Clinical significance of intracavitary electrocardiographic localization in the prevention of PICC heterotopia in children with tumor

Cong-Cong Zhang MD | Yu-Xin Zhu MD | Xin-Xin Yin MD | Jing-Fang Gao MD

1Department of Central Venous Catheter Clinic, Shijiazhuang People’s Hospital, Shijiazhuang, China
2Shijiazhuang People’s Hospital, Shijiazhuang, China

Correspondence
YuXin Zhu, Department of Central Venous Catheter Clinic, Shijiazhuang People’s Hospital, Jianhua South Street, Yuhua District, Shijiazhuang City 050000, Hebei, China.
Email: yuxinzhu_z@163.com

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Abstract
Objective: To explore the clinical significance of intracavitary electrocardiogram positioning technology in preventing catheter ectopic position during peripherally inserted central catheter (PICC) catheterization in children with tumors.

Methods: A retrospective analysis of the clinical data of 62 children who required PICC catheterization was performed. The intracavitary electrocardiogram (ECG) positioning technology was used during the tube placement of the child patients. After the tube was successfully placed, the chest radiograph was taken. The ECG positioning result was compared with the chest radiograph positioning result after the tube was inserted, and the sensitivity and specificity of the ECG positioning were calculated.

Results: The intracavitary electrocardiogram results of 62 children with PICC catheters showed that 56 cases (90.32%) had characteristic P waves, and six cases (9.68%) had no characteristic P waves. The chest radiographs of 56 children with characteristic P wave showed that 33 cases (58.93%) of the catheter tip position was appropriate, 22 cases (39.29%) of the catheter tip was too deep, and 1 case was in a non-superior vena cava; six cases of chest radiographs of children with no characteristic P wave showed: one case was too deep at T8 level, one case was too shallow at T4 level, four cases were at non-superior vena cava, one case was contralateral internal jugular vein, two cases in the contralateral brachiocephalic vein, and one case was the contralateral subclavian vein.

Conclusion: Intracavitary ECG positioning assisted catheter placement in infants can effectively improve the accuracy of catheter tip position.

KEYWORDS
catheter tip positioning, chest radiograph, children, intracavitary electrocardiogram, PICC catheterization

1 | INTRODUCTION

As the number of children with tumors increases, peripherally inserted central catheter (PICC) is widely used in chemotherapy for the children with tumors, and has played an active role in reducing peripheral venous extravasation and phlebitis. However, the children are too young to cooperate and crying leads to increased thoracic pressure. Misplacement of the catheter often occurs during catheter placement. When the PICC tip is ectopic, it is easy to cause complications such as catheter-related bloodstream infection,
vascular erosion, and pericardial tamponade complications (Wang et al., 2019). Chest X-ray is the “gold standard” for checking whether the tip of the catheter is ectopic after PICC catheterization. However, chest X-ray cannot monitor the change at catheter position during catheterization in real time. It needs to be repositioned when the catheter position is incorrect or ectopic. Disinfection and repeated adjustment of the catheter are time-consuming and laborious, and increase the harm of radiation exposure (Jiang & Peng, 2020). In recent years, adults have mostly used intracavitary electrocardiogram (ECG) positioning technology, which can increase the rate of PICC tip reaching the superior vena cava and reduce the risk of catheter ectopic and related complications to a certain extent (Gu et al., 2018). There are also reports in the domestic literature that the use of P wave characteristic changes in newborns can increase the rate of catheter placement (Wu et al., 2016). However, infants and young children are different from adults in terms of physiological, psychological, cognitive, emotional changes, and physical development (Xu et al., 2019). In particular, the heart rate is faster than that of adults. Intracavitary ECG also has its own regularity and characteristics. There are few domestic literatures about intracavitary electrocardiography assisting PICC catheter placement in the children. This study aims to discover the auxiliary role and clinical significance of intracavitary electrocardiogram positioning technology in the prevention of catheter ectopic position during PICC catheter placement. The following patients were included: those >28 days and ≤3 years of age, without PICC catheterization contraindications, with sinus rhythm in body surface electrocardiogram and the condition that can tolerate the PICC catheterization operation. Informed consent was obtained from all family members of children. The average age of 62 children with PICC catheterization was 19.10 ± 8.82 months, and the male-to-female ratio was 32:30. The general conditions of the catheterization in children are shown in Table 1. The three most common types of diseases among the selected children were: hepatoblastoma (27.4%), Wilms tumor (25.8%), and neuroblastoma (11.3%). Parents of all children enrolled in the group signed an informed consent. This study was approved by the ethics committee of our hospital and did not increase the economic burden of the children or cause any harm to the children.

2 | MATERIALS AND METHODS

2.1 | General information

A total of 62 children who were hospitalized in our hospital from February 2016 to April 2020 who needed PICC catheterization were selected as the research objects. This retrospective analysis assessed the clinical significance of assisted intracavitary electrocardiogram positioning technology in the prevention of catheter ectopic position during PICC catheter placement. The following patients were included: those >28 days and ≤3 years of age, without PICC catheterization contraindications, with sinus rhythm in body surface electrocardiogram and the condition that can tolerate the PICC catheterization operation. Informed consent was obtained from all family members of children. The average age of 62 children with PICC catheterization was 19.10 ± 8.82 months, and the male-to-female ratio was 32:30. The general conditions of the catheterization in children are shown in Table 1. The three most common types of diseases among the selected children were: hepatoblastoma (27.4%), Wilms tumor (25.8%), and neuroblastoma (11.3%). Parents of all children enrolled in the group signed an informed consent. This study was approved by the ethics committee of our hospital and did not increase the economic burden of the children or cause any harm to the children.

2.2 | Methods

2.2.1 | Catheter materials and equipment

Two types of catheters, medical silicone and polyurethane, are used, both models are 3F single-lumen, disposable catheterization puncture kit, color Doppler ultrasound machine and twelve-lead electrocardiograph.

2.2.2 | Intubation method

The intubation of all infants and young children enrolled in the group was completed by two nurses with more than 1,000 intubation cases experiences, one chief nurse and one supervisor in charge, both of which were obtained from the Chinese Nursing Association PICC specialist technical training class qualification. Before the catheterization, the venous blood vessel condition was evaluated by ultrasound to exclude phlebitis, thrombosis, and those far from the venous valve;

| Term                      | General condition (n = 62) | Percentage (%) |
|---------------------------|----------------------------|----------------|
| Sex                       |                            |                |
| Male                      | 32                         | 51.61          |
| Female                    | 30                         | 49.39          |
| Heart rate (beats/min)    | 151.62 ± 21.09              |                |
| Average age (months)      | 19.10 ± 8.82               |                |
| Length of upper arm (cm)  | 10.43 ± 1.64               |                |
| Catheter material         |                            |                |
| Medical silicone valve    | 19                         | 30.65          |
| Polyurethane              | 43                         | 69.35          |
| Conduit model             |                            |                |
| 3Fr                       | 61                         | 98.39          |
| 4Fr                       | 1                          | 1.61           |
| Cannulated limb           |                            |                |
| Upper left limb           | 20                         | 32.26          |
| Right upper limb          | 42                         | 67.74          |
| Cannulated vein           |                            |                |
| Basilic vein              | 54                         | 87.10          |
| Brachial vein             | 8                          | 12.90          |
3F single-lumen catheter was selected; about 4 cm above the elbow striae was selected as the puncture point; 0.9% iodophor was used to disinfect the whole arm, and 0.9% NaCl was used pre-flushing catheter and puncture kit; the ultrasound probe with a sterile protective sleeve and a high-frequency superficial organ probe were used. A modified Seldinger was used to puncture the blood vessel under ultrasound guidance. The blood returned well back to the blood circulation. The puncture was successful, the guide wire was smoothly fed, and the steel needle was withdrawn. Lidocaine 0.2 ml was sprayed on the puncture point for surface anesthesia, the skin was expanded, the micro cannula sheath was sent into the blood vessel, the guide wire and the vascular sheath were withdrawn, the catheter was slowly sent along the expansion sheath, and the blood returned well back to the blood circulation after it was sent to the predetermined position. Unobstructed, use the ultrasound probe to explore the internal jugular vein and subclavian vein, without discounted double shadow and double equal sign catheter development, proceeded to the next step of intracavitary electrocardiogram to locate the catheter position.

During the catheterization process, it is easy to puncture the blood vessel and to deliver the catheter because of the crying of the infants and young children. We generally adopt such ways as watching cartoons, giving the children their favorite toys, candies, or the children's mothers to accompany the children to eliminate the children's anxiety.

2.2.3 Intracavitary electrocardiogram positioning method

The child's body surface electrocardiogram was traced and print for later use using Twelve-lead electrocardiograph and sterless guide clip. After the catheter was successfully placed, the red lead wire was connected to the support guide wire in the catheter, and the other leads remained in position. Observe the changes in the amplitude of the P wave and QRS complex in lead II, and when the amplitude of the P wave QRS complex reached the highest, traced the second ECG atlas and continued to deliver the catheter. After observing the negative wave of the P wave, stopped the delivery of the catheter, and withdrawn the catheter until the negative wave was 0.05 or disappear, that would be the best position of the catheter tip, and the third ECG atlas would be printed. If the amplitude of the P wave and QRS complex in lead II did not change or the increase was less than 0.5 mv, the catheter would be readjusted until the characteristic P wave amplitude appears. Continue to the next step, fixed the catheter, took X-ray images of the front and side of the chest, and determined the final position of the catheter tip.

2.3 Judgment criteria of intracavitary electrocardiogram

When the catheter reached the middle of the superior vena cava, the P wave amplitude began to increase, and when its amplitude increased to the maximum, the tip of the catheter could be located in the lower part of the superior vena cava and/or at the junction of the superior vena cava and the right atrium (cava atrium junction, CAJ) as appropriate location; when the catheter was in the right atrium, the P wave amplitude dropped and negative positive two-way waves or/and negative waves appeared; this study set the P wave amplitude $\geq 0.5$ mv as a characteristic P wave (positive result), indicating the tip of the catheter in place; P wave amplitude $<0.5$ mv was non-characteristic P wave (negative result) and negative wave wad the catheter is too deep, indicating that the catheter is ectopic.

2.4 Judgment criteria for X-ray chest radiographs

Two radiologists interpreted the chest radiographs and determined the appropriate position of the catheter for infants and young children; this study referred to the relationship between the heart and great blood vessels and the sternum and ribs, and referred to the standard for the proper position of the adult chest radiograph catheter, (Gao et al., 2012; Infusion Nurses Society, 2016) the tip of the catheter for infants and young children under 3 years of age was in a proper position at the level of T5–T6; the level of ≥T7 was that the catheter is too deep; the level of less than T5 was that the catheter was too shallow. Catheters that are too deep, too shallow, and non-superior vena cava are considered to be ectopic.

3 RESULTS

3.1 Observation of characteristic P waves during the intubation process of the children

A total of 38 cases of characteristic P waves occurred at one time during the intubation process, and 24 cases of specific P waves did not appear. It was temporarily designated as process ectopic, which accounted for 38.71%; 24 cases of children had undergone many catheter adjustments, of which 18 cases had characteristic P waves, and six cases still had no characteristic P waves. In the end, 56 cases of characteristic P wave appeared, accounting for 90.32%; six cases of characteristic P wave did not appear, accounting for 9.68%. A representative image of the intracavitary ECG in children was shown in Figure 1. The characteristics of the intracavitary ECG in children was illustrated by Figure 2.

3.2 Concordance results of intracavity ECG and chest X-ray in 62 children with PICC catheterization

The results of chest X-ray in 56 children with characteristic P wave showed that the suitable position of the catheter tip in 33 cases (at the level of T5–T6) accounted for 58.93%, 22 cases of catheter tip is too deep (≥T7 level) accounted for 39.29%, one case of catheter located in the non-superior vena cava (located on the contralateral subclavian vein) accounted for 1.79%; six cases had no characteristic P wave with results of the chest radiograph showed that the catheter was too deep at the T8 level, one was too shallow at the T4 level, four was at the non-superior vena cava, one was at the contralateral
Internal jugular vein, two was at the contralateral brachiocephalic vein, and one case of contralateral subclavian vein. The sensitivity of the consistency comparison between the intracavity ECG and the chest radiograph in infants and young children was 98.21% (55/56), and the specificity was 83.33% (5/6). A total of 56 cases consisted of P wave amplitude negative wave manifestation, suitable catheter position and excessive depth, of which 24 cases had negative wave, and two cases of 33 cases of suitable catheter position had negative waves: 22 cases of 23 cases of excessively deep catheters negative wave (Table 2).

3.3 | Comparison of P wave amplitude between process ectopic, final location and body surface during ECG positioning of infants and young children

In this study, a total of 56 children with catheters in place and catheters too deep were observed, with an average amplitude of 1.09 ± 0.49 mV; 29 cases of process ectopic, the average P wave amplitude of intracavitary electrocardiogram was 0.26 ± 0.13 mV. The P wave amplitude of the process ectopic, final location and
body surface is statistically significant ($F = 157.540, p < .001$) (Table 3).

### 4 | DISCUSSION

#### 4.1 The clinical significance of intracavitary electrocardiogram positioning technology to prevent ectopic placement of the children

Central venous catheter placement via peripheral vein is more likely to be ectopic than CVC via internal jugular vein due to the long journey, venous vascular network structure, and more branches. In addition, because the children are young and poorly coordinated, the chest pressure is high due to crying in children, and ectopic catheters are more likely to occur than adults. Domestic literature reports that the ectopic rate after PICC catheterization is about 3.7%–40%, even as high as 60% (Li et al., 2018), which brings certain confusion to safety catheterization in the clinic. Domestic literature has confirmed that the intracavitary electrocardiogram positioning technology has great advantages in assisting adult and infant PICC catheterization, and can reduce ectopic catheters and the related complications such as catheter shedding, mechanical phlebitis, and infections (Huang et al., 2019; Qin et al., 2014). The principle of intracavitary electrocardiogram positioning showing that the tip of the catheter is located in the lower 1/3 of the superior vena cava and or at the junction of the superior vena cava and the right atrium, the P wave amplitude increases, and the QRS complex amplitude also increases. When the catheter tip position enters the right atrium, negative positive two-way and/or negative waves appear at the beginning of the P wave, indicating that the catheter tip position is too deep, indicating that the catheter tip is too deep. PICC catheter placement in infants and young children assists in intraluminal ECG positioning, and whether there is a characteristic change in the P wave in lead II of the limb, that is, the amplitude is increased, and then it is judged whether the catheter is in place or the superior vena cava enters the right atrium.

In this study, because the heart rate of infants and young children is relatively fast, the average heart rate of 62 infants and young children is $151.62 \pm 21.09$ according to statistics. Because the baseline of the electrocardiogram is not obvious, it is difficult to distinguish the depth of the negative wave amplitude of the P wave. The biggest difference between infant and young children's assisted intracavitary ECG positioning technology in adult and child applications is that the changes in P wave cannot well reflect the different positions of the catheter. Although the paper speed of the electrocardiogram can be adjusted, the baseline of the electrocardiogram is still not easy to determine, so the negative wave of the P wave is not easy to distinguish, and the catheter is likely to be too deep. The researchers believe that the depth of the catheter in infants and young children should not be shallow, and the catheter can be adjusted according to the results of the chest radiograph after the catheter is successfully inserted. If the catheter is too deep, the catheter can be withdrawn under aseptic conditions. Compared with the shallow catheter, there is no risk of infection or catheter displacement.

In this study, 62 infants and young children were observed. Thirty-three cases (only 53.23%) had characteristic P waves at one time during the catheterization process, 29 cases had no characteristic P waves (46.77%), and nearly half of the children require two-to-four adjustments, and some even seven-to-eight adjustments. The ectopic rate of infants and young children as a special patient population during the intubation process was still relatively high; continue to adjust the catheter without destroying the sterile environment until the characteristic P wave appeared, reducing the risk of potential infection caused by the adjustment. After 29 children tried a various of methods of catheter adjustments, 23 of them had characteristic P waves. After repeated adjustments in six cases, no characteristic P wave appeared. After taking a chest radiograph, it was confirmed that the catheter was too shallow at the T4 level, which could not be changed due to measurement errors and cutting before the catheter. The other five cases were not in the superior vena cava. After continuing to adjust the position of the catheter, the tip of the catheter was all in place in four cases; one case showed no characteristic P wave, and the chest radiograph showed the catheter

| X-ray chest radiograph positioning | Number of cases (n) | Percentage (%) | Characteristic P wave and P wave negative wave in intracavitary electrocardiogram | Sensitivity (%) | Specificity (%) |
|-----------------------------------|--------------------|----------------|--------------------------------------------------------------------------------|----------------|----------------|
| Normal (T5–T6)                    | 33                 | 53.23          | 33 0 2 Negative wave | 88.71          | 83.33          |
| Too deep (≥ T7)                   | 23                 | 37.10          | 22 1 22                   |                |                |
| Too shallow (< T5)                | 1                  | 1.61           | 0 1 0                    |                |                |
| Ectopic (non-superior vena cava)  | 5                  | 8.06           | 1 4 0                    |                |                |
| Sum (n)                           | 62                 | 100%           | 56 6 24                  |                |                |

Note: Table 2 shows ectopic catheter general PR < 50%, indicating that the P wave amplitude does not appear high sharp waveform. Catheter too deep can generally be traced to the negative wave (change the ECG paper speed of 50 mm/s), catheter tip position is appropriate, most of the negative wave.
was at the T8 level. The P wave amplitude when the catheter enters the atrium appears to fall back and become lower, and then negative and positive two-way waves or inverted waves appear. The P wave of intracavitary electrocardiogram in some children has little change, and the reason is unknown. According to the observations of this study, the intracavitary ECG positioning technology is of great significance in preventing ectopic catheterization in the children. If there is no ECG assisted positioning, there is no effective clinical significance in preventing ectopic catheterization in the children. If there are more children who cannot cooperate with a radiologist to take a chest radiograph, and the catheter can only be adjusted by repeatedly taking chest radiographs in addition, the children cannot cooperate with a radiologist to take a chest radiograph by themselves. Parents are required to accompany them, which virtually increases the risk of radiation damage to parents and children.

### 4.2 Analysis of the consistency of intracavity electrocardiogram and chest radiograph in children with PICC catheterization

The results of chest radiograph showed that of 56 children with suitable or deep catheters, 24 had negative waves. Negative waves occurred in two of 33 cases with suitable catheter positions, and negative waves occurred in 22 of 23 cases where the catheter was too deep. The reasons are as follows. First, infants and young children are always crying during the catheterization process, the breathing rate is faster, and the catheter fluctuates greatly in the blood vessel. The 2016 version of the American practice standard for infusion therapy pointed out that when a central venous catheter is inserted from the upper extremity, breathing movement, arm movement, and body position changes will cause the catheter tip to move up to 2 cm. The researcher used to adjust the catheter under X-rays, and observed that the catheter fluctuates about 1–2 cm due to crying. Second, the heart rate of infants and young children is faster. According to statistics, the average heart rate of 62 infants and young children was $151.62 \pm 21.09$, and the ECG baseline is not easy to be sure, the negative wave of the P wave is not easy to distinguish. Thirdly, the coagulation mechanism of infants and young children is not perfect, the puncture point is prone to bleeding, and the catheter is not firmly fixed, which may cause the catheter to move out. Finally, if the catheter is too deep, the catheter can be withdrawn, and if it is too shallow, it cannot be fed into the body. Therefore, the catheter should be placed deep rather than shallow. It is feasible to remove the catheter with reference to the chest X-ray result when changing the dressing for 24 h.

### 4.3 The clinical significance of the special circumstances of intracavitary electrocardiogram

One case of catheter located in the non-superior vena cava (one case located in the contralateral subclavian vein accounted for 1.79%) still appeared characteristic P wave, that is, the P wave amplitude was greater than 0.5 mv, but after adjusting the catheter, the P wave amplitude of intracavitary ECG is 1.1 mv. Empirically, the increase in P wave amplitude, that is, the catheter may be in place may be biased. In actual clinical practice, the position of the catheter should be judged comprehensively in combination with chest radiographs, instead of relying solely on intracavitary electrocardiogram positioning as a method. There were no characteristic P waves in six cases. The results of chest radiograph showed that one case of catheter was too deep at the T8 level, because the catheter was too deep, the P wave generally showed a drop in amplitude, so non-characteristic P waves appeared. The possible reason is that when the tip of the catheter is far away from the superior vena cava and the right atrium, the P wave appears to fall back under the influence of the far field potential, and the distance from the tip of the catheter to the right atrium is not proportional to the increase in the amplitude of the P wave (Zhang et al., 2016).

### 4.4 P wave amplitude change of body surface electrocardiogram and intracavitary electrocardiogram

Regardless of adults or infants, the normal value of the P wave amplitude of the surface electrocardiogram is $0.25 \text{ mv}$, and the increase in the P wave amplitude of the intracavitary electrocardiogram has clinical significance. The domestic and foreign literature has not described it in detail. The P wave amplitude of the process ectopic, final location and body surface is statistically significant ($p < .001$).
indicating that the increase in P wave amplitude is related to the position of the catheter.

4.5 | The clinical significance of non-characteristic P waves

The results of the other five cases with no characteristic P wave conforms to the principle of intracavitary electrocardiogram positioning. The P wave amplitude of the catheter tip far away from the sinus node area has no characteristic changes, but when the catheter is ectopic to the contralateral arm of the head or the subclavian vein, the P wave amplitude is increased by 0.3–0.4 mv compared to the body surface. When the internal jugular vein catheter is ectopic, the electrocardiogram shows the interference wave, or the P wave amplitude is reduced. The above performance may have certain reference value for the ectopic catheterization. We are also accumulating experience in clinical observation. The children are susceptible to breathing rate, crying, and physical activity when taking chest radiographs. In addition, infants and young children have a fast heart rate, and it is difficult to accurately measure the baseline of the ECG. It is difficult to determine the position of the catheter tip using intracavitary ECG as an adult, and it is inevitable that the catheter is too shallow or too deep; however, the characteristic changes in the P wave of the intracavitary electrocardiogram indicate that the catheter orientation is correct, and it must be in the superior vena cava, which has certain clinical significance for preventing catheter ectopic. The results of this study showed that the sensitivity of the consistency of intracavity ECG and chest radiograph in infants and young children was 98.21% (55/56), and the specificity was 83.33% (5/6); the results of this study are similar to those reported in the literature for adult intracavitary electrocardiogram-assisted catheter placement with similar sensitivity (96.33% (Fu, 2017)) and low specificity (literature 100% (Fu, 2017)). Compared with infants and young children, the consistency of intracavitary electrocardiogram and chest radiograph is comparable (newborn 87.4%) (Xiang and Tan, 2016). Intracavitary ECG positioning assisted infant placement can effectively improve the accuracy of the catheter tip position, and its economical, convenient, and radiation hazard avoidance characteristics are more conducive to safe placement of infants and young children. Intracavitary ECG positioning technology assists catheter placement to simplify the operation process, save time and effort, is welcomed by catheter placement personnel, has obvious clinical advantages and is worthy of promotion.

The small sample size in this study may be related to the fact that the investigator’s hospital has fewer children. The investigator’s hospital is a general hospital with fewer children with malignant tumors in the pediatric ward, so the number of cases enrolled in the group is limited. In this study, only infants with malignant tumors were selected to assist in intracavitary ECG positioning during PICC catheterization. When the paper was written, only 60 cases were collected. However, we have always used intracavitary ECG to assist positioning during later PICC catheterization. We observed that the characteristics of intracavity PICC catheterization to infants and young children were the same.

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CONFLICT OF INTEREST
The authors declare that they have no competing interests.

AUTHOR CONTRIBUTIONS
Conception and design: Zhang CC. Administrative support: Zhu YX and Jia CX. Provision of study materials or patients: Zhao WJ and Jia CX. Collection and assembly of data: Zhang CC and Zhu YX. Data analysis and interpretation: Zhu YX, Zhu YX, and Zhao WJ. Manuscript writing: All authors. Final approval of manuscript: All authors.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE
This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Shijiazhuang People’s Hospital. Written informed consent was obtained from all parents/local guardians.

CONSENT TO PARTICIPATE
Written informed consent was obtained from all parents/local guardians.

CONSENT FOR PUBLICATION
The manuscript is not submitted for publication or consideration elsewhere.

DATA AVAILABILITY STATEMENT
All data generated or analyzed during this study are included in this published article.

ORCID
Yu-Xin Zhu https://orcid.org/0000-0002-5155-3006

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