Journal of Clinical and Nursing Research, 2024, Volume 8, Issue 10
http://ojs.bbwpublisher.com/index.php/JCNR
Online ISSN: 2208-3693
Print ISSN: 2208-3685

Research Progress of Intracardiac Electrogram Localization Technology in PICC Tip Localization

Lingyu Li, Xiang Ma, Jiao Yan, Haijing Han*

Department of Neurosurgery, Xi'an International Medical Center Hospital, Xi'an 710100, Shaanxi Province, China

***Corresponding author:** Haijing Han, lilingyu0207@163.com

Abstract: As a safe, accurate and radiation-free method of catheter tip positioning, intracardiac electrogram positioning technology (IC-ECG) has shown significant advantages in the field of peripherally inserted central catheter (PICC), and has been increasingly concerned and welcomed by clinical operators at home and abroad in recent years. This article reviews the technical principle, clinical progress, advantages and limitations of IC-ECG, aiming to provide a reference for further clinical research and application of this technology.

Keywords: PICC; IC-ECG; Research progress

Online publication: October 24, 2024

1. Introduction

Peripherally Inserted Central Catheter (PICC) refers to the technique of placing the catheter tip in the superior or inferior vena cava through peripheral venipuncture [1]. PICC tip positioning is a key step to ensure the accurate placement of the catheter, which has important clinical significance and can reduce the risk of complications and improve the treatment effect. At present, the commonly used positioning methods of PICC tip include body surface measurement [2], chest X-ray positioning [3], electromagnetic navigation-assisted positioning [4], and intracardiac electrogram positioning [5]. Body surface measurement is easily affected by individual anatomical structures, and its accuracy is not high. Electromagnetic navigation-assisted positioning requires professional electromagnetic navigation equipment, and the cost is high. The chest X-ray positioning method is the most commonly used in clinical practice, and it is also the "gold standard" for catheter tip positioning. However, this method increases the risk of radiation exposure in patients and requires professional skills and equipment support. Intracardiac Electrocardiogram (IC-ECG) positioning technology is a method of assisting catheter tip positioning by monitoring the electrophysiological signals in the heart cavity [6]. This technique uses an intracardiac electrode to obtain the electrocardiogram signal in the heart cavity and determines the position of the catheter tip by analyzing the signal characteristics. The intracardiac electrocardiogram localization does

not require radiation, has high safety, and is suitable for special groups such as infants and young children. It can provide real-time ECG signals and accurately determine the position of the catheter. This article aims to systematically discuss the research progress of IC-ECG positioning technology in PICC tip positioning, summarize its advantages and limitations, and provide theoretical and practical guidance for clinical practice.

2. Intracardiac electrocardiogram localization technology and principle

2.1. Principle of positioning

In the electrophysiological cycle of cardiac activity, the first ECG waveform, namely the P-wave, symbolizes the onset of atrial depolarization. Its normal amplitude on the chest lead of percutaneous ECG mapping usually does not exceed 0.2 millivolts, and its spread width usually does not extend beyond 0.11 seconds. Unlike conventional surface electrocardiogram (ECG), IC-ECG directly measures and records the specific electrophysiological activity signals of the heart by inserting a catheter into a fixed position in the heart. During the process of PICC insertion, the shape and amplitude of the P-wave sensed by the PICC electrode will change significantly when the catheter tip touches or approaches the atrium. These changes are closely related to the anatomical position of the catheter tip. This is characterized by the fact that when the catheter tip reaches the interior of the superior vena cava, the electrode captures a strong atrial depolarization electric field effect, and the P-wave profile changes, especially its amplitude increases significantly. When the tip of the catheter reaches the junction of the atrium and the superior vena cava (CAJ), the amplitude of P-wave may climb to the highest point, sometimes even exceeding the amplitude of R-wave, resulting in the so-called “peak P-wave” phenomenon [7].

Continuing the procedure, once the end of the catheter enters the right atrium, the distal electrical potential caused by the excitation of the heart muscle will cause further changes in the P-wave profile. There may be amplitude attenuation of the P-wave and a “bidirectional P-wave” with a double top, meaning that there are two prominent peaks at the top of the P-wave. In addition, during clinical manipulation, especially when the tip of the catheter is close to the right atrial ostium, a “bimodal P wave” with an M-shaped gap and a width of 0.11 seconds or more may be recorded in lead II [8]. The “double peak P-wave” in this case serves as a transitional marker, suggesting that the end of the catheter is gradually approaching the position of the right atrial orifice. The reason is that as the catheter advances, the inner guide wire is almost touched by the depolarization wave of the left and right atria simultaneously. As the catheter progresses, the amplitude of the “double top P-wave” will gradually increase. When the coronary sinus (CAJ) is fitted at the tip of the catheter, the amplitude of the double roof P-wave will reach its peak. At this point, the optimal position of the catheter can be determined by withdrawing the catheter slightly until the amplitude reaches the maximum value and then withdrawing 0.5–1 cm.

2.2. Electrical signal extraction method

The successful application of IC-ECG localization technology largely depends on the acquisition of stable and clear intra-luminal electrical signals. In current practice, there are mainly two common methods to achieve this goal, namely the metal guide wire method and the physiological salt column method.

The metal guidewire technique is a widely used strategy in which a metal guidewire is embedded into the end of the catheter, while the proximal part is connected directly or transversely with the skin-electrode by using an electrocardiogram clip, thus creating an efficient current delivery channel. Due to its good electrical

conductivity, the metal guide wire can effectively capture and transmit the weak electrical signals in the heart chamber, and convert them into the ECG waveforms for analysis, especially the characteristic P wave related to the position of the catheter tip. Previous studies have shown that although there is no significant difference in accuracy between the metal guidewire method and the saline method, the metal guidewire conduction group is significantly better than the saline conduction group in the elicitation rate of characteristic P-waves [9].

On the other hand, when the catheter is filled with saline and connected to the surface electrodes through appropriate sensors, the voltage inside the saline can reflect the electrophysiological state at the opening end of the catheter, because the catheter wall is composed of insulating materials. Technological advances have led to various innovations in saline treatment techniques, such as the vertical drip method using gravity and the injection technique using infusion pumps, which effectively enhance the stability of the extraction of electrical signals and increase the scope of application. Among them, the pump injection method has shown great advantages in clinical practice due to its lower interruption rate of ECG waveform, shorter operation time, less normal saline dosage and higher standardization [10].

However, due to individual differences between patients, the above methods fail to elicit ECG signals in a few cases. In view of this situation, some scholars have proposed the method of using hypertonic saline to enhance conductive stability and sensitivity [11]. Although the preliminary results show that it is effective, isotonic saline is still widely recommended for localization in clinical practice due to safety considerations.

3. Clinical progress

3.1. Application of IC-ECG localization technology in neonates

The anatomical structure of the newborn is small, and the traditional positioning method may not be accurate enough. IC-ECG positioning technology can provide real-time and accurate catheter positioning information by monitoring the electrical signals in the heart cavity. This is particularly important in neonates, where the vessels and cardiac structures are relatively small and traditional localization methods may be limited. Second, the IC-ECG localization technique does not require the use of X-rays, thus avoiding the risk of radiation exposure to the newborn. Liu *et al.* compared the effect of IC-ECG method and *in vitro* measurement on the positioning of PICC catheter tip in neonates. The success rate of IC-ECG-guided PICC in the observation group was 95.6%, and the final extubation rate was 86.2%, which was significantly higher than that in the control group (success rate was 70%, and the final extubation rate was 67.1%), and the difference was statistically significant [12]. Zhu *et al.* explored the application of IC-ECG in neonatal PICC catheterization and found that IC-ECG had high accuracy in determining the position of the catheter tip, and the operation time (12 ± 1.57 minutes) and cost (7.12 ± 0.56 yuan) were increased compared with traditional methods [13].

3.2. Application of IC-ECG in patients with atrial fibrillation

In patients with Atrial Fibrillation (AF), when using IC-ECG technology for PICC tip positioning, it is necessary to take into account the unique electrophysiological characteristics of AF and its influence on the positioning process. In the state of AF, the atrium loses its normal rhythmic contraction and shows irregular rapid electrical activity, which makes the traditional P-wave on ECG disappear and is replaced by a fast and irregular f wave. Nevertheless, IC-ECG positioning technology can still provide effective guidance for PICC tip positioning. Its principle is mainly based on the following aspects:

(1) Electrophysiological signal analysis

Even in the background of atrial fibrillation, IC-ECG electrodes can still capture specific electrophysiological changes when the catheter tip approaches or enters the junction between the superior vena cava and the right atrium. Although the P-wave is not obvious, the correlation between the electrical activity of the atrium and the ventricle and the influence of the catheter tip on the electric field still exist. Through careful analysis of these changes, the position of the catheter tip can be indirectly inferred [14]. Hu *et al.* proposed a prospective study involving 74 patients with atrial fibrillation [15]. All patients received PICC catheterization and the tip was located by IC-ECG technology. The relationship between the morphological changes of the f-wave in the intracardiac ECG and the position of the PICC tip was observed to determine whether the catheter tip was ectopic during catheterization. The results showed that the proposed method had a high sensitivity of 95.2%.

(2) Tip potential characteristics

Although atrial fibrillation leads to disordered atrial activity, certain voltage changes may be recorded at the tip of the catheter at a specific location (e.g., near the CAJ), such as an increase in local potential amplitude or a certain characteristic waveform, which can be used as a reference for localization [16].

3.3. Application of IC-ECG in patients with mirrored dextrocardia

Mirror Image Dextrocardia is a rare congenital cardiac anatomical variation, which means that the heart is located on the right side of the chest, but its internal anatomical structure is the arrangement of the normal heart under the mirror reflection. Specifically, the right atrium and right ventricle are located on the left side, and the left atrium and left ventricle are located on the right side.

In the normal cardiac structure, the P-wave and QRS complex of ECG reflect the electrophysiological activity of the atrium and ventricle, respectively. However, in patients with a mirrored dextral heart, although the heart is located on the right side, the order and direction of internal electrophysiological activities are not fundamentally changed. Therefore, theoretically, when the PICC tip is located by IC-ECG, the position of the catheter tip can still be determined according to the change of ECG waveform. Liu *et al.* in a changing cavity mirror dextrocardia patients electrocardiogram (ecg) in patients with the normal left heart of PICC tip positioning program, use the opposite electrodes (RA: left collarbone midline between first rib; LA: the first intercostal area of the right midclavicular line; LL: lower margin of the left midclavicular line) to obtain a distinct P-wave change to guide catheter placement in this case [17]. It has been experimentally demonstrated that the opposite electrode can be used to obtain a distinct P-wave to locate the tip of the catheter in patients with mirrored dextrocardia.

4. Advantages and limitations of IC-ECG localization technology

As an alternative to traditional X-ray, intracardiac electrocardiogram (IC-ECG) positioning technology has shown unique advantages and potential limitations in PICC tip positioning. In the following, its advantages and limitations are discussed.

4.1. Advantages

(1) High accuracy

IC-ECG positioning technology has a significant accuracy advantage in PICC tip positioning. Compared with the traditional X-ray positioning method, IC-ECG technology can accurately determine the position of the catheter tip by monitoring the changes in electrical activity in the heart cavity, avoiding the error caused by X-ray irradiation. Studies have shown that the positioning accuracy of the IC-ECG positioning method is more than 90%, which is significantly better than that of traditional methods.

(2) Real-time monitoring

IC-ECG technology can monitor the change of catheter position in real-time and provide timely feedback for medical staff. By continuously monitoring the ECG signal, the position deviation or abnormal situation can be found immediately during the catheter placement process, which helps the medical staff to adjust the operation in time and ensure the correct placement of the catheter. The results show that the real-time monitoring ability of IC-ECG technology can significantly improve the success rate and safety of catheter placement.

(3) Reduce the risk of complications

The use of IC-ECG technology can reduce the risk of complications during catheter placement. By accurately determining the position of the catheter tip, complications such as vessel perforation, catheter misplacement, infection, and thrombosis can be effectively prevented. Studies have found that IC-ECG technology can significantly reduce the incidence of complications and improve the safety and treatment effect of patients.

4.2. Limitations

(1) Complex technology

ECG localization technology is based on ECG waveform changes to infer the position of the catheter tip. It is usually necessary to monitor and compare the ECG changes of multiple chest wall leads (such as RA, LL, LA, etc.) at the same time to determine the location of the tip. However, due to the variability of cardiac anatomical structure between individuals and the non-specificity of ECG performance, it may lead to difficulties in waveform interpretation, and it requires high experience and technical requirements for operators, which increases the complexity and uncertainty of technical implementation.

(2) It is not possible to trace the whole process

Intracardiac electrogram localization relies on P-wave morphological changes to determine the position of the catheter tip, but it cannot reveal the direction of the catheter throughout the blood vessel. IC-ECG cannot realize real-time detection and correction when the intravascular catheter is tortured or collapsed, and only changes after the catheter tip enters the vena cava. Therefore, it is impossible to determine whether the catheter is in the blood vessel or into the artery by mistake. X-ray and other means must be used to evaluate the displacement of the catheter.

(3) High cost

Compared with the traditional positioning method relying on X-ray fluoroscopy, the cost of ECG positioning technology mainly includes the purchase of special equipment, maintenance costs, and professional training of medical staff. Although ECG positioning has the advantage of no radiation, in many medical settings, especially in primary hospitals with relatively limited resources, the

introduction of an ECG positioning system and its continuous operation cost may become an obstacle to its promotion and use.

5. Summary

This article aims to systematically discuss the research progress of intracardiac electrogram positioning technology in PICC tip positioning, summarize its advantages and limitations, and provide theoretical and practical guidance for clinical practice. This article introduces the principle, application methods and clinical progress of IC-ECG positioning technology in different populations in detail, emphasizes its importance in neonates and patients with special cardiac structure, and points out the limitations such as complexity and high cost of technology.

Disclosure statement

The authors declare no conflict of interest.

References

[1] Qing T, Hu L, 2012, Nursing Intervention of PICC Infusion Push Venipuncture Technology. China Medical Equipment, 35(3): 169–170.

[2] Yang W, Chen S, Cao S, 2012, Comparison of Three Methods for Measuring the Length of Peripherally Inserted Central Catheter in Vitro. Journal of Nursing, 19(7): 68–69.

[3] Yu J, Xu K, Li W, et al., 2015, Imaging Study on the Positioning of PICC Catheter End in Adults. Journal of Practical Radiology, 2015(2): 204–207, 233.

[4] Barr L, Hatch N, Roque PJ, et al., 2014, Basic Ultrasound-Guided Procedures. Critical Care Clinics, 30(2): 275–304.

[5] Cales YK, Rheingans J, Steves J, et al., 2016, Electrocardiogram-Guided Peripherally Inserted Central Catheter Tip Confirmation Using a Standard Electrocardiogram Machine and a Wide-Mouth Electrocardiogram Clip Compared with Traditional Chest Radiograph. Journal of the Association for Vascular Access, 21(1): 44–54.

[6] Hoffmann E, Møller-Hansen M, Tengberg LT, et al., 2020, Intracardiac ECG for Verification of Central Venous Catheter Tip Position in Patients with Impaired Coagulation: A Randomized Controlled Trial. Critical Care Clinics, 48(9): 1317–1324.

[7] Pittirutim, Lagreca A, Scoppettuolo, 2011, The Electrocardiographic Method for Positioning the Tip of Central Venous Catheters. The Journal of Vascular Access, 12(4): 280–291.

[8] Zhou L, 2019, To Explore the Morphological Changes of P Wave in Intracavitary Electrocardiogram and Its Clinical Significance in Peripherally Inserted Central Catheter. Systema Medicine, 4(19): 150–152.

[9] Hu L, Cui C, Wu G, et al., 2019, The Application of Different Methods of Intracavity Electrocardiogram Localization Technology in the Implantation of Intravenous Infusion Port through the Upper Arm Vein. Chinese Journal of Nursing, 54(3): 443–446.

[10] Ren X, 2018, Research on the Effect of Three Methods in Electrocardiogram Positioning of Valvular PICC. Huzhou Normal University, Huzhou.

[11] He X, Li J, Wang L, 2008, Localization of Peripherally Inserted Central Venous Catheter Assisted by Intra-Atrial Electrocardiogram. Journal of Medical Education for Future Demands, 2008(2): 83–84, 87.

[12] Liu Y, Liao Q, He J, et al., 2020, Study on the Effects of IC-ECG Method in Neonatal PICC Catheterization. American Journal of Pediatrics, 6(2): 178–182.

[13] Zhu LB, Liu L, Zhang TS, et al., 2021, A Clinical Study on the Tip Localization of Peripherally Inserted Central Catheter (PICC) Guided by Intracavitary Electrocardiography in Newborns: A Randomized Trial. Translational Pediatrics, 10(10): 2409.

[14] Gao Y, Liu Y, Zhang H, et al., 2018, The Safety and Accuracy of ECG-Guided PICC Tip Position Verification Applied in Patients with Atrial Fibrillation. Therapeutics and Clinical Risk Management, 14: 1075–1081.

[15] Hu X, Zhu Y, Liu F, et al., 2020, A Study of Intracavity Electrocardiogram in Positioning PICC Tip in Patients with Atrial Fibrillation. Hebei Medicine, 42(21): 3286–3289.

[16] Calabrese M, Montini L, Arlotta G, et al., 2019, A Modified Intracavitary Electrocardiographic Method for Detecting the Location of the Tip of Central Venous Catheters in Atrial Fibrillation Patients. The Journal of Vascular Access, 20(5): 516–523.

[17] Liu C, Jin T, Meng A, et al., 2022, An ECG Method for Positioning the Tip of a PICC in “Mirror People” with Dextrocardia: A Case Report. The Journal of Vascular Access, 23(6): 962–965.