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An accuracy study of the Intracavitary Electrocardiogram (IC-ECG) guided peripherally inserted central catheter tip placement among neonates

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Abstract: Objective: To explore the clinical application of the intracavitary electrocardiogram (IC-ECG) guided Peripherally Inserted Central Catheter (PICC) tip placement among neonates.

Background: the ECGs of neonates are difficult to perform and their wave shapes are of doubtful accuracy due to various interfering factors

Method: 115 neonates were admitted to perform PICC guided by IC-ECG. Logistic regression was performed to analyze all possible influencing factors of the accuracy from the tip placement. The puncture site of the PICC, gestational age, height, weight, basal P/R amplitude and positioning P/R amplitude might be related to the accuracy of IC-ECG location.

Result: The accuracy in the lower extremity was higher than that in the upper extremity. Multivariate logistic regression analysis showed that the weight (Odds Ratio (OR)=1.93, 95%Confidence Interval(CI):1.06–3.50) and positioning P/R amplitude (OR=32.33, 95%CI: 2.02–517.41) are statistically significant risks to the accuracy PICC tip placement.

Conclusions Possible methods to improve the accuracy might be Catheterizing through lower extremity, keeping the neonates calm, enhancing the electrocardiogram signal and strengthening technical training. Therefore

it is practical to perform a tip placement by the dynamic change in the P waves from an electrocardiogram (ECG) guided PICC among neonates and as reliable as using X-rays.

Keywords: Peripherally Inserted Central Catheter; Electrocardiogram; Accuracy; Neonates

1 Introduction

The peripherally inserted central catheter (PICC) is a common infusion device in clinical settings that provides an ideal vein tunnel for successful treatment in critical neonates. The placement of the PICC tip plays a vital role in the effectiveness of the PICC [1]. A substantial body of research has demonstrated that locating the tip placement by the dynamic change in the P wave from an electrocardiogram (ECG) is as reliable as using X-rays [2, 3]. Studies in China have successfully used ECGs to locate the PICC tip placement in an upper extremity [4-6], but study of the intracavitary electrocardiogram (IC-ECG)-guided lower extremities is lacking. Study is underway to develop such an application, motivated by the fact that the ECGs of neonates are difficult to perform and their wave shapes are of doubtful accuracy due to various interfering factors [7, 8]. To further explore the application of the IC-ECG-guided PICC tip placement among neonates, In present study we designed to analyze the accuracy of the IC-ECG from the 115 neonates.

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2 Material and methods

2.1 Neonate inclusion and exclusion criteria

Inclusion criteria: 115 neonates admitted to the Children's Hospital affiliated to the School of Medicine, from January 2015 to July 2016 who underwent PICC placement, of which 79 were upper extremity cases and 36 lower extremity cases. Exclusion criteria: obviously abnormal body surface ECG, known severe and complex congenital heart disease, coagulation dysfunction, neck and shoulder thoracic deformity, wearing of a heart pacemaker, wearing of dynamic ECG inspection equipment, unclear basal ECG obtained during monitoring. This study was approved by the ethics committee of the hospital; all guardians or parents were told of the study objective and signed an informed consent form.

2.2 Catheterization preparation

Two nurses, both qualified to implement PICCs, inserted the catheters (Medcomp 1.9F PICC catheters) at the bedside, applying a blinding puncture, without the use of a routine guide wire.

2.3 Catheterization procedure

The neonate subjects were kept in a supine body position and their PICC placement procedures were monitored using a three-lead monitoring system (PM-8000, Mindray, China). 30 minutes before catheterization, Luminal IV bolus 5mg/kg was administered to keep the neonates calm. Then, for each subject, the vein puncture site was cleaned with pieces of cotton dampened with 75% ethanol, and after the ethanol had volatilized, three electrode pads were affixed to body surface areas below the left subclavian, the right subclavian and the lower left abdomen, respectively. A surface lead-II ECG was recorded with an output speed equal to 25mm/s and a sensitivity of 10mm/mV. Next, the surface ECG records were printed out for comparison. After successful routine puncture, 10ml 0.9% NaCl (normal saline, NS) was used to disinfect the catheter heparin cap. An adequate amount of saline via a 10-ml syringe was used to pre-rinse a scalp needle (size 7), and then half the length of the scalp needle was inserted through the heparin cap. An electrode labeled with the R logo (clip type) formerly placed in the right subclavian and topically sterilized with alcohol swabs, then was con-

nected to the remaining half of the scalp needle. A syringe pre-loaded with 10ml NS was used to draw blood from the subject, and NS was then used to pulse-wash the catheter. After the catheter was judged to be unobstructed, a lead-II IC-ECG was recorded, observing the amplitude changes of the P wave and QRS wave group. Then, the catheter was gradually retracted until the maximum P wave occurred in the veins of the upper limb. Next, when the P wave's amplitude was approximately 50% to 60% of the R wave's, the catheter was fastened and an ECG was recorded and printed out. The catheter was again fastened when the P wave's amplitude matched that of the R-wave's in the veins of the upper limb.

If the ECG failed to appear or its wave shape exhibited disorder during the process, the catheter was withdrawn and the process to observe the changes in the ECG was repeated. Neonates who cried heavily were calmed again when necessary. After the insertion was complete, the catheter was washed and sealed with NS and a 5 U/ml dilute solution of heparin sodium in a routine manner, and an X-ray examination was also performed.

2.4 Standard of optimal tip placement

For an ECG to be judged as stable during the PICC placement, the baseline of the ECG must be constant, the waveforms of the P wave and QRS wave must be clear and easy to identify, and the P wave must have measurable amplitude. The stability of the ECGs was evaluated by a physician of the ECG Department. According to the 2016 guidelines of the American Infusion Nurses Society [9], if the veins of the catheter tip in the upper limb are placed at the junction of the lower portion of the superior vena cava (SVC) and the right atrium, the tip is regarded as optimally settled. However, if the catheters tip is located elsewhere, outside the SVC, it is defined as ectopic. If the veins of the catheter tip in the lower limb are located in or above the flat diaphragm of the inferior vena cava [10], which cannot access the atrium, this is optimal for the requirements of the central vein following the X-ray procedure; any other placement should be relocated.

2.5 Statistical analysis

All of the data analysis was performed using SPSS20.0. The *t*-test and chi-square test were used for univariate analysis appropriately, and logistic regression was used for multivariate analysis. Two sides of $P < 0.05$ was selected as the significance level.

3 Results

3.1 Subject main characteristics

A total of 115 subjects met the inclusion and exclusion criteria, including 64 males (55.7%) and 51 females (44.3%). Among them, 79 were catheterized through veins of an upper extremity and 36 through veins of a lower extremity. 41 neonates were injected with 5mg/kg Luminal to maintain adequate pacification during the process. 7 cases were catheterized through the right superficial temporal vein, 2 cases through the left superficial temporal vein, 6 cases through the right external jugular vein, 8 cases through the left external jugular vein, 22 cases through the right axillary vein, 24 cases through the left axillary vein, 8 cases through the left basilica vein, 2 cases through the right basilica vein, 11 cases through the left lower extremity and 25 cases through the right lower extremity (including 1 case through the right popliteal fossa, 2 cases through the right saphenous vein and 22 cases through the right femoral vein). All PICC tips (100%) were found to be placed in the vena cava after location, and no ectopia occurred.

3.2 Accuracy rates comparison between upper and lower extremity.

The accuracy rates of the IC-ECG-guided PICC in upper and lower extremities were 59/79 (74.7%) and 33/36 (91.6%) respectively. The accuracy of the tip placement in the lower extremity in the neonates was thus higher than that in the upper extremity ($\chi^2=4.46$, $P=0.035$).

3.3 Factor analyses of the IC-ECG guided PICC tip placement.

The accuracy of the process was taken as the dependent variable (1= unstable,0=stable), and the gestational age, chest circumference, height, weight, body surface measurement, basal P/R amplitude, basal heart rate, length of immersion, positioning heart rate and positioning P/R amplitude were taken as the independent variables to perform a univariate analysis. The results indicated that the gestational age, height, weight, basal P/R amplitude and positioning P/R amplitude had a statistically significant effect on the IC-ECG-guided PICC tip placement (Table 1).

Table 1: Factors of subject characteristics on tip placement according to the accuracy:[Mean(Standard Deviation)/frequency(percentage)]

Factor	accuracy		t/Z/X ² *	P	
	YES	NO			
Puncture site*	Lower extremity	33 (91.6)	3 (8.4)	4.46	0.035
	Upper extremity	59 (74.7)	20 (25.3)		
Sex	Female	43 (84.3)	8 (15.7)	1.49	0.222
	Male	48 (75.0)	16 (25.0)		
Gestational age* (weeks)		35.42(3.40)	37.00(3.44)	1.982	0.049
Chest circumference (cm)		31.41(3.502)	32.71(3.391)	1.628	0.106
Height (cm)		47.12(4.235)	49.23(5.593)	2.020	0.046
Weight (kg)		2.629(.8394)	3.014(1.1091)	1.862	0.065
BSM (cm)		11.11(3.582)	10.83(3.933)	0.331	0.741
BasicP/R		.2254(.10118)	.2733(.14513)	1.767	0.080
Immersion length (cm)		11.592(3.7351)	11.463(4.0998)	1.492	0.139
Baseline heart rate b/m		130.84(17.236)	129.96(10.564)	0.238	0.8122
Positioning heart rate b/m		137.63(14.487)	135.67(12.534)	0.605	0.546
Positioing P/R*		.4631(.20457)	.5976(.23975)	2.626	0.0099

BSM, body surface measurement; *,t-test, Wilcox test or chi-square test

Taking the statistically significant influencing variables identified above as independent variables to perform multiple-variable logistic regression analysis, two variables, i.e., weight and positioning P/R amplitude, were included in the final model (Table 2).

4 Discussion

4.1 Higher accuracy of the IC-ECG guided positioning technique through the lower extremity than that through the upper extremity

In this study, the univariate analysis found that the IC-ECG-guided positioning technique achieved significantly different accuracies in the upper extremity and lower extremity. The reason for the greater accuracy of the technique in the lower extremity is that, compared with the superior vena cava, the inferior vena cava is straighter, less branched and has fewer influencing variables. When positioning the puncture in the femoral veins of the lower extremity, changes in body position, such as buckling or extending, do not strongly affect the PICC tip placement; in contrast, body position changes in the upper extremity can greatly disturb the tip placement.

The P wave increases in amplitude as the PICC tip in the upper extremity approaches the junction of the SVC and the right atrium, necessitating a slight retraction of the catheter to maintain the proper position [11]; however, this repositioning is difficult to perform accurately. The ECG waves in the lower extremity differ from those of the upper extremity: as the catheter reaches a greater depth, the amplitudes of the P wave and QRS waves remain either unchanged or atactic. The latter indicates invagination of the catheter or its misplacement into the hepatic or spleen area, which necessitate pulsing with NS and observation of the change in amplitude of the QRS waves after retraction of the catheter. Regular QRS waves with the same amplitude as the body surface indicate that the catheter

has not yet arrived at the inferior vena cava. After arrival of the catheter at the inferior vena cava, the QRS waves continually increase in amplitude as the catheter approaches the heart. Meanwhile, the appearance of an upright P wave indicates that the PICC tip has been placed at the level of the right atrium; in this case, the catheter should be retracted to its normal position, inside the deep inferior vena cava but outside the right atrium [12]. Wave changes in lower extremity placement are clearer, more distinct and easier to accurately manipulate than those in upper extremities.

4.2 Main influencing factors of the accuracy for PICC tip placement

Multivariate model analysis indicated that the weight of the neonates was related to the accuracy: the heavier the neonate, the lower the accuracy. This may be related to the noisiness of the neonates: premature infants have relatively low mobility and are easily calmed in a nest-like special therapy bed, especially after injection with small doses of sedatives. The heavier neonates were all term infants with relatively high mobility; they cried more readily and the effect of sedative injection in small doses was less pronounced. This is consistent with the fact that placement is more accurate in taller and younger neonates according to the invariance analysis, which may be due to the relationship between height, gestational age and weight. 70 neonates in this study had high mobility and cried heavily; they were pacified patiently and given a pacifier to suck, or fed sweetened water in advance of the procedure. 41 neonates could not be pacified in this way; they were injected with small doses of Luminal following doctors' advice. When they became calm and their heart rates reverted to normal, the amplitudes of the P waves could be read correctly. During the actual procedure, the ECGs of the heavier neonates were easier to obtain, and their waves were also clearer, when performing the procedure in quiet surroundings.

Table 2: Multivariate logistic analysis of the accuracy of IC-ECG from PICC

Factor	OR 95%CL						
	Coefficient	SE	Wald	P	OR	LCI	UCI
Weight	.656	.305	4.637	.031	1.927	1.061	3.501
Positioning P/R	3.476	1.415	6.037	.014	32.331	2.020	517.407

SE, Standard Error; OR, Odds Ratio; LCL, Lower Confidence Interval; UCL, Upper Confidence Interval

Model analysis also indicated that the positioning P/R amplitude was related to accuracy: the higher the amplitude, the lower the accuracy. It is advisable for the tip placement to be retracted slightly when the P wave reaches maximum amplitude, especially when a small Q wave occurs [5, 13]. In our study, placement was made when P/R reached 50–60%. There were 20 cases of non-standard placement, including 12 cases where the P/R was higher than 50–60% due to the PICC tip penetrating the right atrium. During the actual procedure, it would have been preferable for an assistant to measure the stability of the P/R with a measuring ruler to provide a basis for correct placement, rather than relying on visual inspection, which no doubt caused errors.

Neonates are susceptible to Patent Ductus Arteriosus (PDA), Atrial Septal Defect (ASD) and Ventricular Septal Defect (VSD); although the body surface ECGs of affected neonates are almost normal, and they can receive ECG placement in the veins, the accuracy of placement is reduced. 16 cases in this study presented PDA, ASD or VSD upon examination, including 5 neonates who were diagnosed with congenital heart disease; the ECG baselines of these 16 remained unstable, with the P waves increasing in amplitude. 4 of the 16 cases received accurate placement, 2 cases received placement in the middle of the SVC, and 10 cases in the right atrium. The overall accuracy of only 74.7% was partly affected by the above conditions, which caused difficulties in determining the P/R amplitude. Consequently, heart B ultrasonography should be performed before PICC puncturing to exclude congenital heart disease and influencing variables of the P/R amplitude, and to increase placement accuracy in neonates.

4.3 Other influencing factors of the accuracy for PICC tip placement

One of the most important factors in ECG is the signal-transferring connection between the electrode and the steel needle. Movement of the catheter affects this connection, thus compromising the stability of the ECG recording; therefore, it is necessary to ensure slow catheter movement to obtain a stable and reliable ECG recording when the tip enters the vena cava [2, 14, 15].

Some studies have indicated that connecting a guide-wire to the electrode vein facilitates ECG recording in adults and children [7, 16-18]. Possibly, because a 1.9rPICC is relatively thin, the path length of the electrocardiographic leads is very long; thus, the electrocardiographic signal must travel a long distance to diffuse throughout the blood, NS, scalp needle and connection wire, and the

signal is degraded by this long path length. However, neonates have a heart rate of 120–160 beats/minute, which influences the stability and clearness of the ECG records. It is necessary to keep neonates calm and minimize all sources of interference.

In this study, the concordance rate of the PICC and the X-ray in the upper extremity of the neonates was lower than that in children [11]. Extraction of the waveform is vital; when the waveform could not be extracted, we examined whether conduction was smooth, the heparin cap was filled with NS, and the needle was in contact with the NS. Furthermore, the needle tip should be perpendicular to the heparin cap and not in contact with the vessel wall, to avoid influencing conduction. The connection between the electrode and the scalp needle may influence the spread of the signals. Having connected the leads, it is inadvisable to observe and record ECGs during catheter placement because the movement of the catheter influences the stability of the lead connection, making it difficult to obtain accurate data in such a short time. Therefore, we suggest that when the catheter has entered into the SVC, the further positioning of the catheter should proceed slowly, with regular stops to examine the stability of the connection and record reliable ECG waves. It is important to monitor the basal heart rate during observation of the P wave, because a stable heart rate is necessary for a stable ECG.

5 Conclusion

During PICC tip placement, it is vital to record a stable and clear ECG. Establishing steady leads and supplying a continual injection of NS can improve the ECG signals. In clinical applications of this technique, interference from environmental signals or factors compromising the smooth operation of the procedure should be eliminated to ensure a stable vein ECG wave and increase the accuracy of tip placement. Tip placement by the dynamic change in the P waves from an electrocardiogram (ECG) guided PICC among neonates is accessible and as reliable as using X-rays.

Declaration of conflicting interests: The authors have declared that no competing interests

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