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Effectiveness of Intracavitary Electrocardiogram Guidance in Peripherally Inserted Central Catheter Tip Placement in Neonates

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ABSTRACT

Correct tip location is crucial for a peripherally inserted central catheter (PICC) to maximize the effects of central venous infusion. However, it is difficult to place the tip in a correct location in neonates because of the unreliable estimated length by surface landmark. Therefore, we evaluated the feasibility and safety of an improved intracavitary electrocardiogram (IC-ECG) technique in guiding PICC placement in neonates based on the ratios of P/R wave amplitudes on IC-ECG. The results showed that all of the 32 neonates whose PICCs had been successfully placed and correct tip position verified by chest radiography acquired qualified P wave on IC-ECG. The average ratio of P/R wave amplitude was 0.6 ± 0.1, with a range of 0.4 to 0.8. The 49 neonates who received IC-ECG–guided PICC catheterization showed higher success rates of correct PICC tip position on the first attempt than traditional, predetermined length estimation on surface landmark (93.9% vs 62.5%, $\chi^2 = 18.01$, $P < .001$). No significant complications occurred in the studied neonates. Based on these findings, IC-ECG–guided tip placement appears to be a promising approach in improving the success rate of tip location when placing a PICC in neonates.

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Peripherally inserted central catheterization is a commonly used technique for intravascular access in critically ill patients. Correct tip location is crucial to maximize the effects of central venous infusion. Moreover, incorrect tip placement is associated with risks of complications including venous thrombosis, heart cavity lesions, and arrhythmia.[1–4] Catheter tip is defined as central when located in the cavoatrial junction (CAJ) or lower third of the superior vena cava (SVC) or upper part of the right atrium (RA).[2] Chest radiography has been regarded as a practical standard for the verification of correct tip location after catheterization.[5] However, tip location might be affected by a lot of factors, such as posture of the patient, breathing, and movements of arms. Venkatesan et al[6] reported that the percentage of peripherally inserted central catheter (PICC) tip residing in the lower SVC and close to the CAJ simultaneously is 14.85%. In neonates, it is more difficult to place the tip in a correct location because of the unreliable estimated length from the puncture site to the CAJ[2]; therefore, reposition and more radiation exposure may occur in PICC placement for neonates.

Recently, intracavitory electrocardiogram (IC-ECG) has been developed for real-time monitoring and verification of PICC tip placement.[7,8] It is particularly applicable for neonates. However, few studies regarding PICC placement in neonates using IC-ECG technique have been reported. Herein, we assessed the accuracy and feasibility of IC-ECG technique for guiding PICC placement in neonates.

MATERIALS AND METHODS

This study was approved by the hospital's Medical Ethics Committee (code no. 2015-IRB-076), and parents or guardians of all enrolled patients provided written informed consents.

Study design and patients recruited

There are 3 periods in our study. In the first period, we retrospectively analyzed the data of PICC placement during January 2014 to July 2015. During that time, traditional catheterization method based on estimating the length of the catheter by surface landmark was adopted. In the second and the third periods, the study was conducted prospectively. During the second period, IC-ECG was used as an adjunct for guiding PICC insertion in the enrolled neonates and tip position was verified by chest radiography. The IC-ECG chart was documented, and the ratio of the amplitudes of P/R waves measured. During the third period, IC-ECG–guided PICC tip placement was used in the enrolled neonates, based on the experience of the second period; clinical feasibility and accuracy of IC-ECG for PICCs were evaluated in these patients.

Patients with the following conditions were excluded during the second and third periods: (1) those with abnormal prior ECG; (2) those with known severe and complex congenital heart diseases, coagulation disorders, and neck and chest deformity; (3) those currently using a cardiac pacemaker or Holter device; and (4) those with illegible or unclear ECG display at pre-PICC monitoring.

Traditional PICC methods during the first period

Two qualified professional nurses implemented PICC insertion using a Medcomp 1.9-F PICC at the bedside. Peripheral veins were selected, and the expected length was estimated on the basis of surface landmark. Neonates were kept in a supine body position and received venipuncture and catheterization until the expected length was reached. Then, the catheter was flushed and locked with normal saline and 5 U/mL of dilute solution of heparin sodium routinely. The whole procedure of PICC placement was monitored using a bedside ECG monitor (PM-8000, Mindray China). A postprocedural chest x-ray examination was performed, and the correct position of the PICC tip was verified by 2 radiologists together. Tip location was defined as central when present on T5 and T6 of thoracic vertebral bodies.[2]

To maintain the stability of PICC tip location, the body position should be kept the same during catheterization or chest x-ray examination. The neonates should lie in a supine position and after the PICC passes through the upper limb vein, the upper arms and torso should be maintained at a 45° angle, that is, the natural flexed position.

Inducement of IC-ECG

After verification of correct tip location of the PICC, IC-ECG was induced. After ethanol disinfection and volatilization, 3 electrode pads were affixed to body surface areas below the left subclavian, right subclavian, and lower left abdomen, respectively. A surface lead-II ECG was arranged with an output speed equal to 25 mm/s and also 10 mm/mV and then the surface ECG records were printed out.

IC-ECG–related products include catheter heparin cap, scalp needle, and ECG electrode lead clip (see Figure 1). The catheter heparin cap was disinfected, and a scalp needle (size 7) was inserted, leaving half outside the heparin cap. Adequate amount of normal saline by a 10-mL syringe was injected through the scalp needle to rinse the heparin cap and catheter, making the catheter fully loaded with normal saline. Take down the electrode labeling with R logo posted in the right subclavian (the clip type), make a local disinfection with alcohol swabs, and then connect it to the remaining external half of the scalp needle (see the Figure). Then, the catheter was bolus injected using the syringe preloaded with normal saline to verify the patency of the PICC. After the catheter was judged as unobstructed, a lead-II IC-ECG was induced. The ratio of the amplitudes of P/R waves was measured. Qualified ECG was defined when present with stable baseline, clear, and easy-to-identify

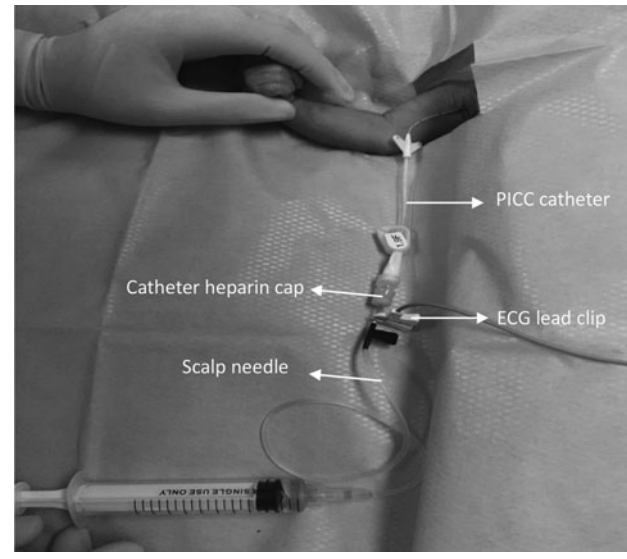

Figure 1. Induction of intracavitary electrocardiogram in a PICC. PICC indicates peripherally inserted central catheter.

P wave and QRS wave form. The stability of ECG was evaluated by professionals from the ECG department.

IC-ECG–guided PICC tip placement

IC-ECG was induced when PICC tip reached the point 1 cm away from the target point based on the expected length. By using a continuous ECG monitor, the insertion depth was regulated until the target P/R wave ratio appeared. In brief, the P wave became higher when the catheter proceeds into the SVC and reached its peak at the CAJ. Deeper on, a significant reduction in P wave will appear. Then the catheter was pulled back until the ratio of the amplitudes of P/R waves was within the range determined earlier. Finally, the catheter was fastened and a postprocedural chest radiograph was obtained.

If the ECG did not appear or its wave shape was disordered during the process, the catheter was pulled back 3 to 4 cm and reinserted to observe ECG changes again.

Statistical analysis

All data analyses were performed in the SPSS Windows, version 20 (IBM, Chicago, Illinois). Quantitative variables were expressed by mean ± standard deviation, whereas qualitative variables were described in terms of percentages. The χ^2 test was used to test for qualitative variables. A P value of less than .05 was considered as statistically significant.

RESULTS

Success rate on first attempt by traditional catheterization based on surface landmark

Between January 2014 and July 2015, PICCs were placed in 200 neonates by traditional catheterization based on surface landmark. General characteristics of the enrolled patients are shown in Table 1. The most commonly punctured vein was the right axillary vein ($n = 49$), followed by the right basilic vein ($n = 39$), left axillary vein ($n = 38$), left basilic vein ($n = 24$), right superficial temporal vein ($n = 14$), left superficial temporal vein ($n = 11$), and others.

The success rate on first attempt was 62.5% (125/200). PICCs were replaced in 75 neonates, and 49 of them had a PICC tip in the RA and required a pullback. One neonate showed a tip location at T4 of the thoracic vertebral body on a postprocedural chest radiograph. Tachypnea appeared and Spo_2 declined 3 days later. The chest radiograph found PICC tip in the subclavian vein complicated by pleural effusion. The PICC was drawn 6 days later, and pleural effusion disappeared. No arrhythmia, thrombosis, or pericardial effusion occurred.

Inducement of IC-ECG and measurement of P/R wave amplitude ratio

Between August and October 2015, we used IC-ECG in 32 neonates for guidance of PICC placement; all were successfully placed, and tip locations were verified by chest radiographs. Patient data are summarized in the Table. The most commonly punctured vein was the left axillary vein ($n = 13$), followed by the right axillary vein ($n = 6$), right superficial temporal vein ($n = 5$), left basilic vein ($n = 4$), right basilic vein ($n = 2$), and others.

All of the 32 neonates showed identified P wave on IC-ECG. The average ratio of P/R wave was 0.6 ± 0.1, with a range of 0.4 to 0.8.

Success rate on first attempt by an improved catheterization technique based on IC-ECG

Between November 2015 and February 2016, a total of 49 neonates were enrolled to perform IC-ECG–guided PICC catheterization. Patient data are summarized in the Table. The most commonly punctured vein was the right axillary vein ($n = 18$), followed by the left axillary vein ($n = 15$), right superficial temporal vein ($n = 7$), right basilic vein ($n = 5$), and others.

The success rate on first attempt was 93.9% (46/49). PICC tips in 3 neonates were found to be in the incorrect

Table 1. **General information of enrolled neonates and success rate of PICC placement on the first attempt**

	Traditional PICC	Induction of IC-ECG	IC-ECG–guided PICC
Case number	200	32	49
Sex (male/female)	101/99	23/9	32/17
Gestational age, mean ± SD (range), wk	36 ± 3 (28-41)	34 ± 3 (27-40)	35 ± 4 (28-41)
Postnatal age, mean ± SD (range), d	13 ± 12 (1-28)	13 ± 9 (1-28)	17 ± 16 (1-28)
Weight, mean ± SD (range), kg	2.7 ± 0.9 (1-5)	2.3 ± 0.7 (0.9-4.3)	2.7 ± 0.9 (1.1-4.9)
Success on first attempt	125/200 (62.5%)		46/49 (93.9%)

Abbreviations: IC-ECG, intracavitary electrocardiogram; PICC, peripherally inserted central catheter.

location on postprocedural chest x-ray verification. One was at T2 level, which was thought to be too high, but on ultrasonographic examination, the tip was found in the correct location (within the lower third of the SVC). Chest x-ray reevaluation showed that the arms of this neonate were raised above the shoulders, which may be related to the incorrect tip position. The tip locations in other 2 neonates were at T8 level, which was thought to be too low. On ultrasonographic examination, the tip was found within the RA. After pulling back 0.5 cm and fixation, correct tip location was verified by chest radiography and ultrasonography. No side effects or complications associated with IC-ECG occurred. None of these case patients died because of catheter complications.

Statistical analysis showed a significant difference in the success rate on first attempt between a traditional PICC technique based on length estimation and IC-ECG–guided PICC tip placement (62.5% vs 93.9%, $\chi^2 = 18.01$, $P < .001$).

DISCUSSION

PICCs have been widely used in the neonatal intensive care units. In 2015, the National Association of Neonatal Nurses (NANN) issued the latest guideline for practice of PICCs. The approach we followed was mainly consistent with recommendations by NANN. However, the most commonly punctured veins in this study were axillary veins, which is different from NANN's recommendation. Our hospital is a tertiary hospital, and most of hospitalized patients in our ward were transferred from the local hospital. Therefore, the recommended veins for PICC, such as basilica veins and cephalic veins, were usually acupunctured and damaged. Axillary veins have large size and short distance to the SVC, which makes it easy to cannulate and thread, but they are very close to the axillary artery. Therefore, clear visualization and clear identification to avoid the risk of arterial cannulation are the guarantee of success. Of course, application of ultrasound technique is sure to help increase success rate and reduce complications. We now perform axillary vein cannulation under ultrasound guidance. Scalp veins (mainly right superficial temporal veins) were also commonly used for cannulation in this study. They are easily visualized, easily fixed, and easily observed after catheterization. But resistance to threading can occur where the catheter traverses the area in front of the ear and where it enters the subclavian vein, thus reducing the success rate of PICC placement.

Appropriate tip location is crucial for successful application of PICCs. The traditional method is based on predicted surface length measurement and postprocedural chest x-ray verification. Therefore, it is very important to accurately measure the length of PICC catheterization. However, surface landmark used for estimating the length from the puncture site to the CAJ is less reliable, especially in neonates,[2] which have a certain impact on the correct location of neonatal PICC tip placement.

X-ray examination is the practical standard to verify the PICC tip location, but it is usually used for final determination after PICC procedure.[9,10] However, there are some disadvantages. In addition to radiation exposure, chest radiographs cannot be used to visually adjust catheter tip during the insertion; replacement is required in some neonates, which may cause complications. It is also not applicable during emergency when critically ill neonates are not convenient to be moved and x-ray examination is not available at bedside. Furthermore, it required radiologists to check chest radiographs for correcting the tip location.

According to the latest 2015 NANN guideline, the position of the SVC is described as T3-T5 level and the lower one-half to one-third of the SVC is recommended as the ideal tip location for upper-body insertions. But it varies depending on radiographic technique and infant anatomy. Our study found, by IC-ECG, that T5-T6 on a chest radiograph was corresponding to the lower one-third of the SVC near the CAJ site in neonates. This result is consistent with results of the Rossetti et al[2] study.

On the basis of real-time monitoring and verification, IC-ECG technique showed promising future in guiding tip position of PICCs. In our study, all of the 32 neonates whose PICCs had been successfully placed and correct tip location had been verified by chest radiography acquired stable and legible ECG and P wave on IC-ECG. The average ratio of P/R wave was 0.6 ± 0.1, with a range of 0.4 to 0.8. We applied IC-ECG–guided PICC catheterization with the target point of P/R wave from 0.4 to 0.8 in 49 neonates. The results showed that 93.9% of IC-ECG–guided PICC catheterization in neonates lead to correct tip location in the first attempt, similar to other reports.[8,9,11] It is much higher than that with traditional, predetermined length estimation on surface landmark (62.50%, $\chi^2 = 18.01$, $P < .001$). Thereby, ectopic PICC tips were reduced with potential benefits of reducing infections due to multiple repositioning of the catheters.

There are several practical challenges we faced in the clinical practice of ECG-guided neonatal PICC tip placement. First, IC-ECG stability should be improved during PICC insertion. Owing to the smaller diameter of the catheter used for neonates, it might not be easy to induce a legible ECG.[2] Furthermore, PICC tip placement with the use of ECG in adults was guided with a guide wire, but in neonates, 1.9-F PICCs were used with normal saline for conduction. Although a continuous, stable, and clear ECG could be induced because of the conductivity of saline and scalp needle theoretically,

the ECG signal transmission may be weakened to some degree because of long distance conductive path, multiple mediums including blood, saline, needle, and connecting lines, and the connecting status as well. Hence, the key to successful inducement of stable and legible ECG is to maintain unobstructed conduction. It is very necessary to calm down neonates and abate any interference in the insertion process.[10] A recent Italian multicenter study involving 309 children aged 1 month to 18 years showed that the increase of the P wave on IC-ECG is detected in all except 2 cases.[2] In our study, 32 neonates whose PICCs had been successfully placed and correct tip position been verified by chest radiography were enrolled; the percentage of successfully inducing stable IC-ECG was 100%. The normal saline-mediated conduction is more economic and safer than that with a metallic guide inserted inside the catheter.

Second, there is no widespread agreement on the optimal tip location of PICCs. Tip position is defined to be central at the CAJ or in lower third of the SVC or in the upper part of the RA.[2] Many clinicians agree that the optimal location for a PICC is the CAJ. However, reports from the United States recommended the lower third of SVC as the correct location[12] whereas European guideline recommended the upper part of the RA as the correct location.[13] More importantly, the choice of the tip location greatly depends on the clinical need. For dialysis or hemodynamic monitoring, the RA is preferred whereas for long-term fluid therapy, the SVC is preferred.[2,5] In our study, all of the enrolled neonates had the indications of PICC for long-term parental fluid therapy. Therefore, we regarded the lower third of the SVC and CAJ as the optimal location.

Finally, inducement of eligible P wave might be affected by several technical factors, including electrode position, the choice of voltage and the monitoring system, and interference from other electromedical devices.[2,5] On IC-ECG, the P wave will become higher when the catheter proceeds into the SVC and reaches its peak at the CAJ. Deeper on, a significant reduction of P wave will appear, followed by a small negative component of P wave, and even diphasic P wave.[2] At this time, the catheter should be pulled back until a significant P wave appears again to avoid termination of the PICC in the RA. There exists a great discrepancy in the amplitude of P wave at the maximal position.[10] Here, we explored the ratio of P/R waves as a target point for IC-ECG–guided PICC catheterization. It was successfully applied in 49 neonates with the target point of P/R wave from 0.4 to 0.8, producing as high as 93.9% of the success rate on first attempt. In addition, we did not find any interference from other electromedical devices commonly used in the intensive care unit, such as incubator, monitors, and infusion pump.

It is also worth mentioning that the body posture, especially the position of arms, has a great effect on the tip position of a PICC. The neonates should lie in a supine position and be kept at the natural flexed position (the upper arms and torso at a 45° angle). In our study, one neonate receiving IC-ECG–guided catheterization was found to have a tip location at T2 level, but on ultrasonographic examination, the tip was found in the correct place. Chest radiographs reevaluation showed that the arms of this neonate were raised above the shoulders, which may be related to the incorrect tip location. Therefore, the posture should be kept the same during catheterization or evaluation by chest x-ray examination, IC-ECG, and ultrasonography. It is also important to keep the same position during the whole process of fluid infusion. Even so, a PICC might travel despite good placement and securing because of a lot of factors such as body posture change and growth of body. Therefore, intermittent or continuous PICC monitoring is necessary and IC-ECG technique must have more advantages over repeated x-ray examinations in such situations.

There are some limitations for ECG-guided neonatal PICC tip placement. In some neonates with congenital heart diseases, such as patent ductus arteriosus, atrial septal defect, or ventricular septal defect, their ECG records at baseline were not stable enough. Those with severe arrhythmias, such as atrial fibrillation or the presence of a pacemaker, usually have a relatively ineffective ECG.[5,10] Therefore, it is necessary to have a careful review of clinical history, especially cardiac history before catheterization. It should also be noted that most infants in our study were in late-preterm or term range and weighed more than 0.9 kg. More experience in very low-birth-weight infants is to be accumulated in the future.

In addition to IC-ECG, ultrasonography as an alternative method in assessing PICC tip placement had been reported to improve the success rate and reduces complications since 1987.[14–16] But this technique needs more skills and is more expensive, while IC-ECG–related products such as catheter heparin cap and scalp needle are very easily available on the market and also very cheap (totally about 3 yuan). There are no studies comparing the efficacy of IC-ECG and ultrasonography on the tip location of a neonatal PICC until now. We are now applying ultrasonographic technique in neonatal PICC tip guidance. Further large, multicenter, prospective, and comparative studies are needed.

In conclusion, our study shows that IC-ECG using the column of saline technique can be induced during neonatal PICC placement and IC-ECG–guided tip position can be successfully applied to neonates, avoiding the risks, delays, and costs of PICC tip replacement.

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