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Diagnostic accuracy of central venous catheter confirmation by bedside ultrasound versus chest radiography in critically ill patients: A systematic review and meta-analysis

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Abstract

Objective—We performed a systematic review and meta-analysis to examine the accuracy of bedside ultrasound for confirmation of central venous catheter position and exclusion of pneumothorax compared to chest radiography.

Data Sources—PubMed, EMBASE, Cochrane Central Register of Controlled Trials, reference lists, conference proceedings and ClinicalTrials.gov

Study Selection—Articles and abstracts describing the diagnostic accuracy of bedside ultrasound compared with chest radiography for confirmation of central venous catheters in sufficient detail to reconstruct 2×2 contingency tables were reviewed. Primary outcomes included the accuracy of confirming catheter positioning and detecting a pneumothorax. Secondary outcomes included feasibility, inter-rater reliability, and efficiency to complete bedside ultrasound confirmation of central venous catheter position.

Data Extraction—Investigators abstracted study details including research design and sonographic imaging technique to detect catheter malposition and procedure-related pneumothorax. Diagnostic accuracy measures included pooled sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio.

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Data Synthesis—15 studies with 1553 central venous catheter placements were identified with a pooled sensitivity and specificity of catheter malposition by ultrasound of 0.82 [0.77, 0.86] and 0.98 [0.97, 0.99] respectively. The pooled positive and negative likelihood ratios of catheter malposition by ultrasound were 31.12 [14.72, 65.78] and 0.25 [0.13, 0.47]. The sensitivity and specificity of ultrasound for pneumothorax detection was nearly 100% in the participating studies. Bedside ultrasound reduced mean central venous catheter confirmation time by 58.3 minutes. Risk of bias and clinical heterogeneity in the studies were high.

Conclusions—Bedside ultrasound is faster than radiography at identifying pneumothorax after central venous catheter insertion. When a central venous catheter malposition exists, bedside ultrasound will identify four out of every five earlier than chest radiography.

Keywords

central catheter; ultrasonography interventional; chest radiograph; systematic review; meta-analysis; intravenous

INTRODUCTION

Central venous catheter (CVC) placement is the most common procedure performed in the management of critically ill patients (1). Ultrasonography is being used with increasing frequency in critical care settings to rapidly and non-invasively evaluate life-threatening conditions and to improve procedural success rate and safety (1–4). CVC placement is associated with risks (5–9) including CVC malposition (up to 14%) and iatrogenic pneumothorax (up to 3.3%) of internal jugular and subclavian CVC attempts (10, 11). CVC malposition is important because it is associated with hemodynamic inaccuracies, venous thrombosis, and delays in treatment (5, 7, 8). Pneumothorax is associated with additional monitoring and possible procedural interventions.

For over 50 years, chest radiography has been the standard method to evaluate CVC position and to identify potential complications (12–14). Bedside ultrasound has advantages over chest radiography including lack of ionizing radiation exposure, decreased resource utilization and decreased diagnostic time (15–18). This earlier confirmation of CVC positioning allows for earlier clinical management which could potentially affect patient outcomes (19). The bedside ultrasound CVC confirmation approach is demonstrated in Supplemental Digital Content 1–2 (digital videos and legend) and consists of a focused exam of the vascular structures and the right atrium to identify catheter position and examination of the anterior chest wall to assess for pneumothorax (20–22). This includes direct ultrasound identification of the CVC tip within the right atrium or the aberrant placement within the internal jugular or subclavian vein as well as indirect identification of the CVC tip location by rapid entry of turbulent flow into the right atrium or vascular structures after agitated saline or rapid saline flush of the distal CVC. We conducted this systematic review and meta-analysis to evaluate the diagnostic accuracy of bedside ultrasound, as compared to chest radiography, for the confirmation of CVC position and identification of pneumothorax in critically ill patients.

MATERIALS AND METHODS

This meta-analysis was performed according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (23) (Supplemental Digital Content 3). Ethical approval from the human research protection office at the principal investigator's institution was not required.

Literature Search

Published literature was searched using strategies created by a trained medical librarian (SF) experienced in systematic reviews. The searches were implemented in Medline via PubMed, Embase, Scopus, the Cochrane Database of Systematic Reviews, the Database of Abstracts of Reviews of Effects, and the Cochrane Central Register of Controlled Trials (CENTRAL). All searches were completed in June 2016. Full search strategies are provided in Supplemental Digital Content 4.

Selection of Studies

Two authors (AB, EA) screened titles and abstracts obtained from the database searches. Details of the inclusion and exclusion criteria for reviewed studies are listed in Supplemental Digital Content 5. Two authors (EA, DT) also reviewed abstracts accepted for publication at national conferences and published in *Critical Care Medicine*, *American Institute of Ultrasound in Medicine*, *Chest*, or *Annals of Emergency Medicine* from 1990 to June 2016. Studies deemed potentially relevant after the screen were reviewed by two authors (EA, AD).

Data Extraction

The authors (EA, AD) independently extracted data from the included studies using a standardized data collection form. To calculate sensitivity and specificity for diagnosing catheter malposition and pneumothorax, a 2×2 table was constructed based on raw data from each article (Supplemental Digital Content 6). Any disagreements in data collection were resolved by consensus with a third reviewer (DT). Where needed, one author (EA) contacted the authors of included studies via electronic mail for further clarification of study data and results.

Outcome Measures

The primary outcomes, determined *a priori*, were the sensitivity and specificity of ultrasound to confirm CVC position and to identify pneumothorax using chest radiography as the reference standard. In constructing 2×2 tables, "disease-present" was defined as the detection of malposition (catheter tip terminating in a vein other than the superior vena cava, in the right atrium, or outside the venous system) or the presence of immediate post-procedural pneumothorax. We intended to calculate likelihood ratios for ultrasound confirmation of both CVC position and pneumothorax however we were unable to calculate likelihood ratios for pneumothorax given the imperfect gold standard (chest radiography) and low incidence of pneumothorax. Secondary outcomes assessed were: the feasibility of adequate ultrasound image acquisition (cardiac and lung) as defined by the ultrasound operators, inter-rater reliability of the ultrasound image interpretation, and efficiency.

Feasibility is defined as the percent of patients in whom ultrasound images to evaluate for CVC position could be obtained. We defined efficiency as time to confirmation of the CVC by ultrasound.

Subgroup analysis was allocated to specific ultrasound protocol (cardiac ultrasound only or cardiac ultrasound with vascular ultrasound and contrast enhanced or no contrast) and operator experience. Contrast enhanced is defined as agitation of saline prior to the flush of the CVC. Study operators were determined to be inexperienced if the study defined them in a resident training program or faculty requiring additional training before participating in the study.

Assessment of Risk of Bias in Included Studies

Two authors (EA, AD) independently assessed the methodological quality of all included studies using the QUADAS-2 (Quality Assessment of Diagnostic Accuracy Studies) tool for quality assessment questionnaire (24). Studies were judged to either have high or low risk of bias for each domain based on composite assessment of 13 questions. Discrepant quality assessments were adjudicated by discussion or resolved by a third author (DT). We did not create a summary score because of the unclear applicability of a summarized score to evaluating the quality of the studies (25). Risk was adjudicated in each domain based on *a priori* decisions that were made for questions with points of contention between the two authors assessing QUADAS-2 quality (Supplemental Digital Content 7). All studies fitting inclusion criteria were included in the meta-analysis despite their risk for bias.

Data Analysis

Meta-analysis estimates were computed when 1 studies assessed the same finding on bedside ultrasound in similar patient populations and settings using Meta-DiSc (MetaDiSc.) We generated combined estimates for diagnostic accuracy using a random-effects model (Meta-DiSc Hospital Universitario Ramón y Cajal, Madrid, Spain). Inter-study heterogeneity was assessed using the Der-Simonian-Laird random effects model and the Index of Inconsistency (I^2) (26–28). Pooled estimates of dichotomous positive (LR+) and negative (LR-) likelihood ratios were also reported from the random effects model. *A priori* subgroup analyses stratified by operator experience and ultrasound techniques were performed. Publication bias was not assessed because of the small number of studies identified (29).

RESULTS

Details regarding the search, study selection, and reason for exclusion are shown in Fig. 1. The 15 articles (16, 30–43) included 1511 patients and 1553 CVC insertions. Thirteen studies (87%) were full reports and two studies (13%) were in abstract form. Corresponding authors of the two abstracts were contacted via electronic mail without response and included in the analysis. One study author was contacted to verify extracted data and responded. Details of the patient characteristics are shown in Supplemental Digital Content 8.

Details of the study design characteristics are shown in Table 1. Of the 15 studies, five studies reported only CVC malposition, while 10 evaluated both CVC malposition and pneumothorax. Operator experience was stated in 13 studies and unknown in 2 studies. Three studies used physicians with limited experience, 4 studies used both experienced and inexperienced physicians, and 6 studies used only experienced physicians.

Risk of bias in the 15 studies is shown in Table 2. No study fulfilled all QUADAS-2 criteria for low risk of bias. Nine of 15 studies (60.0 %) were assessed as having a low risk of bias in the domain of patient selection. Blinding of outcome assessments with the index test (44) was reported in 12 of 15 studies. However, in 8 of 15 studies (53.3%) blinding of the reference study (chest radiography) was unclear or not reported. Nine studies (60.0%) had high risk of bias for incomplete data reporting.

The primary and secondary outcomes of this meta-analysis are shown in Table 3. A total of 1469 CVC were included in the final analysis with 258 catheter malpositions (17.6%) identified on chest radiography. Two studies could not be analyzed in this meta-analysis because there were no catheter malpositions identified by the index test (44) or the reference test (chest radiography)(35, 41). Subgroup analysis of study operator experience and ultrasound protocol is listed in Supplemental Digital Content 9. The pooled sensitivity and specificity of ultrasound for catheter malposition was 0.82 (95% CI 0.77, 0.86, $I^2 = 81.0\%$) and 0.98 (95% CI 0.97, 0.99, $I^2 = 77.1\%$) respectively (Fig. 2). The pooled positive and negative likelihood ratios were 31.12 (95% CI 14.72, 65.78, $I^2 = 51.4\%$) and 0.25 (95% CI 0.13, 0.47, $I^2 = 83.2\%$) (Fig. 2).

Subgroup analysis showed that the sensitivity of ultrasound for catheter malposition was 0.69 (95% CI 0.58, 0.79, $I^2 = 80.5\%$) in experienced operators. Subgroup analysis of contrast enhanced (agitated) versus no contrast study protocol showed a sensitivity of ultrasound for catheter malposition of 0.79 (95% CI 0.64, 0.90, $I^2 = 70.9\%$) versus 0.80 (95% CI 0.73, 0.85, $I^2 = 86.9\%$). Subgroup analysis of ultrasound protocol of vascular and cardiac ultrasound versus cardiac ultrasound alone showed a sensitivity of ultrasound for catheter malposition of 0.82 (95% CI 0.76, 0.87, $I^2 = 90.3\%$) versus 0.64 (95% CI 0.43, 0.82, $I^2 = 26.6\%$).

There were 12 pneumothoraces (1.1%) identified in the studies; all were identified on ultrasound, while only ten were identified on chest radiography. The additional 2 pneumothoraces were identified on computed tomography. We were unable to calculate sensitivity of pneumothorax detection in 6 studies because of the lack of pneumothorax detection in the gold standard (chest radiograph). The calculated sensitivity of pneumothorax detection in the 4 studies was 100%. The specificity of ultrasound for pneumothorax detection in all 10 studies was 100%.

The feasibility of obtaining adequate cardiac ultrasound images for confirmation of CVC positioning was 96.8% and 100% for pneumothorax evaluation. Because both Weekes articles excluded patients in whom cardiac images could not be obtained thus potentially artificially raising the reported feasibility in these studies. A sensitivity analysis was performed to evaluate feasibility in the absence of the Weekes' articles. This resulted in a

feasibility of 96.4%. Interrater reliability of the ultrasound interpretation was assessed in 4 studies via Cohen's Kappa. Some studies reported inexperienced-to-inexperienced kappa while some reported inexperienced-to-experienced kappa. The reported interobserver reliability in the four studies that evaluated this variable was 94.5%.

Eleven studies reported time to catheter placement confirmation. The average mean time required for bedside ultrasound confirmation of CVC was 5.6 minutes as compared to an average mean time to chest radiograph completion of 63.9 minutes and an average mean time to chest radiograph interpretation of 143.4 minutes (Table 3).

DISCUSSION

This meta-analysis demonstrates that bedside ultrasound can detect nearly all pneumothoraces and four out of five catheter malpositions following central venous catheter placement. It also shows that bedside cardiac and lung ultrasound is feasible in greater than 95% of patients and can be completed more efficiently than chest radiography. The pooled LR+ of 31.12 (95% CI 14.72, 65.78) indicates that ultrasound is sufficient to rule in CVC malposition, but there was evidence of high levels of statistical heterogeneity. The LR- of 0.25 (95% CI 0.13, 0.47) suggests that bedside ultrasound is insufficient to rule out catheter malpositions. This quantitative diagnostic data provides Bayesian clinicians with sufficient knowledge to formulate pre- and posttest disease probabilities based on the best available evidence. Supplemental digital content 10 illustrates how the meta-analysis results can be used to guide real-world practice decisions (45).

The sensitivity and specificity of ultrasound for identification of post procedure pneumothorax was nearly 100%. This superiority of ultrasound when compared to chest radiography for pneumothorax detection is consistent with previous literature (21, 46–49). Since sensitivity for detecting pneumothorax on supine chest radiographs is poor (21, 22), results of the included studies may have been affected by an imperfect gold standard bias (50) which raises observed estimates of sensitivity and specificity for the index test (44). The risk of incorporation bias was also high since several studies did not mention if interpretation of the chest radiograph was blinded to the results of the ultrasound which may have falsely increased observed estimates of sensitivity and specificity (51). In addition, lower rates of pneumothorax than what has been reported in the literature could overestimate the observed estimates of sensitivity and specificity of pneumothorax detection by ultrasound.

This meta-analysis shows that obtaining adequate ultrasound images for confirmation of CVC placement is feasible and has good interobserver reliability in spite of varying operator experience levels. Operator ultrasound experience in the included studies ranged from experts to operators with only limited training in bedside ultrasound. Clinician access to and experience with ultrasound is highly variable in actual practice (52, 53). Although some evidence suggests that prior experience with bedside ultrasound-guided CVC placement can affect both the safety (9) of the procedure and the diagnostic accuracy (54) of the ultrasound interpretation, our subgroup analysis did not show a clinically significant difference in the sensitivity of ultrasound to detect catheter malposition.

Finally, the results of our analysis show that using bedside ultrasound to confirm CVC placement is efficient. Bedside ultrasound for CVC confirmation was associated with a time reduction of 58.7 minutes compared to chest radiography completion and 137.7 minutes for chest radiography interpretation. This demonstrates that ultrasound provides faster confirmation of procedural success. In addition, given the high incidence of bedside ultrasound use during the insertion of the CVC, the efficiency of post-insertion CVC confirmation would be augmented.

There are important limitations in this systematic review and meta-analysis. Substantial statistical heterogeneity was observed which limits the ability to generalize the pooled diagnostic statistics. In an effort to explain this statistical heterogeneity, subgroup analyses were performed based on the main factors contributing to clinical heterogeneity among the studies. Ultrasound protocols that employed vascular and cardiac views demonstrated improved sensitivity to detect catheter malposition and better probability of ruling out a catheter malposition when analyzed separately from techniques that used only cardiac views. However, subgroup analyses limited to studies with experienced operators and use of contrast enhanced (agitated) saline flush did not have significantly different diagnostic accuracy as compared to the overall pooled data and did not improve statistical heterogeneity. In addition, several studies had high risk of bias.

The definition of catheter malposition used in this meta-analysis has been debated in the literature (55) and may be ready for reinterpretation. Of note, Meggiolaro et al (43) classified catheter tip in the right atrium as correct catheter positioning; however, we considered atrial catheter tips to be malpositioned when calculating the diagnostic statistics for this study. Thus, the sensitivity of CVC malposition detection by ultrasound as reported by Meggiolaro et al is slightly higher than that used in this meta-analysis (64% compared to 53%). Given recent literature regarding the safety of the intra-atrial position (56–58), perhaps the definition of correct catheter positioning should be reevaluated. Most of the other included studies reported catheter malposition in aggregate and did not distinguish between intra-atrial catheter positioning and other types of malposition. Therefore, it is unknown whether the overall pooled sensitivity of ultrasound for catheter malposition would be increased if intra-atrial catheters were considered correct position.

Lastly, it is possible that the search did not uncover all of the published literature in this domain, as nonrandomized studies are indexed poorly in study registries (59). However, this systematic review provides an evaluation of the current literature to date and by demonstrating benefit, it provides evidence for the need of reevaluation of guidelines in this area.

Additional research in this area should focus on randomized controlled studies comparing CVC confirmation by ultrasound and chest radiography to further assess diagnostic accuracy, efficiency, and clinical outcomes such as adverse events. Future studies should consider re-defining CVC tip malposition to exclude atrial catheter tip positioning. In addition, future researchers should consider performing both cardiac and vascular ultrasounds for detection of CVC position, as this was associated with an improved sensitivity for detecting malposition as compared to cardiac ultrasound alone. Cost analysis

of ultrasound versus chest radiography for CVC confirmation in critically ill patients is another area of potential research.

Conclusions

Our analysis demonstrates that bedside ultrasound accurately identifies pneumothorax after CVC insertion. When a CVC malposition exists, bedside ultrasound will identify four out of every five. Importantly, ultrasound provides results regarding catheter position and pneumothorax faster than chest radiography. We recommend that bedside ultrasound be used as first-line confirmation method to determine catheter malposition. If the CVC is found to be malpositioned in a venous structure, the CVC can be expediently addressed without obtaining a chest radiograph first. However, if the CVC malposition is not detected by ultrasound and concern is high for malposition, such as in the case of multiple cannulation attempts or incomplete/inadequate ultrasound confirmation technique, chest radiography should be performed to rule out catheter malposition.

After review and analysis of the current literature, we suggest that best practice for ultrasound-guided confirmation of CVC positioning include a focused vascular and cardiac ultrasound with rapid non-agitated saline flush. Given the relative benefits of ultrasound versus chest radiography with respect to image feasibility and efficiency, this modality needs further dissemination and implementation into clinical practice. Furthermore, there is a need for randomized controlled trials to provide a solid evidence base for future updates of clinical practice guidelines.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Search, inclusion, and exclusion flow diagram. Flow diagram illustrating search strategy and identification of relevant articles.

Figure 2.
Pooled sensitivity, specificity, and likelihood ratio of included studies.

Table 1

Study design characteristics of included studies

Study/Year	Design ^a	CVC, n	CVC site	Primary outcome measure	Secondary outcome measure	Operator experience ^b	Ultrasound technique
Vezzani et al (30)/2010	Prospective	111	IJ/SC	Malposition, PTX	Time to confirmation	Experienced	Vascular and cardiac views, agitated saline used
Maury et al (16)/2001	Prospective	81	IJ/SC	Malposition, PTX	Time to confirmation	Inexperienced	Vascular and cardiac views, nonagitated saline used
Zanobetti et al (31)/2013	Prospective	210	IJ/SC	Malposition, PTX	Time to confirmation	Both experienced and inexperienced	Vascular and cardiac views, nonagitated saline used
Cortellaro et al (32)/2014	Prospective	71	IJ/SC	Malposition	Time to confirmation	Both experienced and inexperienced	Cardiac views, agitated saline used
Matsushima et al (33)/2010	Prospective	69	IJ/SC/PICC	Malposition, PTX	Time to confirmation	Inexperienced	Vascular and cardiac views, nonagitated saline used
Bedel et al (34)/2013	Prospective	98	IJ/SC	Malposition	PTX, Time to confirmation	Experienced	Cardiac views, nonagitated saline used
Baviskar et al (35)/2015	Prospective	25	IJ/SC/Axillary	Time to verification	Malposition	Experienced	Cardiac views, agitated saline used
Duran-Gehring et al (36)/2015	Prospective	25	IJ/SC	Time to verification	Malposition, PTX	Inexperienced	Cardiac views, agitated saline used
Weekes et al (37)/2013	Prospective	148	IJ/SC/Femoral	Malposition	–	Both experienced and inexperienced	Cardiac views, agitated saline used
Wen et al (38)/2014	Retrospective	202	IJ	Malposition	Time to confirmation	Both experienced and inexperienced	Cardiac views, agitated saline used
Syed et al (39) ^c /2012	Prospective	4	–	Malposition	–	–	Cardiac views, agitated saline used
Madhulika et al (40) ^c /2014	Prospective	100	IJ	Malposition, PTX	–	–	Cardiac views, nonagitated saline used
Gekle et al (41)/2015	Prospective	81	IJ/SC	Malposition, PTX	Time to confirmation	Experienced	Cardiac views, agitated saline used
Weekes et al (42)/2015	Prospective	156	IJ/SC	Malposition, PTX	Time to confirmation	Experienced	Cardiac views, nonagitated saline used
Meggiolaro et al (43)/2015	Prospective	105	IJ/SC	Malposition, PTX	Time to confirmation and time to bubble test	Experienced	Vascular and cardiac views, agitated saline used

Dashes indicated information was not reported.

^a All included studies were observational.^b Operators were determined to be inexperienced if they were in a resident training program or required additional training before participating in the study.

Abstract only. CVC, central venous catheter; IJ, internal jugular vein; SC, subclavian vein; PTX, pneumothorax; PICC, peripherally inserted central catheter.

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Table 2

Quality Assessment of Diagnostic Accuracy Studies (QUADAS)-2 summary of included studies

Reference	Risk of bias			Applicability concerns			
	Patient selection ^{a,b,c}	Index test ^{e,f}	Reference Standard ^{g,h,i}	Flow and Timing ^{k,l,m}	Patient Selection ^d	Index test ^g	Reference standard ^j
Vezzani et al (30)	Low	Low	Unclear	High	No	No	No
Maury et al (16)	Low	Low	Low	High	No	No	No
Zanobetti et al (31)	Low	Low	Low	High	No	No	No
Cortellaro et al (32)	High	Low	Low	Low	No	No	No
Matsushima et al (33)	Low	Low	Low	High	No	Yes	No
Bedel et al (34)	Low	Low	Unclear	High	No	Yes	No
Baviskar et al (35)	High	Low	Unclear	Low	Yes	No	No
Duran-Gehring et al (36)	High	Low	Unclear	High	No	No	No
Weekes et al (37)	High	Low	High	High	No	No	No
Wen et al (38)	High	Unclear	Unclear	Low	No	No	No
Syed et al (39)	High	Low	Low	Low	No	No	No
Madhulika et al (40)	Unclear	High	Unclear	Low	No	No	No
Gekle et al (41)	Low	High	High	High	No	No	No
Weekes et al (42)	High	Low	Low	High	No	No	No
Meggiolaro et al (43)	Low	Low	Low	Low	No	Yes	No

The terms "low", "unclear" and "high" refer to the risk of bias according to the QUADAS-2 Tool for Quality Assessment Questionnaire (18).

^aWas a consecutive or random sample of patients enrolled?^bWas a case-control design avoided?^cDid the study avoid inappropriate exclusions?^dAre there concerns that the included patients and setting do not match the review question?^eWere the index test results interpreted without knowledge of the results of the reference standard?^fIf a threshold was used, was it prespecified?^gAre there concerns that the index test, its conduct, or its interpretation differ from the review question?^hIs the reference standard likely to correctly classify the target condition?

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Were the reference standard results interpreted without knowledge of the results of the index test?
j
Are there concerns that the target condition as defined by the reference standard does not match the question?
j
Was there an appropriate interval between the index test and reference standard?
k
Did all patients receive the same reference standard?
j
Were all patients included in the analysis?
m

Table 3

Results of included studies

Reference	Feasibility (%) ^a	Incidence of CVC malposition	Sensitivity (95% CI) ^b	Specificity (95% CI) ^b	Incidence of PTX	CXR time (minutes), mean (SD)	US time (minutes), mean (SD)
Vezzani et al (30)	89.2	0.28	0.93 (0.76, 0.99)	0.96 (0.88, 0.99)	0.04	83.0 (79.0) ^c	10.0 (5.0)
Maury et al (16)	98.8	0.11	1.00 (0.66, 1.00)	1.00 (0.95, 1.00)	0.01	80.3(66.7) ^d	6.8 (3.5)
Zanobetti et al (31)	100	0.55	0.92 (0.85, 0.96)	0.89 (0.81, 0.95)	0.02	65.0 (74.0) ^e	5.0 (3.0)
Cortellaro et al (32)	100	0.085	0.33 (0.04, 0.78)	0.98 (0.92, 1.00)	–	288.0 (216.0) ^e	4.0 (1.0)
Matsushima et al (33)	71	0.17	0.50 (0.19, 0.81)	0.98 (0.89, 1.00)	0.00	75.3 (–) ^f	10.8 (–)
Bedel et al (34)	96	0.06	0.83 (0.36, 1.00)	1.00 (0.96, 1.00)	0.00	103.0 (81.0) ^f	1.76 (1.3)
Baviskar et al (35)	100	0.00	–	–	–	–	0.75 (–)
Duran-Gehring et al (36)	92	0.065	0.33 (0.01, 0.91)	1.00 (0.92, 1.00)	0.04	299.0 (–) ^e	5.0 (–)
Weekes et al (37)	96.6	0.03	0.75 (0.19, 0.99)	1.00 (0.97, 1.00)	–	–	–
Wen et al (38)	100	0.01	1.00 (0.16, 1.00)	1.00 (0.98, 1.00)	–	28.3 (25.7) ^c	3.2 (1.1)
Syed et al (39)	100	0.50	1.00 (0.16, 1.00)	1.00 (0.16, 1.00)	–	–	–
Madhulika et al (40)	100	0.24	1.00 (0.86, 1.00)	1.00 (0.95, 1.00)	0.00	–	–
Gekle et al (41)	100	0.00	–	–	–	30.0 (–) ^f	8.9 (–)
Weekes et al (42)	97.4	0.03	0.75 (0.19, 0.99)	1.00 (0.98, 1.00)	0.00	20.0 (30.0) ^c median (IQR)	1.1 (0.7) median (IQR)
Meggiolaro et al (43)	100	0.45	0.53 (0.38, 0.68)	0.95 (0.86, 0.99)	0.00	67.0 (42.0, 84.0) ^e median (IQR)	10.0 (7.0, 20.0) median (IQR)

Dashes indicate information was not reported.

^a feasibility is defined as the percent of patients in whom cardiac ultrasound images to evaluate for catheter malposition could be obtained.

^b value of catheter tip location.

^c time to perform CXR.

^d time until CXR received.

^e time until CXR report available.

^f time until emergency department physician or intensivist interpretation of CXR.

CVC, central venous catheter; CI, confidence interval; PTX, pneumothorax; CXR, chest radiograph; SD, standard deviation; US, ultrasound; IQR, 25%, 75% interquartile range.