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Confirming central line position through bedside ultrasound, a prospective registration

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Abstract: *Objective:* Ultrasound (US) techniques are common practice for the placement of central venous catheters (CVC). Although chest X-ray (CXR) is still the golden standard for confirmation of a correct position, ultrasonic alternatives have been proposed.

Methods: A prospective observational 2 center study to evaluate the feasibility and accuracy of bedside US techniques to confirm the CVC tip position. Four different approaches were assessed: (i) occurrence of extrasystoles (ES), (ii) direct vascular US of the subclavian and jugular veins, (iii) observation of the guidewire in the right atrium and (iv) indirectly with visualization of the Rapid Arterial Swirl (RAS) - sign. Lung US is performed to diagnose a potential pneumothorax (PTX). As reference, the CXR protocol made by a radiologist was used.

Measurements and main results: 131 patients were included. Ten suboptimal CVC tip placements were detected by CXR. Occurrence of ES and vascular US are feasible bedside tests (resp, 96% and 97%), whereas the feasibility of the subcostal view of the heart is much more cumbersome (83%-84%). Chi-Square analysis shows a specificity of 100% with the occurrence of ES during placement, whereas vascular US shows a high sensitivity of 99%. If feasible, visualization of the guidewire and RAS is seen to be specific (both 100%) for a correct CVC position. The 4 methods are put together in 5 flowcharts, allowing us to possibly reduce CXR up to 77.5 percent. No conclusion can be made about the accuracy of lung US, considering the low incidence of PTX, although the one PTX that occurred was not diagnosed by US.

Conclusion: The four bedside approaches each have their own feasibility and use in confirming CVC position and putting them all together might reduce the need for CXR. The provided flowcharts can be used as a firsthand tool to safely avoid CXR after CVC placement.

Keywords: Anesthesia; central venous catheter; ultrasound.

Introduction

Central venous catheters (CVCs) play an important role in perioperative care and management of critically ill patients. Therefore, their placement is an essential skill for anesthetists and critical service physicians. Common indications for a CVC are the administration of medication and fluids, hemodynamic monitoring, poor peripheral access, and renal replacement therapy (1-3).

The universally accepted CVC placement technique is considered as a safe technique (4). Nevertheless, placement issues such as arterial punctures, air embolisms, pneumothorax (PTX), catheter infections, occlusion and venous thrombosis can occur, requiring extended monitoring or other interventions, possibly causing life-threatening situations (2-6). Next to this list of possible complications, the mispositioning of CVCs is associated with hemodynamic measurement errors and delay in initiation of treatment (6).

Over the past fifty years, chest X-ray (CXR) has been the golden standard for confirming the position of a CVC, as for the diagnosis of a potential iatrogenic PTX (7,8). Be that as it may,

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the execution of a CXR straight after placement of a CVC in a preoperative or acute setting is not always possible due to the difficulties of the setting itself (1). Additionally, CXR can prove to be time consuming due to the lack of availability of a CXR technician, the device's lack of portability and the delay caused by the need to capture the image and render it. Hence, the replacement of this technique with a qualitative alternative could result in time gain and in an increase of the quality of the overall treatment of the patients (1, 4).

A decrease in the number of complications, as well as in failed punctures, has been noted since the use of ultrasound (US) for CVC placement (1, 10, 11). The non-invasive and painless use, the real-time registration, the portability of the US device and the fact that US does not cause any ionized radiation exposure makes its use attractive (1, 8). Over time, an array of different US guided techniques to validate CVC position have surfaced such as vascular US, echocardiography and the 'bubble test' (3, 4, 9). The first two rely on a direct visualization of the guidewire, the bubble test relies on the fact that the bubbles induced by a turbulent saline flow should be immediately visible in the right atrium when the CVC is correctly positioned (3).

To this day however, literature describes different techniques to verify the position of central venous catheter by US. However, it provides no consensus on the accuracy of these tests (6, 8, 9). There is currently more evidence regarding the use of US in the diagnosis of a PTX, through evaluation of the "sliding sign" of the pleura. The US was proven to be more sensitive and efficient compared with CXR (12, 13).

The objective of this study was to examine the accuracy of bedside US for confirmation of CVC position and exclusion of PTX compared with CXR. Secondary outcomes include efficiency (confirmation time) and feasibility.

Methodology

Study setting and population

This prospective observational study was approved by the ethics committees of the 2 participating centers: AZ Delta on 25-02-2018 (B117201835323), University Hospital of Ghent on 28-01-2020 (B670201942574). All patients were included after informed consent in line with the Helsinki Declaration and ICH/GCP. Inclusion criteria were: >18 years, approval of an awake, adequate patient without premedication and legitimate indication for CVC placement. We considered the classical contraindications for CVC placement as described by Smith et al. (2) as exclusion criteria.

The study was conducted in the operating theatre and intensive care unit (ICU). All planned supradiaphragmatically CVCs (Subclavian Vein (ScV) or Internal Jugular Vein (IJV)) were placed by 5th year anesthesia residents. During placement, the CVC tip position was examined by both the direct visualization of the veins using US and the direct visualization of the guidewire in the right atrium. Additionally, indirect visualization was achieved by performing a 'bubble test'. We also looked for 'lung sliding' in the anterior chest wall, in order to rule out a PTX. For every patient a CXR was taken, and the protocol of the radiologist was used as reference.

Study protocol

During the placement of the CVC, the investigator followed a 4-step protocol to screen for catheter misplacement and PTX.

1. After placement of the guidewire in the desired vein (IJV, ScV), both ipsi- and contralateral veins were scanned. An aberrant course of the guidewire was registered.

2. US visualization of the subcostal 4 chamber view using a convex probe. A visible J-tip was considered as a correct position of the guidewire (9).

3. The bubble- test was performed as described by Megahed et al. (4). After an injection of 10ml agitated saline through the catheter, its appearance in the right atrium using the subcostal 4 chamber view was recorded. Timing of the appearance of the turbulence (< 2sec, 2-6sec, > 6sec) and the intensity (turbulent, speckled of absent) were noted. The Rapid Arterial Swirl (RAS) sign is positive at a time <2 seconds after injection and a high contrasting intensity in the right atrium.

4. Screening for PTX:

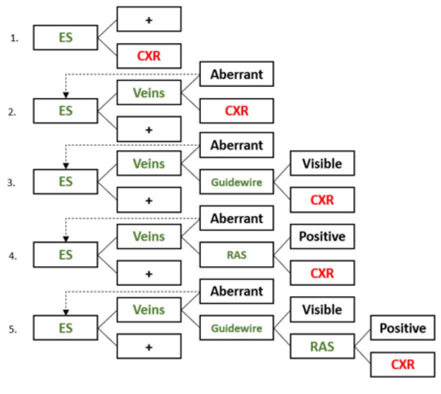
The anterior thoracic wall of the ipsilateral side was scanned. The presence of the pleural sliding sign was considered to rule out a PTX (6, 9).

The reason for the inability to perform a step in the protocol was registered.

During placement of the guidewire, extrasystoles (ES) on the monitor were registered.

After placement and US check-up, the patient was taken to the recovery room, where a CXR was taken. The radiographic verification of the position of the CVC and possible PTX was done by a qualified radiologist blinded for US findings. We defined a correct placement of CVC

Figure 1. — Five flowcharts, sequential steps of beside confirmation and CXR necessity.



(Flowchart 1) In the presence of ES during placement: omit CXR, else CXR. (Flowchart 2) In the presence of ES during placement: omit CXR. If no ES, perform vascular US, in case of aberrant course of guidewire, reposition and follow the chart again from the beginning. (Flowchart 3) extension of Flowchart 2: Omit CXR when direct visualization of the guidewire in the right atrium by TEE. (Flowchart 4) extension of Flowchart 3: omit CXR when positive RAS. (Flowchart 5) extension of Flowchart 3: omit CXR when positive RAS.

if (i) the catheter-tip projected in the superior vena cava (SVC) and if (ii) a PTX was absent on CXR. Misplaced catheters were replaced immediately after diagnosis, in accordance with current practice of the two study centers. We recorded elapsed time between placement and US conformation, as well as time between placement and CXR.

We performed a sub-analysis using the data of 1 center, containing complete data for all predictors. A simulation was made based 5 different scenarios/flowcharts (Fig. 1). For every simulation the percentage of patients needing a CRX, the percentage of incorrect placements and the number of missed incorrect placements were calculated.

Statistics

Descriptive statistics are given as percentage and frequencies. Feasibility is expressed as the proportion of tests where a result could be withheld. For each of the four binary predictors a 2 by 2 confusion matrix was built using complete data sets. These were used to determine sensitivity, specificity, likelihood ratios and their respective 95% confidence intervals. All statistical tests were done using the epiR-package (2.0.19) with R (R core team, Vienna, Austria v4.0.2 Taking Off Again).

Results

Descriptive statistics

131 patients have been analyzed, 40% of the study population were female patients (Table 1). All CVCs were placed in the operating room or ICU, 21 patients were under general anesthesia with mechanical ventilation during placement. Administration of medication (73%), total parenteral nutrition (11%) and dialysis (9%) were the most important indications for CVC placement.

Table 1

Characteristics of subjects

Clinical Characteristics (n = 131)		
Female	52	(40%)
BMI (n=121)	25.9	(5.6)
MAP (mmHg) (n=91)	96.8	(13.5)
General Anesthesia	21	(16%)
Indication		
- Administration medication	96	(73%)
- TPN	14	(11%)
- Dialysis	12	(9%)
- Volume resuscitation	8	(6%)
- Others	1	(1%)
CVC insertion site		
- Right IJV	37	(28%)
- Left IJV	11	(8%)
- Right ScV	51	(39%)
- Left ScV	32	(24%)
Type of CVC		
- 3 lumen CVC (7 Fr,16 cm)	31	(24%)
- 2 lumen CVC (7 Fr,16cm)	81	(62%)
- 1 lumen CVC (4 Fr,16 cm)	7	(5%)
- Dialysis CVC (12 Fr,16 cm)	12	(9%)

Data are presented as number (percentage) or mean (sd). BMI: Body Mass Index, MAP: Mean Arterial Pressure, TPN: Total Parenteral Nutrition.

The site of insertion was chosen according to personal preference. Eighty-three (63%) CVCs were placed in the ScV, 48 (36%) in the IJV. In 72% of the cases only one single puncture was needed. An iatrogenic arterial puncture occurred in eight cases, with no serious sequelae.

Feasibility of different techniques

Extrasystoles

In 5 out of 94 cases identification of ES was not possible due to pre-existing arrhythmias.

Direct visualization of veins

In 127 out of 131 cases direct visualization of the ScV and IJV was possible, in 4 cases the visualization was complicated by the presence of an implantable cardioverter-defibrillator (ICD), pacemaker (PM) or port-a-cath.

Subcostal view with direct visualization of guide wire and bubble contrast

A feasibility of 84% is noted when using the direct visualization of the guidewire; in 21 out of 131 cases it was not possible to have a reliable subcostal four-chamber view of the heart, due to superposition of air (e.g., bowel obstruction) (10), obesity (4), external bandages (4) or unknown reasons. In the four cases of the presence of an ICD or PM, it was difficult to distinguish their leads from the guide wire, for this reason they were registered as impossible to interpret. A similar feasibility of 83% was seen for the bubble or RAS-test. The same hindering factors were responsible as described above, except for the disturbance of existing leads.

US of the anterior chest wall

In all cases, it was possible to establish a good US view of the lung.

Confirmation of CVC position

Gender, vascular access, incidence of ES and ultrasonic results in the overall study sample and according to the presence of malposition are shown in Table 2. Ten (8%) suboptimal CVC tip placements were detected by CXR, there was no correlation with site of insertion.

Table 2

Characteristics of patients with CVC malposition

Gender	Vascular access	Tip position	Extra-systoles	Vascular US	Guidewire Right Atrium	'Bubble-test' US
M	RScV	RScV loop	N/A	Incorrect	Negative	N/A
F	RScV	RIJV	No	Incorrect	Negative	Negative
F	RIJV	cranial RIJV	No	Incorrect	Negative	Negative
M	LIJV	RScV	No	Correct	Negative	Negative
F	RScV	LIJV	No	Correct	Negative	Negative
F	LIJV	SVC loop	No	Correct	Negative	Negative
M	LScV	RIJV	No	Incorrect	Negative	Negative
F	LScV	LIJV	No	Incorrect	Negative	Negative
F	RIJV	LScV	No	Correct	Negative	Negative
F	RScV	RIJV	No	Correct	Negative	Negative

US: Ultrasound; F: Female; M: Male; RScV: Right subclavian vein; RIJV: right internal jugular vein; LIJV: left internal jugular vein; LScV: left subclavian vein; SVC: superior vena cava; N/A: not applicable.
Vascular US incorrect meaning aberrant position; correct meaning following its expected course; Guidewire negative meaning no guidewire or agitated saline solution seen TTE.

Chi-Square analysis showed a specificity of 100% with the occurrence of ES during placement (100% Positive Predictive Value (PPV)), whereas the sensitivity of this test was low (46%, Negative Predictive Value (NPV) 17%). In contrast, direct US visualization of the veins showed a high sensitivity of 99% and a low specificity of 50% (95% PPV, 83% NPV).

If feasible, transthoracic US with visualization of the guidewire and bubble-contrast was found to be specific, both with a specificity and PPV of 100%. The sensitivity, however, differed with a sensitivity of 72 % of guide wire visualization and 92% with the RAS-test, NPV being resp. 26% and 60% (Table 3).

Simulation flowcharts

The flowcharts (Fig. 1) depict the separate bedside steps, sequentially taken to confirm CVC position. Depending on the bedside test results, according to the flowchart, CXR confirmation might be omitted. It is important to note that negative, non-feasible or doubtful results need to be followed by an extra bedside test or a CXR. If an aberrant course on vascular US is observed, immediate replacement is possible, and the flowchart can be followed again from the start.

A simulation was made when these 5 different flowcharts would have been followed (Fig. 1). For every simulation, the percentage of patients needing a CXR, the percentage of incorrect placements and the number of missed incorrect placements were calculated, as seen in table 4. Overall, incorporating more criteria resulted in higher proportion of patients where a CXR was deemed unnecessary. Using the four different approaches, up to 77.5% of the CXR seem to be redundant. When comparing both transthoracic echocardiographic (TTE) confirmation tests, the RAS-sign reduces the CXR-necessity much more compared to guidewire visualization. Four out of 9 incorrect placements were identified based on the vascular US, with the opportunity for immediate correction. No missed incorrect placements are seen in these simulations.

Table 3

Overview ofnthe four predictors and their feasibility

Predictor	Sensitivity	Specificity	posLR	negLR	PPV	NPV	Feasibility
ES	0.463 (0.350-0.578	1.000 (0.664-1.000)	Inf	0.538 (0.439-0.659)	1.000 (0.905-1.000)	0.173 (0.082-0.303	0.96
Veins	0.991 (0.953-1.000)	0.5 (0.187-0.813)	1.98 (1.07-3.69)	0.02 (0.00-0.13)	0.959 (0.906-0.986)	0.833 (0.359-0.996)	0.97
Guidewire	0.720 (0.621-0.805)	1.000 (0.691-0.1.000)	Inf	0.280 (0.204-0.283)	1.000 (0.950-1.000)	0.263 (0.134-0.431)	0.84
RAS	0.921 (0.836-0.970)	1.000 (0.664-1.000)	Inf	0.079 (0.037-0.170)	1.000 (0.949-1.000)	0.600 (0.323-0.837)	0.83

For each of the four binary predictors a 2 by 2 confusion matrix was built using complete data sets. These were used to determine sensitivity, specificity, likelihood ratios and their respective 95% confidence intervals.

Table 4

Representation of the simulation of the flowcharts 1 to 5

Flowchart	Percentage CXR	Percentage incorrect placement	Missed incorrect placements
1. ES	60.1% (52/94)	9,6% (9/94)	0
2. ES + US veins	58.4% (52/89)	5,6% (5/89)	0
3. ES + US veins + TTE guidewire	32.6% (60/89)	5,6% (5/89)	0
4. ES + US veins + RAS	23,6% (68/89)	5,6% (5/89)	0
5. ES + US veins + TTE guidewire + RAS	22,5% (69/89)	5,6% (5/89)	0

Pneumothorax

In all cases, except for one, ultrasonic lung sliding was seen on the anterior chest wall. Control CXR showed two PTXs, one pre-existing, one originating post puncture. The newly diagnosed

PTX was not seen on the bedside US and was complicated with desaturation, tachypnea, tachycardia, hypotension. Urgent placement of a thorax drain was necessary.

Time management US versus CXR

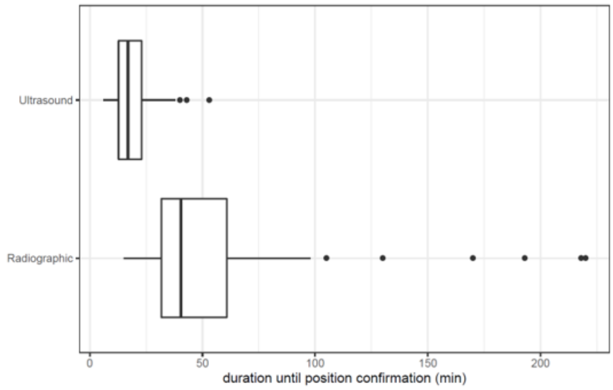


Figure 2. — Time to position confirmation, US vs CXR.

The above boxplot compares US (median 17 min, range 6-53 min) and CXR (median 41, range 15-220 min) in terms of duration in minutes, defined by the time between start of CVC placement (US probe placed on the chest) and US diagnosis of the CVC position (Fig. 2). In case of CXR, time between start of CVC placement and the moment the CXR is taken, is considered. Hence, the CXR duration represented might, through a design bias, be an underestimation of the duration necessary to receive the actual CXR protocol of the radiologist.

Discussion

We aimed to evaluate the accuracy and feasibility of bedside techniques to confirm the CVC tip position, using four different approaches: occurrence of ES, vascular US, TTE with observation of the guidewire and RAS-sign. We observed a high feasibility of both occurrence of ES and vascular US, with ES being a highly specific test and vascular US being very sensitive in objectifying the CVC tip position. The feasibility and practice of TTE is more cumbersome, which may interfere with the high specificity of both tests. Based on the data of this study, we performed a simulation (Fig. 1), using the four bedside approaches, to safely avoid a CXR. The more bedside approaches are used, the less necessity there is for a CXR, as concluded by our sub-analysis. This flowchart can be used as firsthand tool to reduce the use of CXR, which may in turn reduce time delay, costs, additional manpower and radiation exposure (1).

The occurrence of ES during CVC placement showed a specificity of 100%, which indicates that this bedside test has a high positive predictive value to confirm a right positioned CVC. No cases of malign arrhythmias occurred during CVC placement. Fiaccadori et al. (14) however, describe this phenomenon as a complication rather than a useful predictor. The authors question the safety of the technique as they experienced severe ventricular arrhythmias in a subgroup of patients with acute kidney injury (14). In absence of ES, no conclusion can be made (NPV 17%), further, the use of this predictor is only possible in the presence of a baseline sinus rhythm.

The second approach, vascular US of the ipsi- and contralateral ScV and IJV, is an easy and fast method to diagnose wrongly placed catheters due to the fact that it is possible to work with the same linear US probe that is used for the US guided placement as well, as within the same sterile barrier. Due to the superficial location of the supradiaphragmatic veins, vascular US is a very feasible technique (97%), if not bothered by the presence of an ICD, PM or port-a-cath which may obstruct the visualization of the veins. This approach, in contrast to the other three approaches, noted a high sensitivity of 99%, making it a good first screenings tool of CVC mispositioning. The guidewire, if seen in an aberrant vein or taking the wrong course in the inserted vein, has a high probability (83%) of being mispositioned. As a result, this vascular US provides a real-time rapid diagnosis of any superficial misposition, and upon diagnosis allows for immediate repositioning.

The next two tests require a subcostal view of the heart. These tests are more complicated than previous approaches, as an extra hand and a basic US expertise is desirable. The feasibility, defined as the percentage of patients in whom US images could be obtained, is rather low (83-84%) compared to previously mentioned techniques. Literature seems to agree on the good feasibility of vascular and lung US (6, 8), nevertheless, the feasibility of TTE seems to be a matter of diverging opinions, possibly due to the exclusion of patients without adequate visualization by some of these studies (6, 8). Another described technique is transesophageal echocardiography, which has not been used by this study as it was deemed too invasive. The low feasibility of these techniques can be attributed to the deeper position of the heart compared to the superficial position of the veins and other complicating factors, of which the three most important in this study are: superposition of air (e.g., bowel obstruction), obesity, and external bandages.

Megiollaro et al. (3) describe the same complicating factors of the subcostal view and suggest an apical view with a cardiac US probe as good alternative.

When a good four chamber view is accomplished, a high specificity of 100% is achieved for both tests. A positive test result allows to confirm the right position of the CVC and suggests that US confirmation is a reliable alternative to CXR, these findings are supported by similar studies (1, 8, 9). The sensitivity is noticeably higher performing the bubble test (92%) compared to the direct visualization of the guidewire (72%), resulting in a NPV of resp. 60% and 26%. Meaning, if there is no RAS or guidewire visible, it is not possible to make any reliable conclusion about the position of the CVC tip. In case of the absence of RAS in the right atrium, our findings are in line with Kamalipour (15), claiming US not being a suitable replacement to CXR. Although, real-time US control being useful as first triage tool during placement (15).

In practice, to confirm the CVC position, the next bedside approach (following the chart) or CXR confirmation is necessary if a negative, doubtful or non-feasible test result is observed. In case of an aberrant course on vascular US, immediate replacement is possible, and the flowchart loop can be restarted. If replacement is needed, it is important to redo the vascular US, with the guidewire still in the catheter, as one case with a dislocated CVC, after withdrawal of the guidewire during insertion of the catheter itself, was experienced.

A simulation of the five flowcharts is made, with the percentage of patients needing a CXR for every simulation, the percentage of incorrect placements and the number of missed incorrect placements. Depending on the number of bedside tests performed and the results of these test, up to 77.5% of the CXR can be avoided. Furthermore, no missed incorrect placements are seen using the provided flowcharts. Analyzing the simulation, it is important to stress the fact that combining the techniques used in this study increases the overall sensitivity of bedside confirmation of the CVC position. In agreement, the meta-analysis of Ablordeppey et al. (9) states the importance of performing both cardiac and vascular US. The flowcharts take the possibility of a non-feasible or missing test into account, making its use applicable to real-life situations. Hence, the flowcharts can be considered as a guideline to safely diminish the need for a CXR.

Following this, despite CXR being the golden standard for many decennia, its systematic use post CVC placement can be questioned. As mentioned, radiation exposure, cost, additional manpower and time delay subvert its use (1). In this study we observed a mean time delay of 23 minutes between de US diagnosis and the control CXR, a delay that can be inconvenient in case of critically ill patients. Zanobetti et al. (16) describe a bigger time delay of CXR of 65 min. In contrast to Zanobetti's study where the time until reception of the CXR protocol is used, this study examined the moment at which the CXR image was taken. Chui et al. (17) analyzed a group of patients (n= 6875) post CVC insertion, in which they conclude routine CXR post-puncture to be unnecessary and not cost-effective in case of a fluently placed CVC. Pikwer et al. (18) share this statement and promote an individual based approach considering a CXR post-procedure. Cost analysis of US versus CXR confirmation may be an additional area of research.

Post-puncture PTX can be considered as a rare complication, meta-analyses give us a low incidence of 1.1 percent (6). According to CXR, only one iatrogenic PTX occurred in this study, given a similar incidence of 0.8%. The control bedside lung US is done by objectifying the presence of lung sliding on the anterior chest wall. The technique is described as feasible due to the superficial anatomy of the lung, moreover its interpretation does not require a lot of experience because sliding of the lung is easily recognized. In this study, no conclusions about the accuracy of lung US can be made considering the low incidence of PTX. Studies done in the emergency medicine compare de sensitivity of US versus CXR to detect PTX post-trauma, in which there was a statistically significant difference, promoting the usage of bedside US (19, 13, 20, 12). Moreover, Ball et al. (21), mentioned that three out of four traumatic PTX were missed by CXR. In contrast with these studies, we were not able to diagnose the one iatrogenic post-puncture PTX by lung US. The one PTX evolved in a life-threatening situation with a diagnosis of a severe PTX on CXR, associated with hemodynamic and respiratory instabilities, an urgent placement of a thorax drain was necessary. The control CXR was done 2 hours and 30 minutes after CVC placement, a possible explanation might be that a time lag is necessary to develop this severe PTX. It is important to stress the fact that a PTX can evolve slowly. If some late clinical problems are noticed, new imaging should be considered.

The study has several weaknesses. The study might be underpowered considering a limited sample size of 131 patients and the low incidences of mispositioned CVC and post-puncture PTX (resp. 7,6% and 0,8%). Secondly, due to the uniform level of expertise, it was not possible to investigate the impact of experience on the mentioned results. In this study, all CVCs were placed by physicians at a 5-year anesthesia residency. We observed an uncomplicated single-puncture CVC placement in 72% of all cases, in 6 % accidental arterial puncture occurred, without serious consequences. Schummer et al. (17) describe a lower incidence rate of arterial punctions (2.9% of the 1794 patients). In contrast to this study, Schummer et al. (17) mention that all punctions were executed by experienced clinicians, leading us to formulate the hypothesis that the higher incidence rate in this study is due to the lower level of expertise of the physicians. As described by Lennon (16), the level of expertise and experience seems to have a significant positive impact on CVC related complications. Thirdly, not all the collected data sheets have been fully completed, meaning some data gaps might be present. Lastly and most importantly, a correct placed CVC in this study is defined as one with a tip location in the SVC, however the depth of the CVC was not taken into consideration. As defined by Johnston et al. (22), a correct placed catheter tip is one in the low SVC or in the high right atrium. The study noted a higher rate of thrombosis and vessel wall erosion with CVC malfunction if the tip is positioned in the upper SVC (22). On the other hand, a CVC positioned too deep in the right atrium was thought to be at risk of cardiac tamponade, however Pittiruti et al. (23) claim this to be an urban legend.

The strengths of this study are the lack of a selection bias thanks to the heterogenous group used for this study and the lack of an incorporation bias due to the fact that the radiologist is not aware of the US operator's diagnosis when formulating his. The interrater agreement of this study is high, as all the US images have been executed by the three same operators. Additionally, few studies have compared or used the four bedside methods and none of them have put them all together into an applicable flowchart. The flowchart is useful because we incorporated the option of a non-feasible, negative or missing result.

To conclude, the four bedside approaches each have their own feasibility and use in confirming CVC position and putting them all together can reduce the need for CXR. The provided flowcharts can be used as a firsthand tool to safely avoid CXR after CVC placement.

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