Another source of contamination may be the gel used for optimizing US visibility. Several outbreaks due to contaminated US gel probe have been described [29, 30]. However, in our cohort of ICUs, no ongoing outbreak was described between 2010 and 2014 and the distribution of microorganisms between the US and AL groups did not significantly differ, thus mitigating this hypothesis.

Among jugular vein insertions, the use of US guidance clearly reduces peri-interventional complications and adverse events [4]. For femoral and subclavian insertions, the risk of complications and the gain on safety appear to be less pronounced [5]. An additional analysis of the 3SITES database for jugular and femoral catheters confirmed that US guidance reduced the number of attempts needed for successful cannulation, tended to decrease arterial puncture, and reduced

symptomatic deep venous thrombosis. In light of these considerations, we do not discourage the use of US guidance for CVC insertion. Nevertheless, we hope that our findings will stimulate the interest of performing a large, prospective, randomized trial to confirm or refute our results. In the interim, we have summarized key points for optimal US-guided CVC insertion with focus on infection prevention measures (Table 3).

Our study has several limitations. We analyzed observational data, and the patients were not randomized according to CVC insertion using US guidance or AL. Moreover, no information on US technique and US hygiene compliance was available. Although we analyzed experience of the operator, we were unable to determine if that experience was with US guidance or AL. Second, all RCTs were conducted in French ICUs, thus limiting the generalizability of our results to the critically ill patient setting. Third, we showed the results from a large database designed to investigate the impact of certain practices or infection prevention measures, and interactions may have occurred among the study groups or ICUs. However, our statistical analyses considered these potential drawbacks and our models were stratified by ICUs and study. Fourth, CHG-impregnated dressings were excluded: The impact of our results in the setting of routine utilization of CHG dressing remains unknown. However, several guidelines did not routinely recommend using CHG-impregnated dressings, but only use them in adult patients when the risk of infection is high despite the use of appropriate bundles of catheter care [31, 32]. Finally, we showed results close to the limit of statistical significance. The current rates of CRBSI and MCRI are low, and our study may still be marginally powered to illustrate differences between US guidance and AL.

Using the largest dataset ever collected from large multicenter RCTs conducted with consistent catheter insertion and care, we showed that US guidance increased the infectious risk for

Table 3. Key Points for Optimal Ultrasound-Guided Central Venous Catheter Insertion With Focus on Infection Prevention Measures

1. Preprocedure
Operators should be familiar with the operation of their specific US machine prior to initiation of a vascular access procedure.
Use a high-frequency linear transducer with a long sterile sheath to perform vascular access procedures.
Use single-use sterile transmission gel.
Operators should evaluate the target blood vessel size and depth during preprocedural ultrasound evaluation.
2. Techniques
Operators should use a standardized procedure checklist that includes the use of real-time US guidance.
US guidance should be combined with aseptic technique and maximal sterile barrier precautions.
The needle tip should never be in contact with the sterile sheath of transducer.
3. Training
Novice operators should complete a systematic training program before attempting US-guided CVC insertion independently on patients.
Cognitive training in US guided CVC insertion should include infection prevention strategies.
Trainees should demonstrate minimal competence in infection prevention measures before placing US-guided CVCs independently.
Competency assessments should include formal evaluation of knowledge in infection prevention measures using standardized assessment tools.
Periodic proficiency assessment of all operators should be conducted to ensure maintenance of competency.

Adapted from [28].

Abbreviations: CVC, central venous catheter; US, ultrasound.

intravascular catheters in the ICU. US guidance should not be discouraged, but infection prevention measures during US-guided catheter insertion should be carefully followed.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

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