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Validity of ultrasonography in detection of central venous catheter position and pneumothorax compared to portable chest X-ray

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ABSTRACT

Ultrasonographic guidance for insertion of central venous catheter is now almost a standard of care, leading to fewer failed attempts and complications. Nowadays, the ultrasound examination used to detect position of the central line and pneumothorax occurrence as an alternative to X-ray. The aim of this work is to assess validity of ultrasonography and portable chest X-ray in detection of central venous catheter position and post-central line insertion pneumothorax. The study was carried out on one hundred catheter insertions for patients who were admitted to Critical Care Medicine Department in Alexandria Main University Hospital. Confirmation of endovenous placement of the catheter was done by ultrasonography using “Bubble test” and examination of internal jugular veins and subclavian veins of both sides. Then, lung ultrasound was done to detect pneumothorax occurrence. After that, a portable chest X-ray film was done for all patients to detect the catheter tip position and presence of pneumothorax. Then, Computed tomography of the chest was done for all patients after their hemodynamics stabilization to confirm the previous data and compare accuracy of the ultrasound and X-ray to detect catheter tip position and post-insertion pneumothorax. The researcher found that there is statistically significant correlation between site of insertion and incidence of post-insertion pneumothorax occurrence (80% with subclavian approach versus 20% for internal jugular approach). In detection of the catheter position, the ultrasound showed sensitivity and specificity of 82.7%, 96.8% respectively versus 93.8%, 95.8% respectively for portable X-ray. Furthermore, in detection of post-insertion pneumothorax, the ultrasound showed sensitivity and specificity of 90%, 96.3% respectively versus 45%, 96.3% respectively for portable chest X-ray. We can use the ultrasound to detect position of catheter tip and pneumothorax after insertion of central line as a better alternative to routine portable chest X-ray with higher accuracy.

Keywords : *Ultrasound, central venous catheter, portable chest X-ray, pneumothorax, catheter position, CT chest.*

INTRODUCTION

Central venous catheterization of the subclavian (SC) and internal jugular (IJ) veins are being inserted commonly in emergency department (ED) and the intensive care units (ICUs). Establishing central venous access is an essential skill for all critical care physicians[1].

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Common indications for placement of a central venous catheter (CVC) include: (1) Hemodynamic monitoring (e.g., measurement of the central venous pressure). (2) Administration of medications (e.g., vasopressors, inotropes, chemotherapy, and total parenteral nutrition). (3) Plasmapheresis, apheresis, hemodialysis, or continuous renal replacement therapy. (4) Poor peripheral venous access. [1,2]

The modified Seldinger technique is widely used to place central venous catheters. Briefly, the vein is cannulated with a needle and a guidewire is inserted through the needle into the vessel lumen. Once the needle is removed (leaving only the guidewire in position) a tract is dilated and the catheter is inserted over the guidewire. The guidewire is removed and the central venous catheter is secured. [3]

In addition to malposition of the central venous catheters, many other complications are associated with insertion of central venous catheter including arterial puncture, air embolism, catheter occlusion, pneumothorax (PTX), cardiac perforation and subsequent tamponade, catheter infection and venous thrombosis. [5,6]

Ultrasound (US) imaging is safe, painless, non-invasive and produces pictures of the inside of the body using sound waves. Ultrasound examinations do not use ionizing radiation (as used in x-rays and computed tomography), thus there is no radiation exposure to the patient. Because ultrasound images are captured in real-time, they can show the structure and movement of the body's internal organs, as well as blood flowing through blood vessels. [7]

Ultrasonographic (USG) guidance for the insertion of central venous catheter is now almost a standard of care, leading to fewer failed attempts and complications. [8,9]

The Aim of the present study is to assess validity of ultrasound to detect central line position and post-insertion pneumothorax compared to routine portable chest X-ray.

Materials and Methods

Patients:

The present study was carried on 147 CVC insertions for critically ill patients, with exclusion of 47 CVC due to lack of either X-ray or CT scan. So 100 CVC insertions in 88 patients was eligible for this study. These patients were selected from those admitted to the Critical Care Medicine Department of Alexandria Main University Hospital. The study carried on both sex, 60 male patients (60%) and 40 female patients (40%).

Inclusion criteria:

1. Patients indicated for supra-diaphragmatic central line insertion.

Exclusion criteria:

1. Patients with anatomical distortion of any cause (e.g.: kyphoscoliosis, morbid obesity, etc.) that makes ultrasonography interpretation difficult.
2. Patients with chest trauma (e.g.: subcutaneous emphysema, dressings, etc.) that makes ultrasonography interpretation difficult.
3. Pregnant females.

Methods

1. The ultrasonography performed use a convex probe of portable digital ultrasound (SHENZHEN Mindray Bio-medical Electronics CO, LTD china. Model DP-20) of 2.5-5 MHz and a linear probe of 7.5-10 MHZ.
2. The patient was placed in a supine position and CVC inserted using standard Seldinger technique.
3. Confirmation of endovenous placement of CVC was done by ultrasonography through subcostal view (as a first choice) or apical four-chamber view (as a second choice) with the “Bubble test”.
4. Positive “Bubble test”; defined as opacification of right atrium after injection of shaken saline, and according to the origin of opacification at the beginning, either central or eccentric opacification (with push-to-bubbles time less than 3 sec)[19] , the position of CVC tip determined if advanced on the right atrium or on superior vena cava, respectively. In case of eccentric opacification, stopwatch was used to calculate push-to-bubbles time with taking cut off value 3 seconds.[19] Negative or failed “bubble test”; defined as there is no opacification of the right atrium even after 10 seconds of injection of shaken saline.
5. If malpositioned (eccentric opacification with push-to-bubbles time more than 3 sec) or negative “bubble test”, then examine both internal jugular veins, both subclavian veins through direct view using the linear probe of ultrasound to detect malposition of the CVC.
6. Lung ultrasound was done to detect occurrence of pneumothorax using lung-sliding sign or comet-tail artifacts on the upper three intercostals spaces on the same side of CVC insertion.
7. A portable Chest X-ray film was done for all patients after that to detect the position of catheter tip and the presence of pneumothorax.
8. CT of the chest was done after that for all patients after their hemodynamics stabilization to confirm the previous data and compare the accuracy (sensitivity and specificity) of ultrasound and chest X-ray to detect malposition of CVC tip and pneumothorax resulted from its insertion.

Statistical analysis

Statistical analysis was done using IBM SPSS statistics program version 21. Categorical variables were summarized by frequency and percent. Chi-square test was used to study significant association between two qualitative variables. Fischer exact and Monte-Carlo tests were used if more than 20% of total expected cell counts <5 at .05 level of significance. Kappa measure of agreement was done to test agreement between two different diagnosis methods of U/S and CT and also between CXR and CT. Agreement interpreted as <0.2 poor, 0.21-0.4 fair, 0.41-0.6 moderate, 0.61-0.8 substantial and 0.81-1 almost perfect agreement.

RESULTS

The present study was carried on 147 central venous catheter insertions for critically ill patients with exclusion of 47 patients with missing either X-ray or CT scan. These patients were selected from those admitted to the Critical Care Medicine Department of Alexandria Main University Hospital in whom central line insertion on supra diaphragmatic site (internal jugular vein or subclavian vein on both sides). The following data were recorded and analyzed:

Position of CVC as detected by U/S:

After insertion of central venous catheter for patients, we use “Bubbling test” using agitated saline and ultrasound (curved probe) on subcostal window (as a first option) or apical window (as a second option) to view right atrium to identify position of tip of catheter. The bubbling test was positive in 85 patients (85%).

Table-1. Distribution of patients according to site of insertion of CVC

	Frequency	Percent
Rt IJV	48	48%
Rt SCV	20	20%
Lt IJV	17	17%
Lt SCV	15	15%
Total	100	100%

Rt: right, Lt: Left, IJV: internal jugular vein, SCV: subclavian vein

Table-2. Distribution of patients according to gender

	Frequency	Percent
Male	60	60%
Female	40	40%
Total	100	100%

According to the pattern of opacification of bubbles (fig. 1), we determine if tip of CVC is advanced in right atrium (central opacification), in SVC (eccentric opacification, with short push-to-bubbles time less than 3 sec)[19] or malpositioned (eccentric opacification, with delayed push-to-bubbles time more than 3 sec). On the other hand, the bubbling test was negative in 15 patients (15%). In case of positive bubbling test with malpositioned central line or negative bubbling test, we use linear probe of ultrasound to detect the tip position by view it directly in one of the big veins (SCV, IJV) on both sides. After that, portable X-ray and CT chest were done for all patients to detect tip position of central venous catheter. Results were collected and analyzed as in figure-1 and Table-3:

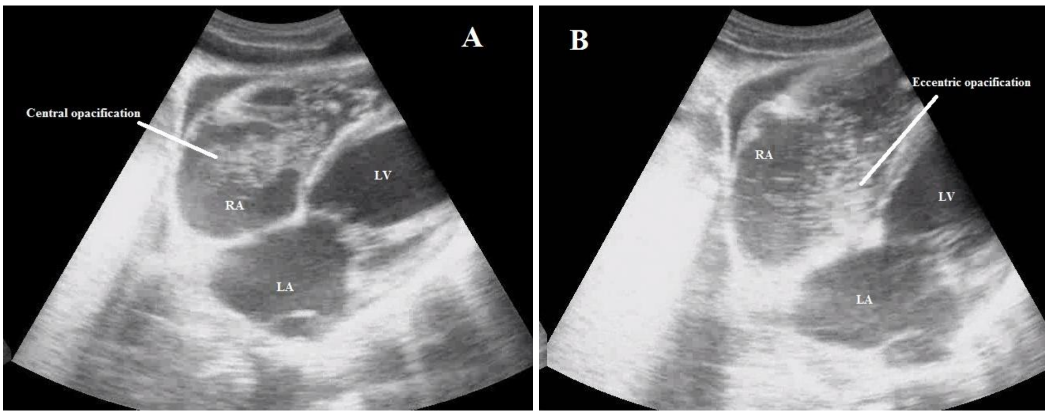
Table-3. Detection of CVC position by ultrasound versus CT

		Position by CT (gold standard)					Total
		SVC	**Right atrium**	**Right SCV**	**Left IJV**	**Left SCV**	
Position by ultrasound	**SVC**	57	6	0	0	0	63
	Rt atrium	0	22	0	0	0	22
	Rt SCV	0	0	4	0	0	4
	Lt IJV	0	0	0	5	0	5
	Lt SCV	0	0	0	0	5	5
	Not seen	0	0	1	0	0	1
Total		57	28	5	5	5	100

SVC: superior vena cava, Rt: right, SCV: subclavian vein, IJV: internal jugular vein, CT: computed tomography

From data in table (3) and fig. 2, statistical analysis showed that there is significant agreement between determination of central venous catheter tip position by U/S (using bubbling test) and CT chest with a ρ value of

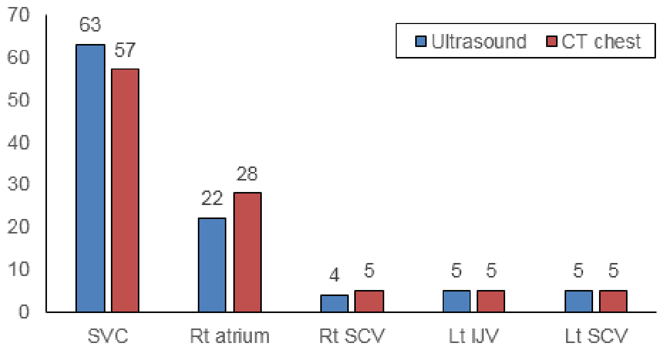
Figure-1. Opacification pattern of bubbling test, A) central one B) eccentric one



RA=right atrium; LA=left atrium; LV=left ventricle

< 0.001, Kappa value of 0.878 with 95% confidence interval from 0.790 to 0.965 indicate that strength of agreement is "perfect".

Figure-2. Detection of central venous catheter position by ultrasound (U/S) versus CT chest



Validity of ultrasound to detect the position of central venous catheter is: specificity of 96.76% and sensitivity of 82.74% with PPV of 84.89% and NPP of 97.19%.

Position of central venous catheter by portable chest X-ray versus position by CT chest:

CXR: chest X-ray:

From data in table (4) and **fig. 3**, statistical analysis showed that there is a significant agreement between determination of central venous catheter tip position by portable chest X-ray (CXR) and CT chest with a ρ value of < 0.001, Kappa value of 0.829 with 95% confidence interval from 0.725 to 0.932 indicate that strength of agreement is "perfect".

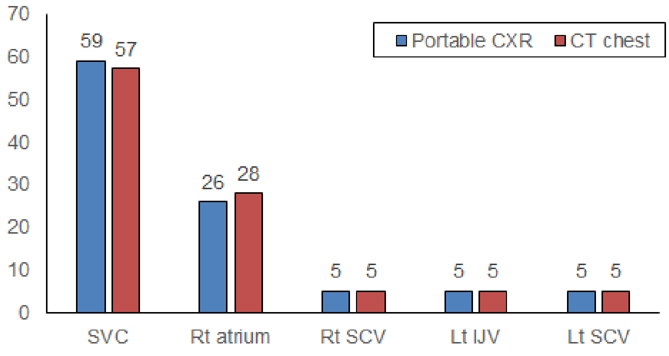
Validity of portable X-ray to detect position of central venous catheter is: specificity of 95.82% and sensitivity of 93.77% with PPV of 95.54% and NPP of 96.76%.

Table-4. Detection of CVC position by protable CXR versus CT chest

		Position by CT (gold standard)					Total
		SVC	Right atrium	Right SCV	Left IJV	Left SCV	
Position by CX R	SVC	53	6	0	0	0	59
	Rt atrium	4	22	0	0	0	26
	Rt SCV	0	0	5	0	0	5
	Lt IJV	0	0	0	5	0	5
	Lt SCV	0	0	0	0	5	5
Total		57	28	5	5	5	100

SVC: superior vena cava, Rt: right, SCV: subclavian vein, IJV: internal jugular vein, CT: computed tomography

Figure-3. Detection of central venous catheter position by portable X-ray versus CT chest



Pneumothorax Identification:

Distribution of cases of pneumothorax according to site of insertion:

The incidence of pneumothorax occurrence was more in using subclavian approach (80%) than using internal jugular approach (20%).

Table-5: detection of pneumothorax by ultrasonography versus CT

		PTX by CT		Total
		-ve	+ve	
PTX by U/S	-ve	77	2	79
	+ve	3	18	21
Total		80	20	100

PTX: pneumothorax, U/S: ultrasound, CT: computed tomography

From data in table-5, statistical analysis showed that there is a significant agreement between identification of pneumothorax by ultrasound and CT chest (as a gold standard test) with a ρ value of < 0.001 and Kappa value of 0.724 with 95% confidence interval from 0.716 to 0.977 indicate that strength of agreement is "substantial".

The validity of ultrasound to detect pneumothorax is as follow: specificity is 96.3% and sensitivity is 90%. NPV is 97.5% and PPV is 85.7

Table-6. Detection of pneumothorax by portable X-ray versus CT

		PTX by CT		Total
		-ve	+ve	
PTX by X-ray	-ve	77	11	88
	+ve	3	9	12
Total		80	20	100

PTX: pneumothorax, CT: computed tomography

From data in table-6, statistical analysis showed that there is significant agreement between determination of central venous catheter tip position by ultrasound (using bubbling test) and CT chest (as a gold standard test) with a ρ value of < 0.001 and Kappa vale of 0.597 with 95% confidence interval from 0.259 to 0.712 indicate that strength of agreement is “moderate”.

The validity of portable X-ray to detect pneumothorax as follow: specificity of 96.3% and sensitivity of 45% with NPV of 87.5% and PPV of 75%.

DISCUSSION

Central venous catheterization of the subclavian (SC) and internal jugular (IJ) veins are being inserted commonly in emergency department (ED) and the intensive care units (ICUs). Common indications for placement of a central venous catheter (CVC) include: (1) Hemodynamic monitoring (e.g., measurement of the central venous pressure). (2) Administration of medications (e.g., vasopressors, inotropes, chemotherapy, and total parenteral nutrition). (3) Plasmapheresis, apheresis, hemodialysis, or continuous renal replacement therapy. (4) Poor peripheral venous access.[1,2]

In addition to malposition of the CVCs, many other complications are associated with insertion of central venous catheter including arterial puncture, air embolism, catheter occlusion, pneumothorax (PTX), cardiac perforation and subsequent tamponade, catheter infection and venous thrombosis.[5,6]

Ultrasonographic (USG) guidance for the insertion of CVC is now almost a standard of care, leading to fewer failed attempts and complications. However, the risk of inadvertent puncture of surrounding structure persists. Carotid artery puncture and/or cannulation may occur even if proper precautions are taken, sometimes with disastrous consequences. [8,9] Furthermore, the ultrasound is used after CVC insertion to detect position of its tip and exclude occurrence of post-insertion pneumothorax.

The present study was carried on 147 CVC insertions for critically ill patients, with exclusion of 47 CVCs due to lack of either X-ray or CT scan. So 100 CVC insertions in 88 patients was eligible for this study. These patients were selected from those admitted to the Critical Care Medicine Department of Alexandria Main University Hospital in whom central line insertion was on supra-diaphragmatic site (internal jugular or subclavian vein).

In the present study, there is a statistically significant correlation between site of insertion and incidence of iatrogenic occurrence 0f pneumothorax (80% occurred with SCV approach versus 20% occurred with IJV approach). Therefore, the subclavian approach has higher risk for occurrence of post-CVC insertion pneumothorax. In agreement with the present study, Lewis A. Eisen et al., in 2006, mentioned that the subclavian approach had a higher complication rate than the internal jugular or femoral approach.[11]

On the other hand, Wolfram Schummer et al, in 2007, mentioned that the incidence of PTX was not related to the insertion site.[12]

In the present study, determination of CVC position by ultrasound using bubbling test was the first step after CVC insertion. The ultrasonography examination was performed by critical care resident who had undergone two days of training on cardiac-focusing ultrasonography with an expert cardiologist. The researcher used an ultrasound curved probe on subcostal or apical window for right atrium by using an agitated saline injected on largest port on CVC with notification of opacification pattern either central (turbulent flow) or eccentric (laminar jet flow) one. There was 85 CVCs found on correct position (positive bubbling test either central opacification or eccentric with short push-to-bubbles time less than 3 sec)[19] and 15 CVCs was malpositioned (either positive bubbling test with eccentric opacification with delayed push-to-bubbles time more than 3 sec or negative bubbling test).

Ultrasound showed sensitivity, specificity, PPV and NPV which were 89.65%, 96.5, 96.9% and 97.2%, respectively taking CT scan as a gold standard test. After that a portable CXR film was done for all patients and the results were reported by an expert radiologist who was blinded to the ultrasonography results. Moreover, the portable CXR has showed sensitivity, specificity, PPV and NPV which were 85.8%, 90.3%, 87.2% and 91.1%, respectively. Throughout this study, low sensitivity of ultrasonography in detection of CVC position is explained by some cases (6 CVCs) in which the CVC tip was just beyond the junction between SVC and right atrium (seen by CT scan) which showed eccentric flow and interpreted as positioned in SVC by U/S.

In agreement with the present study, Alonso quitela P et al, in 2015 mentioned that the bedside U/S showed a good agreement with CXR in detecting CVC tip and revealing incorrect position, the study was in pediatric patients aged from 0 to 14 years old.[13] Duran Gehring PE et al, as well in 2015 found that U/S can confirm CVC placement and role out PTX significantly faster than CXR with sensitivity and specificity 96% and 93%, respectively.[14]

On the other hand, Hamid Kamalipour et al, in 2016 mentioned that despite the close concordance between U/S and CXR, contrasted enhanced U/S (bubble test) was not suitable alternative to standard chest radiography in detecting CVC location; yet, considering its high sensitivity and acceptable specificity in his study, its usefulness as a triage method for detecting CVC location on a real-time basis in the operating room which can't be ignored.[17]

In the present study, we use lung ultrasound to detect presence of iatrogenic pneumothorax or not after CVC insertion by using lung sliding and comet tail artifact signs. The sensitivity and specificity of ultrasound to detect pneumothorax was 80% and 93.8%, respectively. And by using portable CXR to detect pneumothorax, the sensitivity and specificity was 45% and 96.3, respectively. Therefore, there is a statistical difference between U/S and CXR promote using bedside U/S better than portable CXR for detection of PTX with higher sensitivity.

In agreement with the present study , Uzma Mumtaz et al., in 2016 mentioned that U/S can be used as as a useful and suitable adjunct to CT in trauma patients as it is easily available, non-invasive, bedside, easily examined with no radiation risk, the specificity and sensitivity of ultrasound to detect pneumothorax was 94% and 100%, and for X-ray was 31.8 and 100%, respectively.(18)

Conclusion

Bedside ultrasound in the intensive care unit is increasingly being used. This study suggests that ultrasonic examination is accurate in detecting pneumothorax and catheter position after subclavian and internal jugular vein cannulation. Furthermore, the ultrasound can be used as a good alternative to routine portable CXR post-CVC insertion with better accuracy.

Limitations

The present study has a limitation; In case of positive bubbling test with eccentric opacification, the cut off point value to differentiate between two positions (SVC versus malpositioned catheter) determined according to previous studies and not tested.

Conflict of Interests

Authors declare that there is no conflict of interests regarding the publication of this paper.

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