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Comparing the Accuracy of Echocardiography and Radiography for Evaluation of Tip Position of Peripherally Inserted Central Catheters: Experienced in an NICU in Iran

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Abstract

Background: Echocardiography (ECHO) is a non-radiation real-time technique for evaluating Peripherally Inserted Central Catheter (PICC) tips that could overcome the limitations of plain radiographs, including the static and single image and exposing neonates to radiation. This study compared the accuracy of ECHO and radiography for PICC tip positioning in neonates.

Methods: This cross-sectional pilot study was conducted in the neonatal intensive care unit (NICU) of the Children's Medical Center in Tehran, Iran. Ultrasonography was used to visualize the end of the catheter in the vessels. After insertion of the catheter, a chest x-ray along with the ECHO was performed by a pediatric cardiologist blinded to the preliminary radiographic reports, and the results were compared and interpreted.

Results: Forty infants with mean gestational ages of 35.4±3.3 weeks were enrolled in this study which was conducted during 12 months, from 2019 to 2020. The radiography results confirmed the correct PICC location in 29 infants (72.5%), which was simultaneously confirmed by ECHO in 28 infants (70.0%). The ECHO results indicated inappropriate placement in 12 infants (30%), and radiographs indicated correct placement in 11 infants (27.5%). This confirmed the higher accuracy of ECHO compared to radiography. ECHO had a sensitivity of 100%, specificity of 96.55%, PPV of 91.67%, NPV of 100%, and diagnostic accuracy of 97.5%. Both methods were appropriately correlated regardless of the demographics characteristics, sex, birth weight, gestational age, and catheter insertion site.

Conclusion: The findings confirmed that ECHO was more accurate than radiography for visualizing PICCs tip placement. ECHO does not require radiation exposure, has fewer complications, and is faster than radiography; thus, it should be considered as an alternative to standard radiography for line tip confirmation.

Key Words: Echocardiography, Neonate, Peripherally inserted central catheter, Radiography.

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1- INTRODUCTION

Long hospitalization of premature and Low Birth Weight (LBW) infants, and critically ill newborn infants in the Neonatal Intensive Care Unit (NICU) requires safe and effective peripheral blood vessels access (1). Traditional central veins surgical catheterization and insertion of a Central Venous Line (CVL) requires anesthesia, which is time-consuming and costly (2). Today, in NICUs, a Peripherally Inserted Central Catheter (PICC) is common (3, 4) for long-term replacement of electrolytes and fluids, parenteral nutrition, and precise administration of medication (such as antibiotics) for premature newborns and LBW infants (5). Catheter insertion may lead to life-threatening complications, including systemic and pulmonary embolisms, catheter-related septicemia, hemorrhage, thrombosis, arrhythmia, and pleural and pericardial space effusion (6).

To minimize complications, different intra- and post-procedural techniques, such as ordinary radiographs (x-rays), fluoroscopy, ultrasonography, etc., are utilized for confirming PICC tip placement (7). Physiological information can be easily detected using real-time Echocardiography (ECHO), which can assist in decision-making besides clinical information (8, 9). Trans-esophageal ECHO is commonly used in clinics and has several advantages, such as real-time manipulation and reduced exposure to radiation (10). This technique is rapid and reliable for visualization of catheter positioning during a procedure with no need for further repositioning (11). Neonatal ECHO, which is easy to learn, has been demonstrated to be very accurate for Umbilical Venous Catheter (UVC) tip localization (12). In infants, the concordance rate between radiographs as a post-procedural method and ECHO for PICC localization ranges from 60% to 80% (4).

The efficacy of ECHO has been compared with other methods in several studies (13). It has been reported that ECHO can be applied as a suitable alternative to radiography (4). Plain radiographs have disadvantages, including providing a single static image unsuitable for reliable detection of variations in PICC tip positions (4, 14). Also, radiography requires both Anteroposterior (AP) and lateral views for accurate evaluation, thereby exposing a neonate to radiation twice (9). Few studies have examined the accuracy of ECHO as an alternative to radiography for catheter tip visualization in infants. The present study compared echocardiography with conventional radiography, the routine gold standard for PICC positioning visualization, in neonates whose ultrasound indicated that the end of the catheter was in a vessel near or inside the heart cavity in a tertiary neonatal service in Tehran for one year. The objective of the study was to evaluate the sensitivity, specificity, and positive and negative predictive values of this technique as a potential alternative to radiology.

2- MATERIALS AND METHODS

2-1. Study design

This cross-sectional, descriptive-analytical pilot study was conducted at the NICU of a medical and surgical tertiary service in the Children's Medical Center affiliated with Tehran University of Medical Sciences (TUMS) in Tehran, Iran, from February 2019 to January 2020. The study commenced after making the required coordination with the NICU personnel, the trained nursing team, the PICC-inserting personnel, and the radiology and pediatric cardiac departments.

2-2. Ethical considerations

The study protocol was approved by the ethics committee of the Research Institute for Children's Health, Shahid Beheshti University of Medical Sciences, Tehran, Iran (IR.SBMU.RICH.REC.1399.046). The patients were included, after their parents were briefed about the study protocol and signed an informed consent form. There were no charges for radiography or ECHO.

2-3. Inclusion criteria

This research was conducted as a part of a larger study (15). The neonates who met the PICC indications for long-term or moderate IV drug therapy or antibiotic therapy (over six days), total parenteral nutrition (TPN), difficult-to-access blood vessels or very LBW (VLBW; <1500 g) (16) were included. PICC insertion was led by a neonatologist according to the department protocol.

Totally, 90 cases had an indication for PICC insertion during the year of study, and the procedures were performed to evaluate the PICC tip position (15). The catheter was located close to or inside the heart cavities in radiography in 40 patients. ECHO was done for PICC tip position confirmation and its accuracy was compared to radiography.

2-4. Exclusion criteria

Infants with limb perfusion disorders, coagulation abnormalities, dermatitis, or a local hematoma preventing access to the peripheral veins, anatomical abnormalities interfering with proper PICC placement (e.g., Erb's palsy), and blood culture-confirmed sepsis before antibiotic therapy were excluded (16). Infants with reluctant parents were excluded and did not undergo the procedure. All cases of non-participation received routine care, and the conventional management plans were continued.

2-5. Sample size

Considering 95% sensitivity and 5% error, a study sample size of 40 infants was calculated. These numbers were selected experimentally, based on feasibility. Samples were collected by the census in all infants eligible for PICC implantation during the project. As recommended by Jain et al. (9), in their 22 patients who underwent the study, ECHO identified 11 of the assessed PICC lines (50%) in a suboptimal position. Plain radiographs accurately identified 7 of the 11 malpositioned PICC tips. Nonetheless, they erroneously reported 4 of 11 malpositioned PICC tips in a good position (36.3%), while ECHO identified 11 of the 22 PICC lines correctly positioned (50%). Plain radiographs identified only 6 of those 11 (54.5%). The overall concordance between the radiographs and ECHO for the PICC tip position was 59%.

2-6. Data collection

The information about gestational age, neonatal weight, PICC embedment age, and other information, such as catheter embedment location, the underlying diseases, and catheter embedment indications, were recorded. The nurses who assisted with PICC insertion recorded the following information: specifications of the applied processor, catheter type (silicone), size (1 and 2 French sizes), location and date of insertion, and the dressing date.

The PICC was inserted under sterile conditions by a trained nurse or neonatologist. The Optimal Catheter Tip Position (CTP) for venous catheters was the vena cava or vena cava–RA junction, and not within the RA (17).

Ultrasonography was used to visualize the end of the catheter in the vessels for all neonates. Immediately after catheter insertion, an AP chest or abdominal radiograph was performed using the same imaging device for all patients. The results were reported by a radiologist. The

bedside ECHO was done rapidly using a portable single-unit (Kontron Medical; Imagic Agile, Mehrkam Tajhiz, Iran). A single pediatric cardiologist who was blinded to the patient radiography report conducted the ECHO at the earliest possible time after PICC insertion. The ECHO method was the normal B mode. Where the catheter tip was not visible, a small saline bolus was used to facilitate observation of the catheter tip by creating bubbles. Only one patient required normal saline injection; in the other cases, the ECHO was performed without complications.

2-7. Data analysis

SPSS software (version 23.0 for Windows, IBM SPSS Statistics, USA) was used for descriptive and inferential analyses of the data. Mean±standard deviation, and frequency (percentage) were used to describe the variables. For the comparison between ECHOs and radiographs, the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated using 2*2 crosstabs. The accuracy index is the probability of a patient being properly classified. A p-value of ≤ 0.05 was considered as statistically significant.

3- RESULTS

The demographic characteristics of the 40 neonates included in the study are shown in **Table 1**.

The radiography results indicated correct PICC placement in 29 infants (72.5%), which was confirmed by ECHO in 28 infants (70.0%). The ECHO results indicated inappropriate placement in 12 infants (30%), whereas radiography showed that 11 infants (27.5%) had inappropriate placement of the PICC. ECHO had a sensitivity of 100%, specificity of 96.55%, PPV of 91.67%, NPV of 100%, and diagnostic accuracy of 97.5%. **Table 2** shows the results of the catheter placement in both tests based on the underlying variables and the sensitivity, specificity, PPV, NPV, and diagnostic accuracy of the ECHO for each variable.

Evaluation of the concordance between the ECHO and radiography results was based on the gender of the neonates, which demonstrated that the specificity for females was 6% less than for males. The PPV was 75% in females, indicating that, in females who were declared positive by ECHO, the probability of PICC malpositioning was 75% compared to 100% estimation in males.

The specificity of the ECHO in neonates who were above 37 weeks of gestational age was 100%, while this parameter at less than 37 weeks of gestational age was 92%. The PPV was 87.5% for neonates with <37 weeks of gestation compared to 100% for the term neonates.

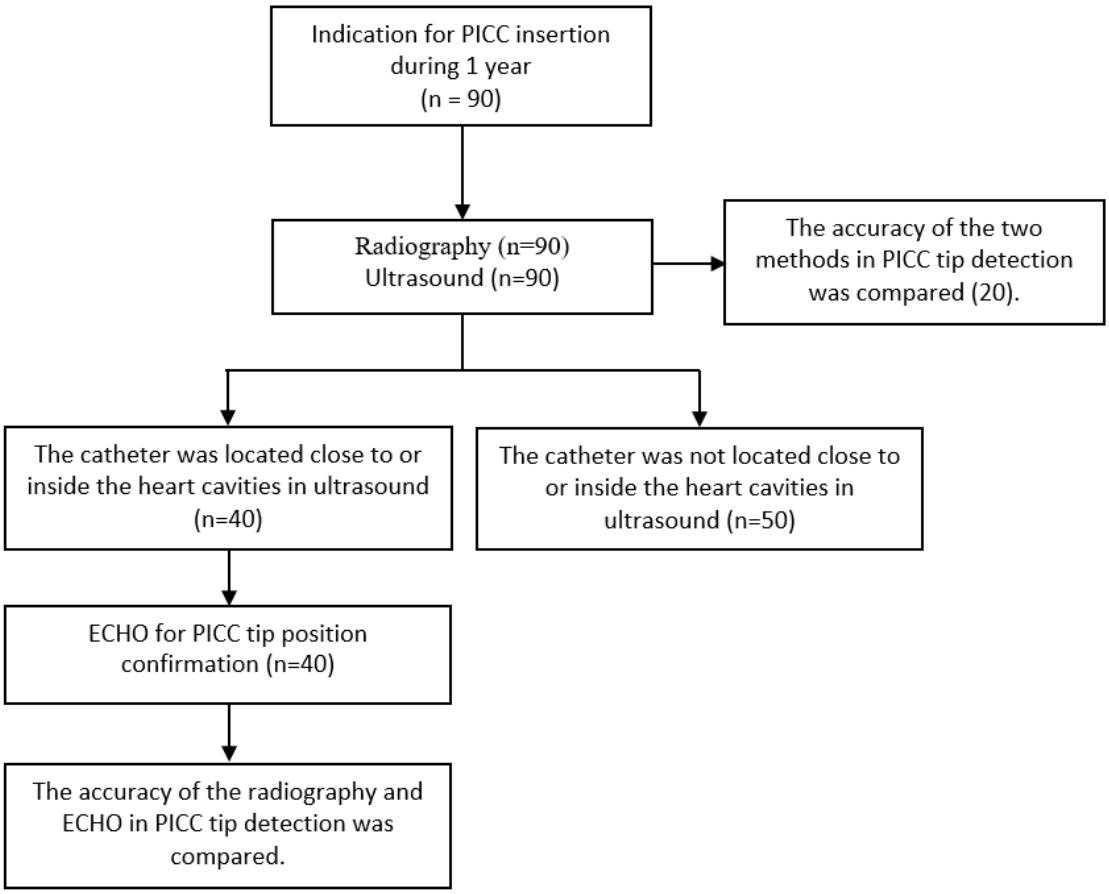

Fig 1: The flowchart of the study

Table-1: Demographic characteristics of the patients

Qualitative variables		n (%)	Qualitative variables		n (%)
Sex	Male	19 (47.5)	Indication of insertion	TPN	11 (27.5)
	Female	21 (52.5)		IV therapy	4 (10)
Underlying diseases	Gastrointestinal	15 (37.5)		Refractory seizure	5 (12.5)
	Cardiac	2 (5)		Antibiotic therapy IV	2 (5)
	Urogenital	2 (5)		Low weight	5 (12.5)
	Birth trauma	1 (2.5)		Prolonged admission	11 (27.5)
	Respiratory	8 (20)		Anticoagulant therapy IV	1 (2.5)
	Neurologic	4 (10)		Dehydration	1 (2.5)
	Infectious	2 (5)			
	Limb gangrene	1 (2.5)	Location of insertion	Right upper limb	15 (37.5)
	Metabolic	5 (12.5)		Left upper limb	10 (25)
Surgery	Yes	16 (40)		Right lower limb	2 (5)
	No	24 (60)		Left lower limb	5 (12.5)
				Temporal	8 (20)
Quantitative variables		Mean		Standard deviation	
Chronological age (weeks)		23.2		22	
Gestational age (weeks)		35.5		3.3	
Weight (g)		2522		665	

Table-2: Comparison of catheter placement for radiography and ECHO by type of variable and sensitivity, specificity, PPV and NPV positive of ECHO

Variable	No. of correct place radio.	No. of correct place ECHO	No. of incorrect place radio.	No. of incorrect place ECHO	Diagnostic accuracy (%)	Echocardiography			
						Sensitivity (%)	Specificity (%)	PPV	NPV
Male	11	11	8	8	100	100	100	100	100
Female	18	17	3	4	95.2	100	94.4	75.0	100
Preterm	14	13	7	8	95.2	100	92.9	87.5	100
Term	15	15	4	4	100	100	100	100	100
BW * <2500 g	14	14	3	3	100	100	100	100	100
BW >2500 g	15	14	8	9	95.6	100	93.3	88.9	100
Right upper limb	10	10	5	5	100	100	100	100	100
Left upper limb	8	8	1	1	100	100	100	100	100
Right lower limb	2	1	0	1	-	-	50	-	100
Left lower limb	6	5	0	1	-	-	50	-	100
Temporal	4	4	4	4	100	100	100	100	100

*Birth weight

This means that ECHO could detect malpositioned PICCs more accurately in the term infants. Regarding birth weight, the specificity, PPV, and diagnostic accuracy of ECHO were higher for neonates weighing <2500 g.

Our findings demonstrated that ECHO sensitivity and specificity were appropriate in the upper right and upper left sites, and all indices were estimated to be 100%. Unlike the upper site, it was impossible to calculate sensitivity in the lower right and left sites because there were none; thus, only the specificity was calculated. The specificity of the lower right and left sites was estimated at 50%. There were no differences between the results of ECHO and radiography of the head (temporal), upper right, and left sites. In the lower right side, ECHO accurately detected one malpositioned PICC, which was reported as correctly-placed by radiography. These findings show that the sensitivity and specificity of ECHO were acceptable for the head (temporal), and all the indices were estimated to be 100%.

4- DISCUSSION

The current study used ECHO and radiography to visualize the PICC tip. The sensitivity, specificity, PPV, and NPV for the ECHO were 100%, 96.5%, 91.6%, and 100%, respectively; and the diagnostic accuracy was 97.5%. The PICCs in 28 cases were determined to be correctly positioned by ECHO compared to 29 cases by radiography. One case that had a correct position based on radiology was detected as mispositioned by ECHO.

PICCs provide safe venous access with minimal manipulation and fewer complications than CVLs, providing long-term maintenance of the catheters. Despite these benefits, determining the tip position after the insertion of a PICC can be challenging (18). X-ray and fluoroscopy have been commonly applied for tip site detection. Chest x-rays (CXRs), as a post-operative method for tip confirmation,

have disadvantages, such as requiring both AP and lateral views; and they cannot provide a dynamic and comprehensive view (11). In this method, a neonate is exposed to radiation during radiography; in contrast, no radiation is involved in ECHO imaging. The radiograph indicates the catheter path well, but when determining the depth of the catheter tip, ECHO can be more accurate, especially when the catheter enters the heart cavity (13). It can be proposed that ECHO is a reliable alternative to radiography for catheter tip localization in infants where the end of the catheter is near or inside the heart cavity. This area has remained understudied to the best of our knowledge (19).

In this study, the diagnostic accuracy of ECHO was 97.5%. In a study by Ades et al. (20), the accuracy of AP CXR, lateral CXR, and oxygenation for the UVC position were compared to the results of ECHO using saline contrast injection. The sensitivity and specificity of ECHO in distinguishing between the placement of the left atrial and other catheters were reported to be 45% and 95%, respectively. In contrast, CXR detected an unsuitable UVC position in 32% and 89% of cases respectively) (20). In the current study, adequate sensitivity and specificity were only in the head (temporal) and the upper right and left sites with an estimated rate of 100% by ECHO compared to radiographs.

In one study, a 59% concordance between the ECHO and CXR has been reported, with 64% sensitivity and 55% specificity of CXRs for mispositioned tips after ECHO (3). Therefore, ECHO was introduced as a suitable method for tip detection and prevention of re-exposure to XRs and extra positioning (3). In another study for PICC site detection in 89 low-weight neonates, ECHO was compared to plain radiographs (4). Tip repositioning was performed in 25% of the XR cases after identification by ECHO, and ECHO coupled with XRs was recommended as the gold standard in PICC tip assessment (4). In the current study, ECHO detected PICC tip mispositioning with an 87.5% probability in neonates <37 weeks of gestational age. For LWNs, the highest sensitivity and specificity rates were detected by ECHO compared to radiography, which is consistent with the literature.

For UVC localization, Pulickal et al. (17-18) compared targeted neonatal echocardiography (Tn-ECHO) with AP CXRs (12, 19). They found that 27% of neonates required UVC replacement, and Tn-ECHO showed sub-optimal tip positioning regardless of an optimal location detected by CXR (12). It has been demonstrated that Tn-ECHO is superior to CXR for the detection of catheter mispositioning (12). Other studies also have revealed concordance between ECHO and CXRs for PICC-tip positioning in neonates, which ranged from 60% to 80% (21, 22). Tauzin et al. (4) found that ECHO was able to significantly detect the precise number of heart catheters (25%; $p<0.001$). Several targeted pediatric echocardiography training standards have been prepared based on US and European published guidelines (23). Targeted neonatal ECHO is gaining popularity and is more accessible as a bedside method, especially in Canadian NICUs (24, 25).

ECHO has also been proposed as an accurate method for detecting atrial thrombosis, a complication of PICCs. ECHO could detect PICC-induced thrombosis with partial dissection of the superior vena cava, confirming its accuracy for PICC tip-positioning and complications during placement (26). Up to now, all available protocols have focused only on radiography or other landmarks for CVC positioning in infants (11). In animal studies, intra-Cardiac Echocardiography imaging has been introduced to provide precise and

reproducible anatomical views which can reduce overall execution time, the labor burden of procedures, and the need for X-rays for several cardiac procedures (27, 28). The reviewed studies demonstrated several significant advantages of ECHO, which have mainly been neglected, including that ECHO does not need new expenses and can be easily performed by equipment already available in most operating rooms. Lacobone et al. (29) proposed that the localization of the tip location of CVCs and PICCs by transthoracic echocardiography is feasible, safe, and accurate through a bubble test in patients with atrial arrhythmia.

The results of the present study demonstrated that the specificity, PPV, and diagnostic accuracy of ECHO were higher for LBW neonates than for those with birthweights more than 2500 g. In line with this finding, Karber et al. (30) observed that echocardiography was effective in the assessment of the original placement or migration of the UVC tip in VLBW infants compared to radiography.

4-1. Strength and limitations of the study

One strength of the present study was using both 1 and 2 French silicone PICC catheters, which being small, are difficult to visualize. Most studies have evaluated Umbilical Artery Catheters (UAC) and UVCs, which are larger than PICC (31). In our study, no side effects were observed among the participating infants. However, this study was conducted on a single population in one center over a limited period. This can be considered a limitation of the study.

5- CONCLUSION

In conclusion, our findings demonstrated that in PICC tip placement, compared to radiography, ECHO seems to be a more accurate procedure that reduces radiation exposure. Therefore, ECHO can be a good alternative for CXRs, and x-rays can be reserved for suspected mispositioning cases. Although ECHO is more expensive and time-consuming than radiography, in cases where the catheter is close to the heart or has entered the heart cavity, ECHO can greatly assist in confirmation of accurate positioning and localization. Neonatology fellows and NICU residents can quickly learn the procedure which can be performed during PICC insertion and provide ongoing quality assurance. Multi-center studies with larger sample sizes should be designed and conducted to confirm the advantages of ECHO over radiography to confirm PICC tip positioning as a potential gold standard test.

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8- CONFLICTS OF INTEREST

None.

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