1. Introduction

Central venous catheterization of the subclavian (SC) and internal jugular (IJ) veins occurs commonly in the emergency department (ED) and is necessary for patients requiring vasoactive medications, hemodynamic monitoring, or multiple drug infusions. Although the placement of central venous catheters (CVCs) is done routinely, it is not without complications that include catheter tip misplacement (5%-9%), pneumothorax (PTX; 0.1%-3%), and arterial puncture (3%-9%) [1-3]. Despite being made safer through ultrasound (US) guidance [4-6], there is still a CVC tip misplacement range of 3.3% to 14% [7] and an iatrogenic PTX rate of 0% to 3.3% [3,5,8,9]. Traditionally, a postprocedural portable chest radiograph (CXR) is performed for CVC confirmation and to rule out PTX; however obtaining one can take up to several hours, delaying use of the CVC in critical patients.

In recent years, numerous studies have attempted to shorten the delay to CVC use and expedite patient care through alternative methods of CVC confirmation [10,11]. Many of these alternatives to CXR involve the use of bedside US. Although several of these US protocols are useful in the intensive care unit (ICU), the time and extensive training required may not be as feasible in a busy ED. However, Liu and Buhl [12] outlined a quick and easy approach to using US to both identify CVC tip placement and rule out PTX by looking at 2 basic US views. Evaluating the anterior chest wall for the lung sliding sign has been well documented to be more sensitive than supine CXR in detecting PTX (98.1% vs 75.5%) [13]. Furthermore, bedside echocardiography can accurately identify catheter tip position by the use of saline flush to aid in the visualization in the right atrium (RA). The visualization of turbulence or microbubbles within the RA within 2 seconds of the distal port flush confirms adequate CVC placement with a 96% sensitivity and 93% specificity [12,14,15].

The primary objective of this study was to determine if bedside US could more rapidly confirm CVC tip position and rule out PTX than...
standard portable CXR in a busy, urban ED. We hypothesized that US confirmation of CVC placement would be faster than CXR confirmation.

2. Materials and methods

2.1. Study design and settings

We performed a prospective, observational, single-cohort study using a convenience sample of ED patients who had an above-the-diaphragm CVC placed from December 2012 to November 2013. The study was performed in the UF Health Jacksonville ED, which is a high-acuity, academic, urban ED that treats approximately 90,000 patients per year. The research protocol was approved by the University of Florida College of Medicine–Jacksonville Institutional Review Board.

2.2. Selection of participants

Participants were identified for inclusion by emergency physicians (either attending physicians or residents) working in the ED. If a potential participant was identified, one of the physician investigators was contacted to evaluate the patient for inclusion in the study. Inclusion criteria were (1) age 18 years and above, (2) placement of a CVC in either the SC or IJ vein with a confirmatory CXR ordered, and (3) patients who were neurologically intact and able to consent for themselves. Patients were excluded if they were pregnant or incarcerated. Patients deemed eligible were approached for enrollment, and written informed consent was obtained per Institutional Review Board requirements.

2.3. Bedside US for CVC confirmation

All bedside USs in this study were performed by 1 of 2 emergency medicine resident physicians. The principal investigator (PI) was the ED US director at the University of Florida–Jacksonville, who has formal emergency US training and certification as a registered diagnostic medical sonographer. Each of the 2 resident investigators had completed a mandatory 1-month US rotation as outlined by the 2008 American College of Emergency Physicians recommendations for resident education [16]. Each had completed a minimum of 25 Extended Focused Assessment with Sonography for Trauma examinations, demonstrating the standard subxiphoid cardiac view and lung US evaluating for the presence of PTX, before the implementation of the study. Furthermore, each physician received a 30-minute review of the specific views required for this study, subxiphoid cardiac view and anterior lung view, to ensure that images would be saved properly.

Our ED uses the 16-cm triple-lumen CVC (Vantex; Edward Lifescience Corp, Irvine, CA) and the 20-cm sepsis catheter (PreSep; Edward Lifesciences Corp, Irvine, CA) for CVC placement. All US views were obtained using a Sonosite (SonoSite, Bothwell, WA) M-Turbo US machine utilizing 2 probes: phased array and linear probes. Two US views were obtained and recorded. The subxiphoid 4-chamber view of the heart was obtained using the phased array probe, demonstrating the RA and ventricle (RV) and the left atria and ventricle. Once obtained, the RA was inspected for the presence of the CVC tip. Its presence or absence was noted on the data sheet. Then the distal port of the CVC was flushed with a prefilled 10-mL sterile saline flush by either a nurse or an ED technician while the physician continued to monitor the heart in the subxiphoid plane, looking for the appearance of turbulence or microbubbles in the RA as the saline infused into the heart (Fig. 1, Video 1). Two 6-second video clips were taken to demonstrate the turbulence and were started at the infusion of the saline flush. If microbubbles were not immediately visualized, then the delay to visualization was noted in the comments on the data sheet. All video clips were digitally recorded and stored for later review.

Next, US of the anterior chest was performed to evaluate for PTX. Using a linear probe in the sagittal plane and starting at the clavicle, each rib interspace was interrogated to the diaphragm, visualizing the slide of the pleura indicating a normal lung (Fig. 2A, Video 2). The absence of lung slide was noted as a PTX, and an attempt was made to visualize the leading edge of the PTX (Fig. 2B, Video 3). Video clips and still m-mode images were taken on each side representing what the physician noted during the examination. Video clips and m-mode images of each side of the chest were recorded digitally and stored for later review.

2.4. Main measurements

Information collected on the data sheet included patient name, medical record number, date of birth, CVC location and side, CVC placement as correct or incorrect, PTX present or absent, time for cardiac US examination, time for total US examination, and notes. Physicians who performed the bedside US were blinded from the results of the postprocedural CXR. However, if the sonographer identified a line complication, the treating team was notified.

2.5. Chart review

An expert sonographer (the PI) who was blinded to all clinical information and outcome data independently reviewed all recorded video clips and images to ensure completeness. The review also included an

Fig. 1. (A) Ultrasound view of the heart in the subxiphoid window during saline flush of distal CVC port. The RA and RV are noted at time 0, at start of saline flush. (B) Microbubbles visible within the RA (bold arrow) and leading into the RV (small arrow) during the saline flush at the 1-second mark indicating CVC tip in correct position in the SVC.
interpretation of the images and video to confirm or refute the findings of the study physician with regard to CVC position and PTX assessment. Once the US was completed, a separate physician reviewer who did not perform the US examination reviewed the patient's medical record and noted the time of the CXR order, the time it was completed, and the time that the attending radiologist performed the final reading. The reviewer also noted the attending radiologist's CXR interpretation to determine the location of line placement and if a PTX was present. The CVC was considered placed correctly when the catheter tip was noted in the distal SVC or at the cavoatrial junction on CXR. All information was recorded on a separate data sheet. The PI performed a blinded review of a 20% sample of randomly selected charts to ensure accuracy of the data entered.

2.6. Data and power analysis

Student's t test was used for comparison of time to CXR vs US confirmation. To identify a time difference of more than 25% between bedside US and CXR, an estimated effect size of 10 minutes was determined based on an average time to perform a portable CXR in the ED of 40 minutes. The standard deviation of time to CXR was estimated to be 20 minutes; thus, a standardized effect size of 0.5 was used. Using a 2-sided $\alpha$ of 0.05 and a $\beta$ of 0.20, a sample size of 34 patients was calculated to achieve 81% power to detect a difference of 10 between the null hypothesis mean of 40 and the alternative hypothesis mean of 30. To account for the possibility of incomplete images or poor-quality US images due to patient body habitus, we sought to enroll 50 patients.

3. Results

Fifty patients were enrolled in the study, of which 4 were excluded because of inadequate cardiac views, leaving 46 patients included in the final analysis. Mean age was 58 years (SD 15.3), patients were mostly female (64%), and most CVCs were placed in the IJ approach (91%) vs the SC approach (9%).

Mean total US time was 5.0 minutes (95% confidence interval [CI], 4.2-5.9) compared to 28.2 minutes (95% CI, 16.8-39.4) for CXR performance, with a mean difference of 23.1 minutes (95% CI, $-34.5$ to $-11.8$; $P < .0002$). When comparing only US CVC confirmation time to CXR time, US was an average of 24.0 minutes (95% CI, $-35.4$ to $-12.7$; $P < .0001$) faster. Comparing total US time to radiologist CXR reading time, US was an average of 294 minutes faster (95% CI, $-384.5$ to $-203.5$; $P < .00001$).

There were a total of 3 misplaced CVCs in our study population, all of which were placed in IJ veins. The tip of the first misplaced IJ line was noted to be kinked against a stent in the left SC vein after originating from the left IJ. This misplaced catheter resulted in minimal microbubbles noted in the RA, which did not appear on the video clip until 5 seconds after the distal port was flushed. The second misplaced line was placed in the right IJ; but the tip was noted in the ipsilateral SC vein, resulting in no microbubbles on saline flush. The last CVC was placed in the right IJ; but the tip did not extend past the termination of the IJ, producing a delay in the appearance of microbubbles with saline flush, appearing weakly at the 5-second mark. Of the 3 misplaced lines, the resident investigators identified 1 but considered 2 of the CVCs to be in good position; however, upon review by the PI, there was a notable delay in the appearance of the microbubbles (~5 seconds), which indicated line misplacement.

There were a total of 2 PTXs. One was right sided and one was left sided; but both were identified on US examination and earlier than CXR by 9.5 and 1.5 minutes, respectively. The left-sided PTX was moderate in size and required a chest tube, whereas the other was a small apical PTX managed with oxygen and observation.

4. Discussion and limitations

We performed a prospective study of ED patients with above-the-diaphragm CVCs and found that 2-point bedside US was significantly faster than CXR at confirming placement and ruling out PTX. To our knowledge, this is the first study to directly compare the timing of contrast-enhanced US to CXR in the ED for CVC confirmation.

Previous studies have addressed US confirmation of CVC placement but were performed in the ICU setting and required more extensive US protocols. Our study attempted to validate these findings using a simplified protocol and demonstrates usefulness in the ED setting. In 2001, Maury et al[17] demonstrated that with limited training, a CVC could be evaluated for catheter tip position with US by viewing bilateral IJ and SC veins, a subcostal view of the heart, and the inferior vena cava (IVC) in short axis. They also showed that PTX could be successfully ruled out by viewing lung slide in the anterior 3 rib interspaces. This technique, performed in 81 ICU patients, was noted to be faster than CXR (US: 6.8 ± 3.5 minutes vs CXR: 80.3 ± 66.7 minutes), without missing any of the 10 catheter misplacements [17]. Matsushima and Frankel [18] used a similar US protocol in their “CVC Sono” evaluation of 83 CVCs in the surgical intensive care unit compared to CXR (US: 10.8 minutes vs CXR: 75.3 minutes) but noted poor sensitivity (50%) for catheter localization due to technical limitations, resulting in only 71% of US examinations completed. However, they correctly identified the CVC placement in 90% of the technically adequate scans in their study. Vezzani et al [14] were the first to use contrast (microbubbles or turbulence) to confirm CVC placement in 111 ICU patients and showed a significantly improved success rate from previous studies of 96% [14]. Contrast-enhanced echo, which was done by flushing agitated saline through the distal port of the CVC to visualize turbulence or microbubbles in the RA within
2 seconds, prolonged US performance time only minimally (US: 10 ± 5 minutes vs CXR: 83 ± 79 minutes). Zanobetti et al [7] demonstrated a faster US confirmation in 210 ED patients but did not use contrast-enhanced echo to get their results (US: 5 ± 3 minutes vs CXR: 65 ± 74 minutes), instead using a similar US protocol as Maury and Matsushita reported a sensitivity of 94% to detect catheter malposition. Although the Zanobetti et al study had the fastest US performance times, the reported times seem unattainable given the requirements of their scan protocol (IJ and SC veins scanned bilaterally in 3 points, apical and subxiphoid cardiac views of the heart, and bilateral chest walls scanned at 5 points). Weakes et al [15] evaluated the use of contrast-enhanced US alone to confirm catheter tip placement in 135 ED patients compared to CXR. This streamlined protocol of only 1 cardiac view yielded a 75% sensitivity and 100% specificity in the ED, as they missed 1 of the 4 misplaced CVCs. This study did not measure study time and was inadequately powered for accuracy. Another study by Wen et al [19] used contrast-enhanced US to evaluate 219 CVC placements and compared time to US completion to CXR performance in a hemodialysis clinic (US: 3.2 minutes vs CXR: 28.3 minutes) [19]. Although a retrospective study, it still demonstrates that US is sufficiently faster than CXR to confirm catheter tip placement while still demonstrating both of the misplaced lines in their study group.

Although the use of bedside US to determine CVC placement is not a novel concept, previous studies required multiple cardiac and SC and IJ vein views to establish CVC position, which may be time consuming in a busy ED. By decreasing the number of views required to complete the protocol, we were able to cut the US performance time by half. The time savings can then be translated directly to the critically ill patient, who would benefit from more expeditious use of the CVC. We used the more simplified 2-view US protocol that Liu and Bahl [12] describe because we felt that it would be more useful for emergency physicians in community EDs who may have limited time and US training. Despite this reduction in protocol requirements, we were still able to successfully identify line misplacement and PTXs accurately.

Previous studies have demonstrated that a saline flush through the distal port of the CVC will result in the turbulence or microbubbles appearing in less than 2 seconds in the RA from the time of injection [14,15]. We found similar results with all confirmed lines demonstrating turbulence in the RA almost immediately. The 3 misplaced lines demonstrated either no turbulence or delayed turbulence appearing at 5 seconds. In either case, our findings support previous studies that demonstrate microbubble appearance immediately or at least within 2 seconds of the saline flush confirms CVC tip placement in the SVC.

Residents were used to perform the US examinations, as we felt that it would be more indicative of the average emergency physician, who are not US experts. This led to 2 important points for discussion. Firstly, the lack of experience led to the inadequate cardiac views in the 4 patients that were excluded. Secondly, there was reliable agreement in US interpretation between resident investigators and the PI except in 2 cases. In these 2 cases, the difference was the result of delayed microbubbles. Although the delay of microbubbles was noted on the data sheet, we did not decide a priori to consider a line misplaced if delayed bubbles were present. Had we done so, these lines would have been correctly classified as misplaced by the resident investigators. Therefore, we believe that training does play a role in the successful use of this US protocol. Physicians looking to use this protocol will need training specific to the protocol they use to ensure adequate sensitivity. Finally, US use in the detection of PTXs has been well proven by previous studies, with sensitivity and specificity of US reaching those of computed tomographic scans in the confirmation of PTX in the supine patient [13,20]. We found similar results and correctly identified both PTXs. The anterior approach to demonstrate pleural sliding was fast, accurate, and easy to achieve in all patients.

This study had several limitations. This was a single-site study performed at an academic institution with emergency medicine residents who receive US training as part of the residency curriculum. Although the resident investigators received the standard 1-month US rotation recommended by the American College of Emergency Physicians, both US views in our protocol are found in the Extended Focused Assessment with Sonography for Trauma examination; previous studies have demonstrated that, with limited training, even novice sonologists can learn to accurately perform these views [21–24]. Therefore, although additional US training may be necessary for physicians who did not receive dedicated US training during residency, it is likely that limited training in the specific views required for this technique would be sufficient. Next, because we used resident investigators for study enrollment, the study was a convenience sample, leaving room for a potential selection bias. Finally, though our study was correctly powered to determine a statistically significant difference in study performance time, it was not powered to confirm the results for accuracy. However, given the limited resources and the fact that the accuracy of US confirmation has already been established by previous literature [7,14,17–19], we felt that additional enrollment to establish accuracy was unnecessary.

5. Conclusion

In conclusion, our 2-point US protocol confirmed CVC placement and identified complications more rapidly than standard portable CXR in this population of ED patients. By expanding on basic US skills, this protocol can be applied at the patient’s bedside to expedite use of CVCS in critically ill patients.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.ajem.2014.10.010.

References


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