Ultrasound localization of central vein catheter and detection of postprocedural pneumothorax: An alternative to chest radiography*

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Objective: **To determine the usefulness of ultrasound to evaluate central venous catheter misplacements and detection of pneumothorax, thus obviating postprocedural radiograph. After the insertion of a central venous catheter, chest radiograph is usually obtained to ensure correct positioning of the catheter tip and detect postprocedural complications.**

Measurements and Main Results: **A prospective study of 111 consecutive central venous catheter procedures, using a landmark technique, was conducted in an adult intensive care unit. At the end of the procedure, a B-mode ultrasonography was first performed to assess catheter position and detect pneumothorax. Then, contrast enhanced ultrasonography was used to facilitate visualization of catheter tip, avoiding unknown right atrium positioning or artifacts. A postprocedural chest radiograph was obtained for all patients and was considered as a reference technique. Right atrium positioning was detected in 19 patients by ultrasonography, and an additional six by contrast enhanced ultrasonography. Combining ultrasonography and contrast enhanced ultrasonography yielded a 96% sensitivity and 93% specificity in detecting catheter misplacement. Concordance was 95% and κ value was 0.88 ($p < .001$). Pneumothorax was detected in four patients by ultrasonography and in two by chest radiograph (concordance = 98%). The mean time required to perform ultrasonography plus contrast enhanced ultrasonography was 10 ± 5 mins vs. 83 ± 79 mins for chest radiograph ($p < .05$).**

Conclusions: **The close concordance between ultrasonography plus contrast enhanced ultrasonography and chest radiograph justifies the use of sonography as a standard technique to ensure the correct positioning of the catheter tip and to detect pneumothorax after central venous catheter cannulation to optimize use of hospital resources and minimize time consumption and radiation. Chest radiograph will be necessary when sonographic examination is impossible to perform by technical limitations. (Crit Care Med 2010; 38:000–000)**

Key Words: chest ultrasounds; echocardiography; chest radiography; mechanical ventilation; central venous catheterization

Central venous catheterization of subclavian (SV) or internal jugular (IJV) veins is considered now commonplace in the care of critically ill patients. This procedure, however, is not without risk and, even in experienced hands, it may cause a considerable amount of early mechanical complications and misplacements (1). Blind insertion of an IJV or SV catheter failed in 10% to 19% of patients and complications occurred in 5% to 11% of patients, depending on the operator's experience (2, 3). Major complications are pneumothorax, catheter tip misplacement, and vascular complications, such as artery puncture, hematoma, or neural injury, the majority of which occurs during the puncture of the vessel and catheter advancement (4). After central venous catheter (CVC) insertion, a chest radiograph (CXR) is usually obtained to ensure correct positioning of the catheter tip and to exclude mechanical complications, such as pneumothorax (PTX) (5).

It has been demonstrated that ultrasounds can detect accurately PTX (6, 7) and easily visualize SV and IJV. By contrast, there is still no consensus regarding their diagnostic power in the identification of silent CVC complications because of the following potential limitations: low-quality imaging by transthoracic route and high interference rate in the visualization of right atrium (RA) and superior vena cava (SVC) (8).

Therefore, to optimize resource utilizations, reduce costs, and minimize repeated unnecessary radiation exposure of patients and physicians, we designed this study to evaluate contrast enhanced ultrasounds (CEUS) as a alternative method to CXR in the assessment of CVC tip positioning and postprocedural complications in critically ill patients.

***See also p. xxx.**

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MATERIALS AND METHODS

Study Population

This study was conducted from April to August 2008 in a multidisciplinary intensive care unit (ICU) (n = 14 beds) of the Ospedale Maggiore di Parma, a 1200-bed University Hospital. During this period, all patients >18 yrs who were admitted to the ICU and underwent CVC cannulation were eligible for this investigation. The study protocol was approved by the Institutional Ethics Committee. Consent to participate in the study was obtained directly from all patients who were conscious or from next-of-kin for unconscious patients. Of the latter, those who recovered confirmed the consent after the study; for those who died or remained incompetent, the data were used with the consent of the next-of-kin.

Procedures

The CVCs were inserted by different critical care physicians including residents, as required by the educational mission of our university hospital. Nontunneled, dual-lumen 7F, 20-cm long CVCs (BD Careflow; Becton Dickinson Critical Care Systems, Franklin Lakes, NJ) were inserted percutaneously at the patient's bedside, following the standard

Seldinger technique, based on anatomical landmarks, without use of either fluoroscopy or intraoperative ultrasound guidance. The patients were lying supine and submitted to intermittent mechanical ventilation. Indication of CVC insertion was established according to medical need by physicians not involved in the study.

After CVC insertion, both B-mode ultrasound and CEUS were performed (Wing Sound, GE Medical System) (with 3.5–10 MHz transducers) by a single intensivist (A.V.) skilled in echographic examinations, but not directly involved in the procedure. We first used conventional B-mode ultrasound to examine both SV and IJV. We then visualized the heart (right atrium and ventricle, SVC and inferior vena cava identified according to conventional imaging criteria) through the epigastric and subcostal acoustic windows along the short heart axis (Fig. 1), allowing us to see both cava veins and right atrium at the same time confirming catheter placement. Catheter misplacement was defined as the CVC tip in the right atrium or in a vein other than SVC or SVC-to-right atrium junction. The catheter tip identification in the right atrium was confirmed by CEUS, using a standard technique, generally performed by cardiologists and neurologists for detecting foramen ovale permeability and approved by the European Society of Neurosonology and Cerebral Hemodynamics (9). In summary, we prepared a saline-air mixture with two 10-mL syringes containing one 9 mL of saline and the other 1 mL of air. By means of a three-way stopcock, the contents of both syringes were mixed until a homogeneous solution was obtained. We injected rapidly 5 mL of this solution as a bolus through the catheter so that a stream of microbubbles could be seen through its tip, to assess positioning. Site and flow pattern of microbubbles were recorded at the time of CEUS examination and images/clips were reviewed a few times at the end of examination, which was repeated in case of uncertainty. No more than two boluses of 5 mL were used. The test was deemed positive for correct CVC placement when real-time CEUS recorded a typical laminar jet flow of multiple microbubbles flowing from the SVC within 1 to 2 secs after the start of injection (Fig. 2). The test was deemed negative when the catheter tip was seen in the atrium or inferior vena cava or when the real-time CEUS recorded a turbulent flow coming from the atrium or inferior vena cava (Fig. 3; Table 1).

Finally, we performed an ultrasound examination of the lung for detection of PTX. A B-mode ultrasonography was performed, using a 10-MHz linear-array ultrasound probe over the parasternal line from the third to the fifth intercostal spaces and then laterally to the anterior axillary line. Lung sliding was searched and its presence in all intercostal spaces was used to rule out PTX. In the absence of lung sliding in one or more intercostal spaces, the lung point (Fig. 4), where the lung approaches chest wall on inspiration, was searched to increase the likelihood of PTX and to quantify its extent (6, 7). Immediately after CVC procedure, the radiology department was

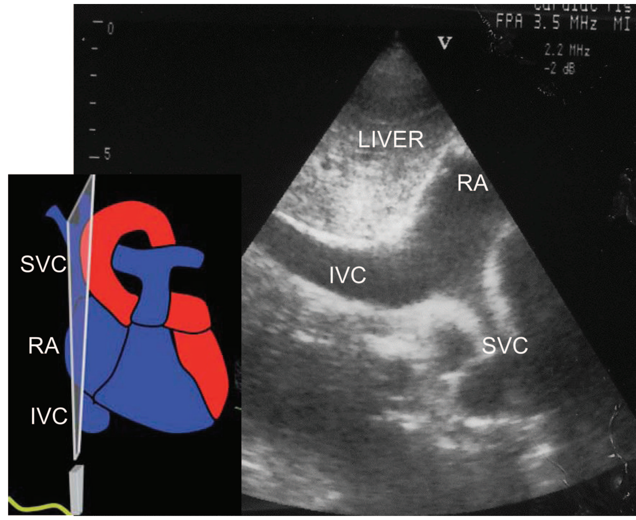

Figure 1. Contrast enhanced ultrasounds studies performed using a commercially available US system and 3,5 MHz transducers on epigastric and subcostal acoustic window in line with the axis of the vena cava along the short axis of the heart. *RA,* right atrium; *SVC,* superior vena cava; *IVC,* inferior vena cava.

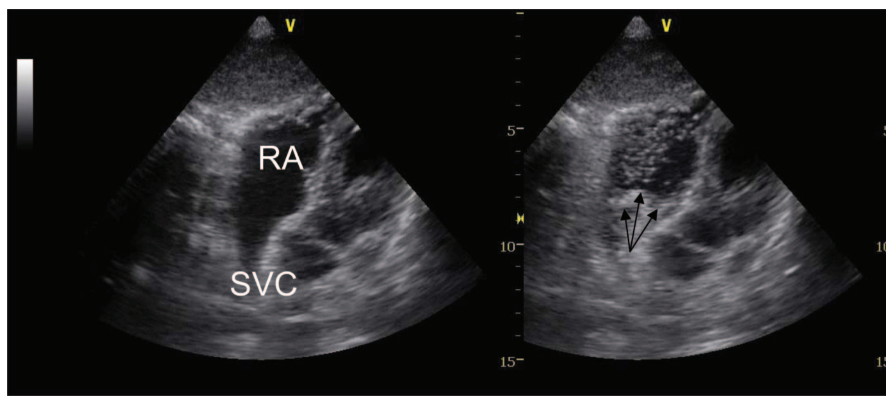

Figure 2. Contrast enhanced ultrasounds study with positive microbubbling test: numerous bubbles indistinguishable separately with linear flow coming from superior vena cava within 2 secs. *SVC,* superior vena cava; *RA,* right atrium; *black arrows,* microbubbles jet flow from SVC.

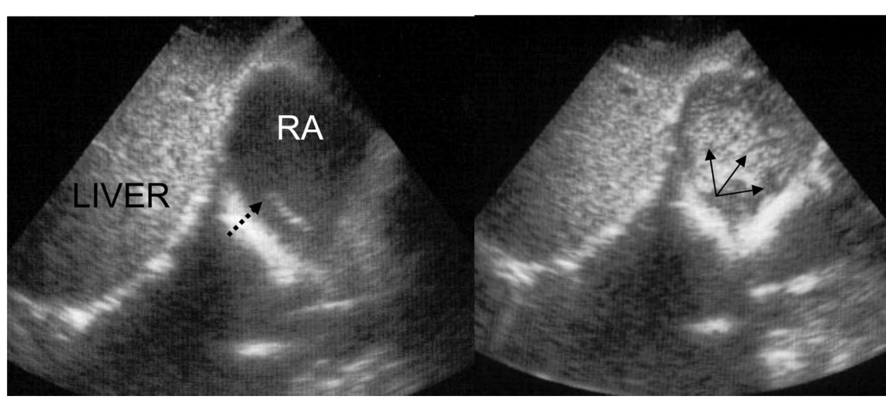

Figure 3. Contrast enhanced ultrasounds study with clear direct visualization of catheter tip into the right atrium and negative microbubbling test: numerous bubbles indistinguishable separately with turbulent flow coming from atrium within 2 secs. *RA,* right atrium; *black arrows,* jet flow from catheter tip; *interrupted black arrow,* catheter tip.

alerted and the time delay to obtain an expiratory anteroposterior in supine position CXR was recorded. A CXR was obtained as reference for CVC tip placement (10).

In 20 consecutive patients, we also assessed the interobserver variability of the method used in this study. Two intensivist clinicians without specific expertise in echography received a 15-hr training in theory and practice. Then, they separately evaluated by echography the CVC tip placement 15 mins apart from each other, without knowledge of radiologic findings and possible difficulties encountered by the physician who positioned the catheter.

Even if there is no fee in Italy for ultrasound tests when performed at the patient's bedside in the ICU, we calculated the total cost of our method. We added the annual depreciation of ultrasound machine and printer, the cost of their maintenance, the cost of consumable materials (gel, photo paper, electric power), the cost of time spent by the doctor in the implementation of methodology, plus 15% of general costs. The cost of the ultrasound test so obtained was compared with the cost of CXR (€15.50 charge reimbursed to the hospital by the Public Health System). To estimate the annual number of examinations performed at the patients' bedside, we recorded the number of daily tests performed in May 2008 and we calculated the average number of daily examinations.

Statistical Analysis

A true positive result was defined as the judgment of correct placement at CEUS that was eventually confirmed by CXR. A true negative result was defined as the judgment of an incorrect placement at CEUS that was confirmed by CXR. False positive and negative results were defined accordingly. The sample size was calculated by taking into account an expected sensitivity of 0.95 and considering that the lower 95% confidence limit should not fall below 0.80, with 0.95 probability; this yielded a sample size of >93 (11). Sensitivity, specificity, likelihood ratio, and concordance between CEUS and CXR were calculated. For the latter, κ statistics were used. Continuous variables were expressed as mean ± standard deviation. The time needed between two methods was compared, using Student's *t* test. Statistical significance was set at $p < .05$. All data were analyzed with Stata software (version 9.1, StataCorp, TX).

RESULTS

Between April 2008 and August 2008, a CVC was placed in 111 consecutive mechanically ventilated ICU patients (Table 2). A subclavian approach was used in 85 patients and an internal jugular approach was used in the remaining 26 patients. Echocardiography was not obtainable in 12 patients because of technical limitations. CXR showed one complication in each of 30 patients including two PTX, four IJV misplacements, 24 intracardiac CVC tip positioning in the right atrium. B-mode ultrasound and CEUS showed one complication in each of 33 patients including four PTX, four IJV misplacement, and 25 right atrium positioning (Table 3). In 19 of 25

Table 1. Classification and interpretation of microbubbling test

Characteristics	Interpretation
No bubbles	Negative test: an aberrant or too distal tip position must be considered.
Few bubbles or appearance time >2 secs	Test to be repeated: if confirmed, possible misplacement (probably in the SV or IJV).
Numerous bubbles indistinguishable separately turbulent flow coming from atrium within 2 secs	Negative test; intra-atrial positioning.
Numerous bubbles indistinguishable separately linear flow coming from superior vena cava within 2 secs	Positive test: CVC tip correctly placed in the SVC.

SV, subclavian vein; IJV, internal jugular vein; CVC, central venous catheter; SVC, superior vena cava.

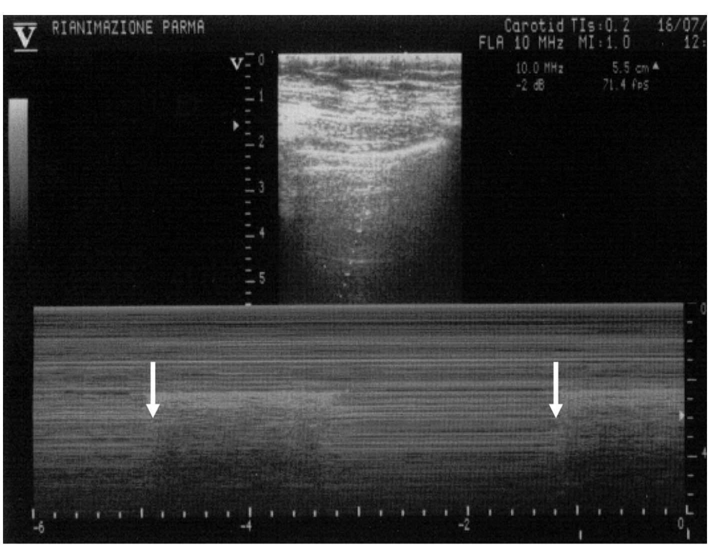

Figure 4. Pneumothorax with lung point shown in a static image by M-mode: the absence of lung sliding is documented by a pattern of *horizontal lines*. The lung point (*white arrows*) is visible when the lung, during inspiration, reaches the wall and the horizontal pattern is replaced by the sandy pattern.

Table 2. Patient characteristics

Sex, male/female	70/41
Age, yr	60 ± 18[a]
Body mass index, kg/cm^2	26 ± 5[a]
Ventilated/nonventilated	111/0
SAPS II	48.2 ± 19.8[a]
Cause of ICU admission, n	
Cardiac arrest	10
Neurologic bleeding	42
Acute respiratory failure	24
Sepsis	5
Trauma	30
Approach, subclavian/internal jugular vein	85/26
Length of stay, days	9 ± 8[a]
Outcome, alive/dead	89/22 (24%)

SAPS II, Simplified Acute Physiology Score II; ICU, intensive care unit.

[a]Mean ± standard deviation values.

Table 3. Complication detection after central venous catheter insertion in 99 patients

Variable	US	CEUS	US + CEUS	CXR
Internal jugular vein	4	—	4	4
Intracardiac (atrial) position	19	6	25	24
Inferior vena cava	0	0	0	0
Pneumothorax	4	—	4	2
Vein thrombosis	2	—	2	0

US, ultrasound examination; CEUS, contrast enhanced ultrasounds; CXR, chest radiograph.

Table 4. Concordance between ultrasound and chest radiograph in detecting pneumothorax (n. patient examinations = 111; concordance = 98%)

US	CXR	Positive	Negative
Positive		2	2
Negative		0	107

US, ultrasound examination; CXR, chest radiograph.

patients with RA misplacement, this was directly detected by B-mode ultrasonography and, in the remaining six patients, it was detected only by CEUS. The latter was useful in all patients to exclude artifacts and confirm catheter tip positioning. None of the patients had the CVC tip positioned in the inferior vena cava. All four PTX detected by ultrasound were confirmed by clinical follow-up and required tube drainage in mechanically ventilated patients. The concordance between CXR and ultrasound for PTX detection is shown in Table 4. Ultrasound vein examination detected all IJV misplacements and, in addition, two preexisting unknown central venous thromboses. The examination of the IJV and SV by B-mode ultrasound was able to detect all catheter misplacements in these veins. Of 70 patients negative for complications at CEUS, only two had the CVC misplaced in the right atrium at CXR. Of the 25 patients found to have the CVC tip positioned in the right atrium at CEUS, three had this finding not confirmed by CXR. Vein and lung examinations were interpretable in all patients. Heart examination was not interpretable in 12 patients (11%) (feasibility = 89%); in nine of them, the CVC tip was found correctly placed in the SVC at CXR and in three in the right atrium. The reasons for the inability to visualize the heart through the epigastric acoustic window were large abdominal surgical wound (n = four patients), patient obesity (n = four patients), low-quality image transmission due to tissue edema (n = three patients), and traumatic pneumopericardium (n = one patient). For misplacement detection, postprocedural B-mode ultrasound plus CEUS had a sensitivity of 96% and a specificity of 93%, using CXR as reference; the likelihood ratio was 13, namely, the probability of judging the catheter correctly positioned (when it really was) was 13 times the probability of declaring it correctly positioned when it was not. CEUS and CXR yielded concordant results in 94 of 99 patients who had both examinations available, concordance was 95%, with an expected agreement of 59% and a κ of 0.88 ($p < .001$). The time required to perform both ultrasonic examinations was 10 $\pm$ 5 mins (range = 3–20 mins) vs. 83 $\pm$ 79 mins for CXR (range = 15–368 mins), a difference that was statistically significant ($p < .05$).

There was 19 of 20 agreement on the assessment of catheter positioning between two observers by the technique used in this study.

Cost analysis of US plus CEUS yielded an overall value of €12.69 per examination, which was €2.81 less than CXR.

DISCUSSION

The placement of CVC catheters is associated with potentially serious complications, such as venous and right heart perforations (12), in addition to drawbacks related to CVC tip misplacement, such as CVC dysfunction, arrhythmias, extravasations, and thrombosis (13–18). For these reasons, the U.S. Food and Drug Administration strongly advises that the CVC tip should not be placed in the heart or allowed to migrate into the heart (10, 19), with the optimal position located between SVC and right atrium.

Currently, the American College of Radiology recommends portable radiographs after placement of CVCs in critically ill patients, because it has been shown that this practice can detect abnormalities previously unknown in 35% to 65% of ICU patients (20). Although previous studies have underlined the high economic costs (21, 22) and the associated exposure risks for both patients and physicians, Gladwin and colleagues (5) concluded that postprocedural CXR remains necessary because clinical factors alone cannot reliably identify CVC tip misplacements. However, it must be considered that the junction of the SVC with the right atrium cannot be directly visualized using a bedside CXR (23). In addition, it has been shown that CXR based on usual radiologic landmarks yields up to 47% of false positive results for intra-atrial CVC tip misplacement and none of the radiographic landmarks is 100% reliable (24). In contrast, multiple transesophageal echocardiography allows the CVC tip to be visualized along the lower SVC-to-right atrium junction (25–28) but this procedure is not suitable for routine use and may compromise the borderline respiratory and hemodynamic status of the critically ill patient (29).

The CXR in anteroposterior view of supine patients has poor sensitivity in identifying hidden PTX because the air initially distributes in the nondependent and medial parts of the chest, which are difficult areas to explore by CXR with the patient in a supine position (30). Only when its volume increases does the PTX extend to the apical and lateral sides where the separation of pleural layers is more easily identifiable (31, 32). CXR is often performed immediately after CVC placement and it is therefore possible that there is not enough time for the development of a PTX large enough to be identified. On the other hand, reports on recognizing a hidden PTX have documented the superiority of ultrasound compared with CXR performed with the patient in the supine position (33–35). In our series, four PTX were identified by ultrasound based on the absence of lung sliding and identification of the lung point (Fig. 2), whereas CXR identified only the two larger PTX. All patients with PTX required chest drainage, two of them because it had developed due to mechanical ventilation and two because it was suggested by CT imaging.

The findings of our study show a good concordance between CEUS and CXR for catheter misplacement detection. In two patients found to be free from complications at CEUS, CXR detected an unexpected misplacement in the right atrium, but at least in one patient, the CXR was of low quality because of the presence of a Fallot disease with cardiomegaly, pulmonary subedema, and a preexisting bicameral PM-AICD. Although we assumed CXR as the reference method and classified this case as false positive at CEUS, we hypothesize that this may not be the case because CEUS provided a good imaging transmission with direct visualization of CVC tip in the atriocaval junction and a clear laminar jet flow coming from SVC. In the three remaining discordant cases, CXR did not confirm the too distal CVC tip location in the right atrium detected by CEUS. Even in these cases, CXR might not have been accurate, as it cannot identify correctly the SCV-to-right atrium junction (36).

A role for ultrasounds and transthoracic echocardiography as an accurate and easy method to recognize CVC misplacements was already suggested by Maury et al (37), who reported a very high success rate in B-mode ultrasonographic heart examination with a close concordance in the detection of RA catheter misplacement. Our study confirms only in part these results, in that we could easily identify by B-mode ultrasonography all CVC misplacements in upper central veins but not in RA. This was likely because of the high interference rate in the visualization of RA and SVC by this technique (38, 39), which may be different depending on the type of patients and ventilation. In six patients, RA catheter tip misplacement was detected only by CEUS. Therefore, the present study is the first one suggesting the need of CEUS to confirm correct SVC catheter positioning even when direct visualization is impossible. Furthermore, we think that intra-atrial CVC detection must be confirmed by CEUS because the high prevalence of low-quality imaging transmission by transthoracic route and this condition could leave potentially unrecognized CVC atrial misplacements.

Transthoracic echocardiography was not feasible in 11% of patients, a figure that is in line with those (10%–40%) previously reported in the ICU (8). Reasons for this finding include mechanical ventilation, presence of abdominal wound or drainage restricting the use of the subcostal acoustic window, edema due to prolonged supine position, or nonechogenic patients.

In the present study, the rate of CVC misplacements was moderately high (24 of 99). This may be due to two reasons. First, we always tried to position the CVC tip as close as possible to the SVC-to-right atrium junction, accepting a high risk of intra-atrium tip placements. This was in consideration of the fact that not only intra-atrium positioning but also catheter tip placement in the SVC or above is associated with higher risk of thrombosis (13–16), which is associated with morbidity and mortality greater than perforation. Thus, we preferred to attempt positioning the CVC tip as close as possible to the SVC-to-right atrium junction and pull it back, if necessary, instead of performing a new cannulation. Another reason may be related with our teaching mission at the university hospital and the high number of procedures done by young residents. In any case, this relatively high number of misplacements increased the power of the study to compare ultrasound techniques with CXR. Furthermore, a more reliable gold standard, like transesophageal echocardiography, was not available, which is a limitation in the interpretation of the discordant cases. However, the conclusion that ultrasonography yields results that are highly concordant with CXR remains valid.

Under a methodologic point of view, we used a dose of saline-air mixture that was half of the one used by cardiologists because we observed that 5 mL was sufficient for our purposes. To the best of our knowledge, none of the published studies reported safety issues regarding side effects of saline-air mixture (9).

For the purpose of this study, all ultrasound examinations were performed by the same person because we wanted to avoid interobserver bias, although the interobserver reproducibility within our team was >90% after a 15-hr training.

CONCLUSIONS

Our study suggests that B-mode ultrasonography plus CEUS are accurate in detecting PTX and CVC misplacements after SV and IJV cannulation and has an accuracy that is similar to CXR. Furthermore, ultrasound examinations are safe for patients and physicians, in that they may avoid radiation exposure and they are less time-consuming, less expensive, and suitable for hemodynamically unstable patients. The use of CXR may be left to those cases where ultrasound examinations are not feasible or yield dubious results.

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