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# Determining the Position of Peripherally-inserted Central Catheter tips in Neonates: A Review of Common Methods during the Last Two Decades

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***Abstract***

***Background:*** Peripherally Inserted Central Catheters (PICCs) are used for providing intravenous therapy to premature neonates. There are different intra- or post-procedural techniques to confirm line-tip placement to decrease the potential complications. The present study provides a literature review of common methods developed for the detection of PICC tip positions over the last two decades.

***Methods:*** The literature search was conducted in various databases without language restrictions for all terms related to PICC and its tip position evaluation methods including plain radiographs, fluoroscopy, ultrasonographic detection, digital imaging, computed radiography, and intra-cavitary/trans-esophageal and thoracic electrocardiographic monitoring.

***Results:*** Among the primary 172 articles, 52 of them met the inclusion criteria and were included in the study. Comparing the methods, it was found that ultrasound should be a complement to, rather than a replacement for, x-rays for PICC placement and CTP confirmation. When the catheter tip is close to the heart, Tn-ECHO should be replaced with x-rays.

***Conclusion:*** Considering advantages and disadvantages of each method, the choice of the most appropriate method for examining the catheter tip depends on the patient's condition, available facilities, and the decision of the physician.

***Key Words:*** Echocardiography, Neonate, Peripherally-inserted central catheter, Radiography, Sonography, Tip position.

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## 1- INTRODUCTION

Regardless of age, central venous access is vital in monitoring and treating critically-ill patients by providing safe and permanent access to peripheral blood vessels (1-3). During the last two decades, Peripherally Inserted Central Catheters (PICCs) have been widely utilized, providing safe and long-term venous access without major manipulations (3, 4). PICCs are placed into a peripheral vein and then progressed to accommodate the catheter tip in the superior vena cava (5). This insertion method minimizes imminent complications compared to conventional tunneled catheters, such as Central Venous Catheters (CVCs) (6, 7). These devices eliminate problems associated with phlebotomy and multiple peripheral intravenous line changes; thus, they have become one of the most frequently used CVCs for non-ICU (Intensive Care Unit) patients (8, 9).

Catheter tip position is very important, but in some cases, the catheter tip should be placed in non-central vessels, such as the brachiocephalic, subclavian, jugular, axillary, or saphenous veins (10, 11). Malpositioned tips can lead to neonatal complications such as thrombosis at the insertion site, dysrhythmia, erosion through the cardiac chamber, and thrombus formation (12, 13). Several blind bedside procedures have been introduced for repositioning PICC lines, including abducting the arm, the high-flow flush technique, or repositioning the patient (14, 15). However, those blind bedside approaches can be unsuccessful and may need several radiograph imagings during repositioning (16).

Central catheters are currently inserted using sonography, and the position is confirmed by electrocardiography, Fluoroscopy (EKG), or Chest X-ray (CXR) (17). However, fluoroscopy is not always available, and intra-atrial ECG may be unreliable for the position confirmation of the left internal jugular CVCs (18). Consequently, these catheters are frequently mispositioned, and repositioning using post-procedural CXR is warranted (19), which extends the optimal nursing care time and increases exposure to radiation (20). Moreover, routine immediate post-procedural CXR may fail to predict potential complications, particularly late ones.

This essay aimed to review the literature on the subject of the utilization of various procedures such as fluoroscopy, CXR, ultrasound, and echocardiography for localization of the central catheters in the newborns in the Neonatal Intensive Care Units (NICUs) and their advantages and disadvantages are discussed.

## 2- MATERIALS AND METHODS

The literature was searched to find the studies published during the twenty-year period of 2000-2020 though the following databases: Cochrane Central Register of Controlled Trials, Web of Science, PubMed, Scopus, EMBASE, Index Copernicus, Thomson Reuters, African Index Medicus, Chemical Abstracts Service, Google Scholar, Scientific World Index, Latin American and Caribbean Health Sciences Information System, Index Medicus for the Eastern Mediterranean Region, Index Medicus for the South-East Asian Region, and Western Pacific Region Index Medicus.

The terms considered were “newborn”, “neonate”, “central catheters”, “umbilical venous catheter”, “umbilical catheter”, “PICC”, “peripherally inserted central catheter”, “fluoroscopy”, “ultrasonography”, “ultrasound”, “USG”, “point-of-care ultrasound”, “bedside ultrasound”, “echocardiography”, “ECHO”, “Tn-ECHO”, “targeted-neonatal echocardiography”, “chest x-ray”, “CXR”, and “radiography”.

Language restrictions were not applied and all trials, case reports, case series, and personal experiences were searched and their abstracts were reviewed. Studies reporting the same findings (duplicate results) and those that did not meet the inclusion criteria were excluded from the study. A total of 179 articles were collected in the initial search. By reviewing the abstracts, 76 articles were selected and their full versions were prepared. Among them, 52 articles met the inclusion criteria and were included in the study (**Fig. 1**).

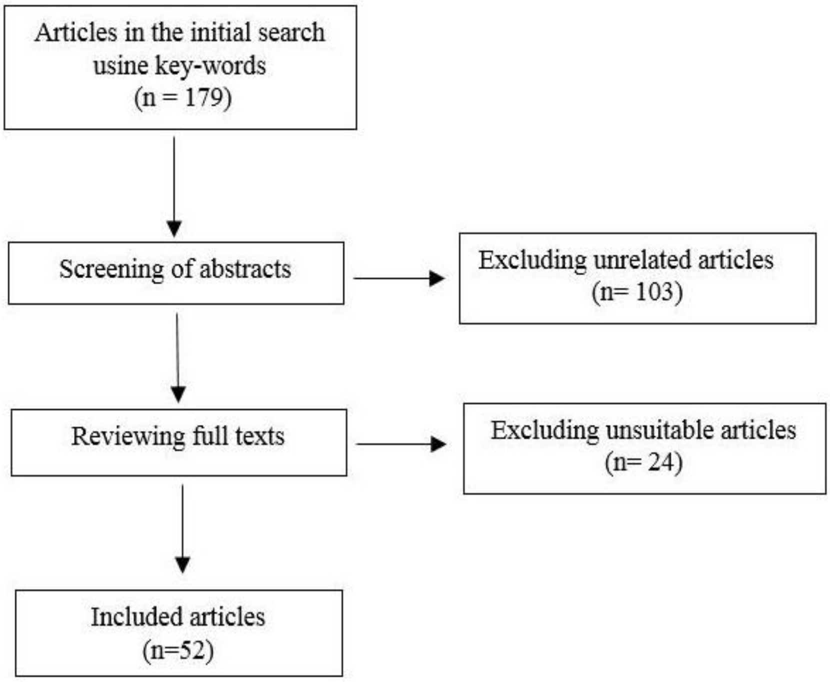


**Fig. 1:** Article selection flowchart

### 2-1. Fluoroscopy

Several Fluoroscopy-Guided Umbilical Vein Catheter Placement (FGUVCP) techniques have been developed by pediatric cardiologists during the past two decades (21). For patients with unsuccessful bedside UVC placement, FGUVCP is considered a relatively safe and straight-forward procedure that can be conducted in pediatric cardiac catheterization laboratories. Increased age during the procedure may be associated with failure, and approximately 9.4% of patients experience complications after the FGUVCP procedure. These complications include bradycardia, umbilical arterial catheter dislodgement during transportation or the procedure, and temporary heart rhythm abnormalities (22).

In a seven-year study by DeWitt et al. (21), FGUVCP was effective in 76.7% of cases. The patients with successful FGUVCP were younger during the procedure compared to the unsuccessful cases. The optimal cutoff age for a successful FGUVCP success was 20 h, with a low negative predictive value of 32.5% and a high positive predictive value of 82.4%. The median radiation time was 3.2 minutes, contrast exposure was 1 ml, and blood loss was 1 ml. FGUVCP led to ten complications in 10 patients. The median time of the procedure was 52 min when only FGUVCP was applied, and 78.4 min when it failed and a CVC was inserted at a different location. The contrast dose, fluoroscopy time, and blood loss decreased when only FGUVCP was conducted, but all were slightly increased in the failure of FGUVCP, and a central venous catheter was inserted at a different location (21).

## 2-2. Radiography

Chest or abdominal radiographs are taken following the insertion to confirm the suitability of the catheter position (20). Successful placement can usually be confirmed using frontal chest/abdominal bedside radiographs that visualize the tip of the catheter protruding above the right hemidiaphragm (in those with abdominal situs solitus) (21, 23). The radiograph sensitivity for detecting malpositioning is 64%, with a specificity of 55% (24). The plain radiographs' positive predictive value has been reported as 58% and the negative predictive value as 60% (24).

A study by Chang et al. (25) demonstrated that CXR could miss a delayed pneumothorax in approximately 0.5% (2 of 424) of cases with right internal jugular lines. They observed no evidence of pneumothorax in routine inspiratory and expiratory post-procedural CXR; and only a delayed CXR due to unusual symptoms detected the complication.

Chest radiography will remain the gold standard unless compelling evidence emerges, although radiation can harm infants (23). Radiation is documented to be associated with cardiac diseases manifested years after exposure with high rates of morbidity and mortality (26). Some catheter tips cannot be detected clearly on a standard postero-anterior CXR because of the sternum and thoracic vertebrae high density, which significantly attenuate x-rays even though the PICC is radiopaque (27).

Significant controversy exists over utilizing radiograph software for on-screen measurement, as the device may not be well-calibrated (24). Also, the arm must be immobilized in a particular position during the procedure to accurately locate the PICC tip, which may be challenging (28). This method can fail due to several factors, such as the measurement method used by technicians, alternations in the puncture point, medical personnel performance, as well as the posture, breathing, and movements of the patient's arms which will reduce the accuracy of PICC catheter tip localization (26, 29).

A chest X-ray is not possible in emergencies when critically ill neonates should not be moved (26). Furthermore, radiographic visualization of the position of PICC tip can demonstrate changes in the upper extremity position, leading to PICC migration in neonates (12, 13). In examining radiographs, it is vital to keep in mind that shoulder abduction and elbow flexion produce the most significant PICC tip movements toward the heart (30).

## 2-3. Intracavitary electrocardiogram

Intracavitary Electrocardiogram (IC-ECG) guidance can support proper tip insertion and provide immediate feedback about the Catheter Tip Position (CTP) during PICC placement. This can assist the operator during accurate tip positioning when precise localization with the US guide is impractical (16, 31). IC-ECG-guided PICC insertion and positioning of the tip could decrease reposition rates, lead to more accurate first-attempt tip positioning, and minimize catheter-associated complications in premature infants (31). It is documented that approximately 94% of IC-ECG–guided PICC catheterization in neonates leads to first-attempt correct tip positioning (32). Some authors have reported the accuracy of the PICC tip positioning of IC-ECG as 89.7% (29).

Considering the decreased costs and the procedure time of post-procedural CXR for PICC tip confirmation, IC-ECG guidance can significantly reduce the costs involved (33). By Zhou et al. (26), it was observed that IC-ECG-guided PICC insertion increased the success of correct PICC tip position in 200 premature infants (94%) in comparison with the conventional PICC insertion in 49 premature infants (63%).

The chest radiography and IC-ECG accuracy for confirmation of PICC or CVC tip placement is documented as 93.7% and 95.8%, respectively (34, 35). Although IC-ECG technique can reduce medical costs, decrease the rate of complications, and needs less repositioning, this new technique in infants remains to be confirmed by more studies (31).

Using an IC-ECG monitor has several limitations, the most important being functional errors or infant crying, which can lead to invisible P-waves during PICC insertion (31). Moreover, the PICC tip must be at the SVC/RA junction with suitable P-wave morphology during initial placement. After initial insertion, if the PICC is secured above the SVC/RA junction, there may not be morphological P-wave changes despite the return to the initial tip location (16).

Several factors can weaken the ECG signal transmission across a long-distance conductive path, including blood and saline, the connection situation, and the needle and connecting lines. Therefore, successful maintenance of a stable and legible ECG needs the preservation of unobstructed conduction (32). Eligible P-wave formation can be influenced by technical factors, including the position of the electrode, voltage choice, system monitoring, and interference generated by other electromedical devices (34, 36).

ECG-guided neonatal PICC tip insertion has certain limitations. Unstable baseline ECG records are common in neonates inflicted with congenital heart diseases, such as patent ductus arteriosus, ventricular and atrial septal defects. Relatively ineffective ECG is reported in patients with serious arrhythmias (including atrial fibrillation) or those with a pacemaker (36, 37).

### 2-4. Ultrasound

#### 2-4.1. Ultrasound during PICC insertion

In neonates, Real-Time Ultrasound (RT-US) for PICC placement can significantly assist in providing crucial physiological information in clinical decision-making (24, 38). The vessel can be evaluated for size, potency, and course by locating veins using US. This, in turn, can decrease the number of insertion attempts by providing a higher insertion site and decreasing the risk of insertion site PICC pistoning (39). In the pediatric wards, insertion difficulties sometimes occur, where obtaining vascular access by suitable vein visualization or palpation can be challenging. A combination of vascular US and vascular assessment during the procedure may enhance PICC insertion in pediatric patients (40, 41).

In one study, RT-US led to a decrease in the line placement time by 30 min (P ¼ 0.034) and reduced the median manipulations number (0 vs. 1, P ¼ 0.032) and radiographic imaging (1 vs. 2 P ¼ 0.001) needed for catheter insertion (20). The results of a study on neonates weighing <1500 g demonstrated that all PICC insertion attempts were successful, and no complications directly related to PICC insertion were detected (42). In PICC tip positioning, the application of RT-US reduced the number of radiographs required and the overall time needed for the procedure in different studies (20, 43). The number of more than one venipuncture to PICC placement was also reduced by 35%. Moreover, the unsuccessful attempts demonstrated a 64% reduction when the US was utilized (44). These findings indicated that US-guided PICC line insertion could be effectively utilized in infants with very low and extremely low birth weights with minimal risk of complication.

### 2-4.2. Ultrasound post-PICC insertion

Post-catheter insertion ultrasonography assessment is widely used to determine the depth of the catheter insertion points in the portal system and heart (45). For identifying the PICC tip position, ultrasonography sensitivity is 100%, specificity 89.5%, positive predictive value 97.3%, and negative predictive value 100% (45). One study observed that with the US, tip malposition detection rate was 82.1%, the rate of US-guided tip navigation success was 98.2%, and the US-guided tip location success rate was 98.0% (46). Ultrasound evaluation of the PICC tip position can be considered an accurate, rapid, and reliable method for identifying the catheter tip (47).

Between US and radiography for determining the CTP in the SVC and RA, a concordance of 75% to 93% has been reported, respectively (48). US is very helpful for confirmation of the line position, and this approach is more effective than plain radiography for determining the exact position of the PICC tip. Reportedly, ultrasound significantly decreased the thrombosis rate to 1.9% from 9.3% with palpation (39). Although the US is unpopular due to the costs involved and the need for training (24), it can significantly assist well-resourced NICUs. In some cases, ultrasound is limited with false negatives and missed surveillance outcomes, particularly in patients with minor extension into the jugular vein and curling in the subclavian toward the insertion site. In an incomplete assessment, these cases could be missed. Therefore, meticulous US surveillance extending to the thoracic inlet level is critical to rule out catheter tip mispositioning. However, in thin, obese, or arthrogryposis cases, visualization of the area can be challenging (46). **Table 1** tabulates some studies on ultrasound-assisted PICC tip positioning.

### 2-5. Echocardiography

Targeted neonatal echocardiography (Tn-ECHO) can provide reliable PICC line tip positioning, particularly in preterm patients. In neonates, between echocardiography and radiography for visualizing the position of PICC tip, the concordance rate ranges from 60% to 80% (28, 48). Tauzin et al. (28) have highlighted the importance of echocardiography for detection of the PICC tip position in low birth weight (LBW) infants. They observed numerous cases of PICC visualization in the heart by echocardiography with an adducted shoulder and flexed elbow. In their study, approximately 25% of the total PICCs identified as normal on plain radiographs were in the heart.

A single static image cannot visualize alterations in the location to determine the tip position. The Tn-ECHO can provide real-time data about the PICC tip position and the position range changes due to limb movement (24). By applying the Tn-ECHO, withdrawal of the line or real-time manipulation against an identified landmark (i.e., SVC/RA junction) is possible with no measurement and minimal risk of error. Tn-ECHO can almost instantaneously confirm the manipulation outcomes. This can minimize the waiting time for a subsequent radiograph and the time under sterile drapes and the possibility of line sepsis, temperature fall, and dislodgement (24).

Dissimilar to radiography, echocardiography can provide real-time PICC tip positioning information, which assists in the precise catheter tip visualization in the US image and limb movement-caused range of position changes.

**Table-1:** Evaluation of PICC tip placement using ultrasonography

| | | | | | | |
|---|---|---|---|---|---|---|
| Conclusion | US is an accurate, almost safe bedside tool with few complications for PICC [c] tip placement determination in neonates. | Bedside US is an accurate and time-efficient modality for confirming the tip of the PICC line. | US is a rapid, precise, and reliable approach and can visualize the catheter tip with high accuracy. | US is a safe and reliable bedside technique for determining the tip of PICC lines. | Point of care application of the US strongly agrees with radiography for confirming central line tip position. | Bedside US accurately shows the position of the catheter tip with high sensitivity and specificity which has high value for clinical promotion. |
| Accuracy (%) | 100 | 100 | 100 | 94 | 95 | 97.1 |
| US technique | Not specified | For subcostal sagittal view to identify the inferior vena cava, saline contrast was used | Inferior costal scanning, Saline contrast used | Line position in vena cava view confirmed, in other views, saline contrast was used | Measurement of the point of insertion to the suprasternal notch to right third intercostal space to level of xiphisternum | Measuring the distance of the tip and the entrance of the RA of the vena cava, intercostal and xiphoid |
| Probe | Not specified | S 12-4 frequency footprint | ML6–15 MHz [b] | 5-12 MHz | 8-4 MHz | L12-4s, L14-6Ns, 6.6-13MHz |
| US [a] operator | Radiologist Pediatric cardiologist | Not specified | Not specified | Radiologist | Neonatologist, trained in ultrasound | Not specified |
| n | 90 | 33 | 186 | 31 | 141 | 52 |
| Population | Neonates | Neonates | Neonates 1-58 day | Neonates | Infants | Preterm infants GA: 28-32 weeks |
| Authors | Kadivar et al. (45) | Singh et al. (55) | Ren et al. (47) | Telang et al. (56) | Thakur et al. (57) | Jiao et al. (58) |

a: ultrasound, b: megahertz, c: peripherally inserted central catheter

The significant movement of a PICC tip towards the heart is due to shoulder abduction and elbow flexion. Echocardiography can provide real-time information which can help explain the high proportion of PICC tips detected in the heart (28). With the application of Tn-ECHO for assessing the tip position and assisting line manipulation, the risk of PICC-associated complications can be reduced through accurate tip placement confirmation.

Another potential advantage of Tn-ECHO is continuous monitoring of catheter tip position in newborns needing PICCs for a long time. This approach can reduce exposure to radiation by eliminating the need for subsequent radiographs and facilitating the detection of potential asymptomatic complications such as thrombus formation and pericardial effusion (24). However, equipping NICUs with Tn-ECHO needs cost-benefit assessment, training staff, and continual quality assurance for updating skills. **Table 2** lists a few studies on PICC tip positioning through echocardiography.

**Table 2.** Evaluation of PICC tip placement using echocardiography

| | | |
|---|---|---|
| Conclusion | ECHO is a useful approach for the identification of the tip position with real-time manipulation, and can reduce exposure to further radiographs. | ECHO and the initial radiographs should be considered the gold standard for evaluating PICC tip positioning. |
| Accuracy (%) | 100 | 100 |
| US technique | Subcostal, apical, and long parasternal RA and SVC views | Apical, subcostal, parasternal LAX, high parasternal, and abdominal parasternal views |
| Probe | 10-Hz multi-frequency probe | 12 MHz |
| ECHO operator | sonographer trained in ECHO | US specialist |
| n | 22 | 109 |
| Population | preterm neonates<br>BW<2000 g<br>GA < 29 weeks | Preterm neonates<br>BW<1800 g<br>GA: 27-33 weeks |
| Authors | Jain et al. (24)] | Tauzin et al. (28) |

## 3- RESULTS AND DISCUSSION

For long-term vascular access, instead of peripheral blood vessel catheters, peripherally inserted central catheters are widely used in NICUs for the provision of electrolytes and fluids, parenteral nutrition, and the administration of precise doses of medications (43, 49). Malpositioned PICCs can lead to life-threatening complications, including systemic and pulmonary embolisms, catheter-related septicemia, thrombosis, hemorrhage, arrhythmia, and pleural and pericardial space effusion (50). Properly positioned catheters can effectively reduce complications. Fluoroscopy-guided umbilical vein catheter placement, a relatively safe and uncomplicated procedure, has a favorable success rate and a low negative predictive value but is limited by long radiation and procedure times (51).

After PICC insertion, standard x-rays are routinely performed and are considered standard procedures to confirm proper catheter tip placement. However, they are considered unreliable for determining the precise tip position. Several studies have suggested that safer methods in neonates need to be regarded as the gold standard for confirming correct CTP (43). Radiation exposure is associated with several complications, potentially harmful for neonates, and may not be available at the bedside (26). The IC-ECG, especially for catheters with tips close to or inside the heart cavity, provides immediate feedback on the CTP and has a better tip detection accuracy than the x-ray. Although this approach is less costly and has fewer complications, the need for repositioning and possible complications on the patient’s heart health can decrease the method’s accuracy.

Ultrasonography has good sensitivity and specificity and is a good alternative to x-rays to detect CTP. The device is usually available at the bedside and has relatively few complications, but not all NCUs are equipped with it (52).

It can be asserted that TnECHO is the most reliable method for catheter position detection, particularly for preterm and LBW neonates. This technique is the best alternative for determining CTPs near or inside the heart cavity. It offers real-time information on PICC tip positioning, minimizes radiation exposure, and its application only requires a short time. Therefore, Tn-ECHO can be considered the superior method under the mentioned conditions (53).

It should be noted, however, that there are other accurate devices for the localization of PICC tips, including the Sherlock tip location system and the electromagnetic detection system. However, these individualized approaches are costly, and their operators require specialized training, particularly for neonatologists (27, 54).

## 4- CONCLUSION

The latest literature indicates that ultrasonography should complement the x-ray rather than replace it for PICC implantation and CTP confirmation. When the catheter tip is near the heart, x-rays should be used instead of Tn-ECHO. The optimal procedure for inspecting the catheter tip depends on the patient's condition, available facilities, and the physician's judgment.

## 5- CONFLICT OF INTEREST

None.


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