Clinical significance of different atlas of intracavitary electrocardiogram for PICC localization in 961 cases

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Abstract

Purpose: To explore the application of ECG-guided localization technology in PICC catheterization and the clinical significance of different maps of intracavitary ECG in PICC tip localization.

Methods: In the process of catheter placement under the guidance of ultrasound, the technique of intracavitary ECG location was used. The length of the catheter was measured on the body’s surface. The amplitude of the P-wave and the QRS-wave groups of electrocardiograms before and during catheter placement was recorded. Nine hundred sixty-one patients who underwent X-ray chest film examination after catheterization were imaged on the chest film at the tip of the catheter.

Results: Eight hundred four cases had a characteristic P wave, 83.66%, of which, 331 cases (50% < P/R ≤80%) had 99.09%; 425 cases (80% < P/R ≤100%) had 99.29%; 48 cases (P/R >100%) had 100%. One hundred eighteen cases of non-specific P wave accounted for 12.28% and 79.66% of chest radiographs, of which 72 cases of P/R <50% were 100%; 46 cases of unchanged P wave were 47.83%; 34 cases of special cases accounted for 3.54% and 55.88% of chest radiographs; five cases of interference wave accounted for 0.25%, and the chest radiographs were self-control. The in-place rate of the body contrast catheter was 80%.

Conclusions: The accuracy of the ECG characteristic map in guiding the location of the PICC tip is higher than that of the non-characteristic P wave, and it has more clinical significance in locating the best position of the PICC tip.

KEYWORDS
different atlas tip location, intracavitary electrocardiogram, P wave, PICC catheterization, X-ray chest film

1 | INTRODUCTION

The peripherally inserted central catheter (PICC) has been widely used in clinical intravenous therapy due to its long indwelling time. The tip position of the PICC is closely related to complications, and the catheter in the superior vena cava can reduce the occurrence of complications such as infection, catheter occlusion, thrombosis, and phlebitis (Feng et al., 2010; Zheng & Wu, 2016). A catheter in a non-superior vena cava allows for a shorter catheter retention time, and re-catheterization increases patient pain and economic burden. There are many methods of catheter positioning, and chest X-ray is primarily used in clinical practice. However, it cannot meet the needs
of clinical catheter positioning because of its X-ray film quality, radiologist interpretation error, and positioning lag (Wang et al., 2017). Due to the advantages of the safe, economic, and real-time positioning of PICC catheter tip by the intracavitary electrocardiogram (IC-ECG) method have been gradually used in clinical catheter positioning, as reported in domestic and international literature. The IC-ECG positioning technique assists PICC placement according to the characteristic changes in P waves, which effectively avoids catheter ectopy and guides the PICC catheter to the ideal position in the superior vena cava (Peng et al., 2012; Zhao et al., 2015). The characteristic change of the P wave is that the amplitude of the P wave is 50%–80% of the amplitude of the R wave, which is the consensus of most literature. However, due to individual differences, cardiac structure and function, and other patient factors, the IC-ECG P wave and QRS complex have various morphological variations, and their relationship with the catheter tip position needs further study. In this paper, we summarized 961 cases of the atlas of IC-ECG to locate the tip position of PICC catheters. We analyzed the relationship between various manifestations and the tip position of catheters and their significance to provide clinical data and guidance for catheter tip positioning.

2 | CLINICAL DATA AND METHODS

2.1 | Clinical data

Patients who required and were suitable for PICC placement at our PICC clinic from January 2015 to December 2017 were selected for this study. Inclusion criteria were as follows: patients aged ≥18 years; patients without contraindications to PICC; patients with sinus rhythm on surface ECG during catheterization; and patients who gave informed consent and signed the consent form to undergo ultrasound-guided PICC. Exclusion criteria were as follows: patients with unsuccessful PICC placement for various reasons; uncooperative patients with mental disorders; patients with pacemaker-dependent pacing rhythm and ventricular tachycardia; patients with ectopic PICC tip not adjusted in place; patients with catheters not placed to the intended location; and patients who did not agree to the study. A total of 961 patients with PICC placement were selected, including 539 males and 422 females, with an average age of 65 ± 10.5 years. There were 844 patients with tumors, including 282 patients with digestive tract tumors, 125 patients with lung cancer, 135 patients with gynecological tumors, 74 patients with hematological tumors, 225 patients with other tumors, and 117 with other diseases patients. This study was reviewed and approved by the Ethics Committee of our hospital.

2.2 | Methods

2.2.1 | Materials

Materials and instruments used in this study included 4Fr polyurethane PICC line with front-end opening, disposable central venipuncture kits, EDAN portable digital color ultrasound diagnostic system (model: AcclarixAX8 super), and EDAN digital 12-channel electrocardiograph (model: SE-1201).

2.2.2 | Catheterization method

In this study, two catheterization nurses were prescribed to operate, and these catheterization nurses were specialist nurses who obtained PICC professional qualification certificates at our hospital. The titles and numbers of these catheterization nurses were one chief nurse and one nurse in charge. These nurses were trained in ECG-related knowledge and ECG positioning techniques and were able to identify body surface ECG mapping, master ECG positioning techniques, and determine IC-ECG diagrams. Procedure: (1) A copy of the patient’s body electrocardiogram was collected before catheterization. The vessel was evaluated by ultrasound before catheterization. The vein and placement site was determined according to the matching of the vessel diameter and catheter type. The basilic vein was preferred and the brachial vein secondarily selected; the length of the catheter and arm circumference on the body surface was measured and recorded. (2) Strict aseptic operation was performed, and the MST was placed under ultrasound guidance. The catheter was inserted into the predetermined location after a successful puncture. When the ultrasound exploration of the internal jugular vein without a catheter and subclavian vein without reflection catheter development was visualized, the preliminary judgment was that the catheter was not ectopic. (3) The blood was pumped back smoothly, the catheter was irrigated pulsatile, and it was initially determined to reach the predetermined position.

2.2.3 | Method of acquiring intracavitary electrocardiogram signal

Connection of the ECG tracer: Before connecting the ECG lead wire, the skin of the patient’s wrist and ankles was cleaned; the green lead wire of the ECG was clamped at 3 cm above the patient’s left ankle; the black lead wire was clamped at 3 cm above the patient’s right ankle; the yellow lead wire was clamped at 3 cm above the transverse striation of the left wrist of the patient; the support wire inside the PICC catheter was connected to the metal part of the red lead wire (the metal part of the red lead wire was wrapped with a sterile towel); and the catheter was connected with a syringe containing 0.9% sodium chloride, and 5–10 ml of 0.9% sodium chloride was injected to fill the catheter with liquid to facilitate the export of a clear and stable ECG diagram. If interference waves appeared, the lead wire clamp was checked to see whether it was in close contact with the skin, or the ultrasound probe was removed to exclude AC interference. The waveforms of the P wave and QRS complex were observed to print a stable diagram.
2.2.4 Observation of the occurrence of characteristic P waves and determination of the position of the catheter tip

When the tip of the catheter reached the middle or lower part of the superior vena cava, the amplitude of the P waves and QRS complex in leads I, II, AVL, AVF, and AVR on the electrocardiograph increased. When the catheter tip reached the junction of the superior vena cava and the right atrium, the amplitude of the P waves increased until the highest peak value appeared. The catheter was inserted when the amplitude of the P wave decreased, a negative-positive bidirectional wave or a negative wave appeared, indicating that the catheter entered the right atrium. The catheter stopped delivering and started to withdraw. When the negative-positive bidirectional or negative P wave disappeared, and the positive P-wave amplitude reached the highest peak, the catheter tip was located closest to the sinoatrial node, that is, the junction of the superior vena cava and the right atrium (Zhou et al., 2016). The baseline of the IC-ECG was printed and saved, and the height values of the P- and R-wave amplitudes were observed, measured, and recorded. If the IC-ECG P-wave amplitude did not change or did not show characteristic changes, the catheter might be ectopic to the non-superior vena cava, and various methods could adjust the catheter. If the characteristic P wave still did not appear after adjustment, the possible ectopic situation of the catheter could be excluded by determining whether the blood return was smooth, whether there was resistance to withdrawing the catheter, and whether the catheter was visualized with the ultrasound probe probing the catheter via the vessel. After initially excluding if the catheter was ectopic, the catheter was delivered to the predicted length, the catheter was properly fixed, and the IC-ECG mapping was printed and recorded. A chest X-ray was taken to determine the position of the catheter tip.

2.2.5 Standard for judging the position of the catheter tip by chest X-ray

INS guidelines (2016 Edition) in the United States and technical specifications for intravenous therapy in China recommend that the location of the tip of the PICC catheter is in the lower part of the superior vena cava or at the junction of the superior vena cava and the right atrium. The reference standard for positioning (chest X-ray image-guided positioning): above T5 for the superior vena cava, below T6 for not entering the right atrium or right ventricle at the middle and lower superior vena cava (T6–T8), and below T8 for entering the atrium (Ou et al., 2011). Judgment criteria: T6–T8 for the catheter in place; above T5, the catheter is too shallow; below T8, the catheter is too deep.

### RESULTS

#### 3.1 General information

A total of 961 patients were included in this study. There were 539 males and 422 females with an average age of 65 ± 10.5 years. There were 844 patients with tumors and 117 other patients, as shown in Table 1.

#### 3.2 Basic information on the classification of various maps of IC-ECG

The P waveform was high, double-branch symmetrical, tangential and/or M-shaped, bidirectional wave, and inverted wave. A P wave of 50%–80% of the R-wave amplitude, a P wave higher than the R-wave amplitude, or a P wave equal to the R-wave amplitude is a typical characteristic P wave. A P wave less than 50% of the R-wave amplitude or no change, or a P-wave amplitude less than 0.3 mv is a non-characteristic P wave. According to the above, the ECG waveforms of 961 patients who underwent IC-ECG localization after catheterization were summarized into four categories: typical characteristic P waves, non-characteristic P waves, special cases, and interference waves, as shown in Table 2.

#### 3.3 Comparison of waveforms of IC-ECG-guided positioning and chest X-ray image-guided positioning

The classification of the IC-ECG localization mapping was compared with the corresponding chest X-ray image-guided localization, as shown in Table 3.
3.3.1 | Description of the results: Typical characteristic P wave

50% ≤ P/R ≤ 80%
There were 331 cases in this mapping, and the accuracy rate of the location of the catheter tip was 99.09% (328/331). (1) Sixty-five cases with increased P-wave amplitude and no change in the QRS complex amplitude accounted for 6.76% (65/961). The body surface ECG mapping showed 65 patients with sinus rhythm, including one case with frequent ventricular premature beats, one case with first-degree atrioventricular block, and one case with atrial premature beats. The catheter placement success rate detected by chest X-ray was 98.46% (64/65); one of the catheters was at the T9 level. (2) The P wave and QRS complex were increased at the same time in 266 cases, accounting for 27.68% (266/961), among which nine cases had occasional bidirectional P waves, and 132 cases had a negative P wave with an amplitude less than 0.05 mv. Three cases were accompanied by an increased T wave. The body surface ECG mapping showed sinus rhythm in 265 cases, atrial premature beats in two cases, sinus arrhythmia in one case, atrioventricular disconnection with sinus rhythm in one case, ventricular premature and atrial paroxysmal tachycardia in one case, right bundle branch block in one case, and old myocardial infarction in one case. The catheter placement success rate detected by chest X-ray was 99.25% (264/266), and two catheters were taken between the T8–T9 levels.

80% < P/R ≤ 100%
There were 425 cases in this mapping, and the accuracy rate of the location of the catheter tip was 99.29% (422/425). (1) Compared with the body surface ECG mapping, there was an increase in P waves and no change in the QRS complex in 10 cases, accounting for 1.04% (10/961), and the body surface ECG mapping showed all 10 cases were of sinus rhythm, and one of them had tachycardia. The catheter placement success rate detected by chest X-ray was 99.09% (328/331), and one of the catheters was at the T9 level. (2) There were 14 cases with increased P-wave amplitude and no change in the QRS complex in 49 cases, accounting for 5.10% (49/961). Chest X-ray images showed catheters at the T6–T8 levels in 49 cases. Body surface ECG mapping showed that all 14 cases were of sinus rhythm, and the catheter placement success rate detected by chest X-ray was 100% (14/14).

P/R > 100%
There were 48 cases of this mapping, and the accuracy rate of the location of the catheter tip was 100% (48/48). (1) The P wave and QRS complex group amplitude were increased, but the amplitude of the P wave was higher than that of the R wave in 34 cases, accounting for 3.54% (34/961). The body surface ECG mapping showed 34 cases of sinus rhythm, including one case of tachycardia with first-degree atrioventricular block and atrial premature beats. (2) There were 14 cases with increased P-wave amplitude and no change in QRS complex amplitude, accounting for 1.46% (14/961). The body surface ECG mapping showed 14 cases of sinus rhythm, and the catheter placement success rate detected by chest X-ray was 100% (14/14).

3.3.2 | Non-characteristic P waves

P/R < 50%, P wave increased to between 0.4 and 0.6 mv with small negative waves
There were 72 cases of this mapping, and the accuracy rate of the catheter tip location was 100% (72/72). (1) Atypical increase in the P-wave amplitude and no change in the QRS complex in 49 cases accounted for 5.10% (49/961). Chest X-ray images showed catheters at the T6–T8 levels in 49 cases. Body surface ECG mapping showed 49 cases of sinus rhythm and one case with atrial premature beats with a pacemaker. (2) The P wave and QRS complex group amplitude were atypically increased in 23 cases, 2.39% (23/961), and chest X-ray images showed catheters at the T6–T8 levels in 23 cases. Body surface ECG mapping showed 23 cases of sinus rhythm, including one case with atrioventricular block and one case with pathological Q waves in V1 and V2.

No change in the P wave and QRS complex
There were 35 cases of this mapping, accounting for 3.62% (35/961), with an accurate localization rate of 40% (14/35). Chest X-ray images...

| Item                          | Number of subjects (n) | Percent (%) |
|-------------------------------|------------------------|-------------|
| Typical characteristic P wave | 804                    | 83.66       |
| Non-characteristic P wave     | 118                    | 12.28       |
| Special cases (atrial fibrillation, atrial flutter) | 34 | 3.54 |
| Interference wave             | 5                      | 0.52        |
| Total                         | 961                    | 100         |

Note: Typical characteristic P waves accounted for 83.66%, non-characteristic P waves accounted for 12.8%, and atrial fibrillation, atrial flutter and interference waves accounted for only 3.54%.
### Table 3: Comparison of waveforms of IC-ECG-guided positioning and chest X-ray image-guided positioning (n = 961 cases)

| P-wave morphology                        | P/R value                  | QRS complex   | Number of subjects (n) | Proportion (%) | Chest X-ray localization | Placement success rate (%) | Placement success rate (%) |
|------------------------------------------|----------------------------|---------------|------------------------|----------------|--------------------------|----------------------------|----------------------------|
| Characteristic P wave (Increased) (n = 804) | 50% ≤ P/R ≤ 80% (n = 331) | No change     | 65                     | 6.76           | In place 64, Ectopia 1  | 99.09                     | 99.25                     |
|                                          |                            | Increased     | 266                    | 27.68          | In place 264, Ectopia 2  |                           |                           |
|                                          | 80% < P/R ≤ 100% (n = 425) | No change     | 10                     | 1.04           | In place 10, Ectopia 0   | 99.29                     |                           |
|                                          |                            | Increased     | 415                    | 43.18          | In place 412, Ectopia 3   |                           |                           |
|                                          | P/R > 100% (n = 48)        | No change     | 14                     | 1.46           | In place 14, Ectopia 0    | 100                       |                           |
|                                          |                            | Increased     | 34                     | 3.54           | In place 34, Ectopia 0    |                           |                           |
| Non-characteristic P wave (n = 118)      | P/R < 50% (n = 72)         | No change     | 49                     | 5.1            | In place 49, Ectopia 0    | 100                       | 79.66                     |
|                                          |                            | Increased     | 23                     | 2.39           | In place 23, Ectopia 0    |                           |                           |
|                                          | No change in P wave        | No change     | 35                     | 3.62           | In place 14, Ectopia 21   | 40                        |                           |
|                                          | Increased                  | No change     | 9                      | 0.94           | In place 7, Ectopia 2      | 77.78                     |                           |
|                                          | P-wave amplitude 0.3 mv and broadened | No change | 2                      | 0.21           | In place 1, Ectopia 1     | 50                        |                           |
| Special cases (n = 34)                   | Atrial fibrillation, atrial flutter | No change | 34                     | 3.54           | In place 19, Ectopia 15   | 55.88                     | 55.88                     |
| Interference wave (n = 5)                | Waveform instability       | No change     | 5                      | 0.52           | In place 4, Ectopia 1     | 80                        | 80                        |
| Total meter                              |                            |               | 961                    | 100            | In place 915, Ectopia 46  | 95.21                     | 95.21                     |

Note: ① The localization accuracy of typical characteristic P wave was 99.25%, non-characteristic P wave was 79.66%, atrial fibrillation and atrial flutter were 55.88%, and interference wave was 80%.
② 50% ≤ P/R ≤ 80% localization accuracy was 99.09%, 80% < P/R ≤ 100% localization accuracy was 99.29%, P/R > 100% localization accuracy was 100%, 3P/R < 50% localization accuracy was 100%.
showed that there were 14 cases of the catheter at the T6–T8 levels, 21 cases where the catheter was ectopic, including three cases at the T9 level, 15 cases at the T5 level, one case that descended to the superior vena cava after rising in the internal jugular vein, one case of ectopic internal jugular vein, and one case of subclavian vein reflexed back to the axillary vein. Body surface ECG mapping showed that all 35 cases were of sinus rhythm.

P-wave widening
P-wave amplitude increased between 0.25 mV and 0.4 mV, widening >0.11 s was in nine cases, accounting for 0.94% (9/961), and the accuracy rate of the location of the catheter tip was 77.78% (7/9). Chest X-ray images showed the catheter at the T5 level in two cases and the catheter at the T6–T8 levels in seven cases. Body surface ECG mapping showed sinus rhythm in nine cases.

No change in P waves, increased T and S waves
There were two cases of this type of mapping, accounting for 0.21% (2/961), with an accurate localization rate of 50% (1/2). Chest X-ray images showed one case of the catheter at the T6 level, one case of the subclavian vein reflexed to the axillary vein. Body surface ECG mapping showed two cases of sinus rhythm.

3.3.3 | Special cases

There were 34 cases of atrial fibrillation and atrial flutter, accounting for 3.54% (34/961). There were 19 cases of an increased amplitude of f waves of atrial fibrillation and F waves of atrial flutter and 15 cases with no change. Body surface ECG mapping showed 33 cases of atrial fibrillation rhythm and one case of atrial flutter rhythm. Chest X-ray images showed the catheter at the T5 level in 20 cases, the catheter at the T6–T8 levels in 14 cases, and the catheter placement success rate detected by chest X-ray of 55.88% (19/34).

3.3.4 | Interference waves

There were five cases (0.52%, 5/961) in which the P wave and QRS complex could not be distinguished due to thick baselines and unstable waveforms of IC-ECG, and the accuracy of the chest X-ray was 80% (4/5). Chest X-ray images showed the catheter at the T9 level in one case and the catheter at the T6–T8 levels in four cases. Five cases were ICU patients, and on surface ECG, five cases were of sinus rhythm.

3.4 | P-wave elevation with QRS complex changes

Typical characteristic P waves and non-characteristic P waves in which the P waves were increased and accompanied by changes in the QRS complex are shown in Table 4.

| QRS complex change | Number of subjects (n) | Percent (%) |
|--------------------|------------------------|-------------|
| Increased          | 738                    | 84.25       |
| No change          | 138                    | 15.75       |
| Total meter        | 876                    | 100         |

Note: P-wave elevation with QRS complex elevation accounted for 84.25%, and P-wave elevation with no change in QRS complex accounted for 15%.

4 | DISCUSSION

4.1 | Overview of P-wave waveform diversity atlas for IC-ECG localization

Due to individual differences in patients, different sinus node structures and heart wall thickness, blood flow, and other factors, we observed various IC-ECG P-wave amplitude changes. The typical characteristic mapping was an increase in P-wave amplitude to tapering and bifurcation symmetry, P wave with tangent or "M" wave, positive and negative bidirectional waves, and inverted waves. In this study, we observed the morphological changes in P waves and the QRS complex in the IC-ECG mapping of 961 catheterized patients.

We classified them into four categories: typical characteristic P waves, non-characteristic P waves, waveforms of a special case, and interference waves. The typical characteristic P waves were divided into three categories: ① 50% ≤ P/R ≤ 80%, ② 80% < P/R ≤ 100%, and ③ P/R > 100%. Non-characteristic P waves were divided into four categories: ① P/R < 50%, ② P-wave amplitude did not change, ③ P wave increased between 0.25 mV and 0.4 mV, widening >0.11 s, and ④ the P-wave amplitude did not change and the T- and S-wave amplitude increased. Special cases included increased amplitude of small f waves of atrial fibrillation and F waves of atrial flutter and unstable interference waves.

4.2 | Different types of IC-ECG with different catheter positioning accuracies

The total IC-ECG-guided localization accuracy rate in 961 patients reached 95.21%, among which the highest localization accuracy was 99.25% for typical characteristic P waves, 79.66% for non-characteristic P waves, 80% for interference waves, and only 55.88% for patients with special cases of atrial fibrillation and atrial flutter. Although the total localization accuracy was highly consistent with the chest X-ray image-based localization, the localization accuracy of different waveforms was different. The localization accuracy of P/R > 100% in typical P waves and P/R < 50% in non-characteristic P waves was up to 100%, and the accuracy of atrial fibrillation rhythm and atrial flutter rhythm was the lowest, which indicated that typical characteristic P waves had greater clinical diagnostic significance and could replace chest X-ray
image-guided localization. Non-characteristic P waves needed to be combined with chest X-ray images to determine the catheter location. There were only five cases of interference waves whose localization accuracy could not be accounted for. Patients with atrial fibrillation and atrial flutter rhythm had absent P waves, small f waves, and large F waves without a baseline. Although there were changes in wave amplitude, it was impossible to determine whether the catheter was in place by waveform increase, so further clinical observation was required. They were temporarily excluded from the routine operation of IC-ECG-guided localization, and it was still recommended that a chest X-ray be taken to localize the catheter.

4.3 | Reconsideration on the localization by different maps of the typical characteristic P wave and QRS complex

4.3.1 | The localization accuracy of the P/Q ratio between 50% and 80% was consistent with most literature studies and had great clinical significance

The increased P wave-to-R wave ratio in this study was 50% ≤ P/R ≤ 80% in 331 patients, 328 were in place, and only three were not, and its positioning accuracy rate was as high as 99.09%. When the catheter was inserted into the middle of the superior vena cava, the P-wave amplitude began to increase and reached the highest. When the P wave started to fall back and a negative-positive bidirectional wave appeared, it indicated that the catheter tip position was near and/or over the junction of the superior vena cava and the right atrium, and the catheter continued to be inserted. When the P-wave amplitude appeared to be a completely negative wave, it indicated that the catheter had entered the atrium. When the catheter was withdrawn until the negative wave of the negative-positive bidirectional wave disappeared, or the negative wave amplitude was less than 0.05 mv, and the percentage of the P wave-to-QRS complex ratio was then observed. Usually, when the P/R was 50%–80%, it was considered that the catheter tip reached the ideal position, which was consistent with the results of most studies in the domestic literature (Huang et al., 2017).

4.3.2 | P/R ratios above 80% were also more accurate in positioning, and it did not indicate that the location of the catheter tip was too deep

In clinical observations, we found that the increased P wave-to-R wave ratio was 80% < P/R ≤ 100% in a total of 425 cases, only three cases had catheter position that was too deep, the remaining 422 cases had the appropriate catheter tip position, and their positioning accuracy rate was as high as 99.29%. There were 48 cases with P/R > 100%, the catheter tips were all in place, and the positioning accuracy rate was 100%. Some researchers believed that when the P wave-to-QRS complex ratio is too high, exceeding 80%, it may result in a catheter tip position being too deep. Yang et al. (2019) showed that when the catheter tip reached the junction of the superior vena cava and the right atrium, the peak of the increased P wave was on par with or exceeded the R wave when the P wave started to fall back. If a slight negative wave (specific “Q” wave) with a downward starting segment appeared, it suggested that the catheter tip had entered the entrance of the right atrium. When the negative-positive bidirectional wave appeared in the P-wave and the negative wave amplitude was greater than 0.1 mv, it suggested that the catheter tip had entered the right atrium. When the positive P wave disappeared and a completely negative wave appeared, it indicated that the catheter tip had reached the lower part of the right atrium. Zhang et al. (2019) showed that the stability and accuracy of IC-ECG bimodal P waves, that is, negative-positive bidirectional waves, in guiding the positioning of the PICC tip, were high, which played a complementary and perfect role in locating the optimal position of the PICC tip. There were three types of IC-ECG maps in this study. One map was that the P-wave amplitude was more than 80% of the R-wave amplitude, and another was that the P-wave amplitude was equal to the R-wave amplitude. The last one was that the P-wave amplitude was greater than the R-wave amplitude. The above three atlases were verified by chest X-ray images for proper catheter tip position. The judgment of whether the catheter tip is too deep should be based on whether there is a negative wave at the beginning of the P wave. The presence of a negative P wave indicated that the catheter tip entered the atrium to receive the ECG signal, so the catheter depth could not be determined solely based on the magnitude of the P wave-to-the QRS complex ratio. When the catheter was close to the sinus node, the strongest ECG signal was received. There was a simultaneous increase in the amplitude of the P wave and QRS complex of the IC-ECG at this stage, which was expressed as P/R greater than 80% and/or P/R of 100%. In addition, the increase in the QRS complex of the IC-ECG was less than the increase in the P wave, which was expressed as a P wave higher than the amplitude of the R wave. This type of map was partly seen in patients with low voltage on the body surface ECG mapping and partly in patients with no abnormal voltage.

4.4 | Variable accuracy of catheter tip localization of non-characteristic P wave

4.4.1 | High localization accuracy of P/R < 50% in non-characteristic P waves but with negative small Q waves

The atypical characteristic P waves in this study were divided into four categories. The ratio of increased P-wave amplitude to QRS complex was below 50% in 72 patients, and all catheters were verified to be in place by chest X-ray with an accuracy rate of 100%. The results of this study showed that although the increase in P-wave amplitude was not large and the P/R was < 50%, the appearance of negative-positive bidirectional waves with continued catheter insertion and the disappearance of the negative wave (small Q wave) in the beginning segment of the P wave with catheter withdrawal could be observed. At this time, although there
was no characteristic increase in the P wave, it was also indicated that the catheter tip was close to or into the atrium if there was a negative-positive bidirectional waveform. The height of the negative wave amplitude in the P-wave initiation segment was mainly observed by such mapping. The location of the catheter tip was verified to be deeper by chest X-ray when the negative wave amplitude exceeded 0.1 mv. This study concluded that even if the ratio of P/R was less than 50%, it indicated that the catheter was in the correct position if there was a downward and then an upward wave amplitude at the beginning of the P wave and that the positive P wave disappeared. The negative wave was more pronounced when the catheter continued to be inserted, indicating that the catheter tip was near or in the right atrium.

4.4.2 | Low localization accuracy of an unchanged P wave

There were 35 cases with no change in P-wave amplitude, 14 cases with the catheter tip in place, and 21 cases not in place, with a positioning accuracy rate of 40%. Twenty-one cases were with catheter tip not in place, and 11 cases had catheter tip position above T5, 10 where the catheter tips were in the non-superior vena cava positions (one case had catheters folding back in the cephalic vein, two cases had catheter tips ectopic to the contralateral internal jugular vein, two cases had catheter tips ectopic to the contralateral subclavian vein, and five cases had catheters folding back to the axillary vein in the subclavian vein). In 14 cases, the catheter was in place, and the catheter tip position was observed to be at the level between T5 and T6 by chest X-ray. The catheter was in the upper part of the superior vena cava on late follow-up CT, so there was no change in the P-wave amplitude of the IC-ECG. After observation, we found that when the catheter was ectopic, the P wave in the cavity was unchanged or lower than the P-wave amplitude on the body surface, while the morphology of the QRS complex was different from that of the body surface ECG. When the catheter tip was in the middle and upper parts of the superior vena cava, the amplitude and morphology of the P wave and QRS complex were consistent with the body surface ECG. This study showed that when the P waves did not change, most of the time, the reason was that the catheter tip was ectopic, or the catheter tip might not reach the lower part of the superior vena cava or the junction of the superior vena cava and the right atrium, or the catheter tip was shallow and located in the upper or middle of the superior vena cava.

4.5 | Clinical significance of QRS complex amplitude changes

In this study, there were a total of 876 cases with an increased P wave and 738 cases with increased QRS complex, accounting for 84.25% of cases with increased P wave. The sinoatrial node sends out an excitation signal transmitted by the cardiac conduction system at a certain speed. The cardiac cell membrane forms an action potential through the flow of ions, which completes the depolarization and repolarization of the heart's atria and forms an ECG vector waveform, which can be received by placing electrodes on the surface of the human body through an ECG machine (Zhao et al., 2015). We call it ECG mapping. When the catheter tip enters the lower part of the superior vena cava near the sinoatrial node, it corresponds to the close reception of the unattenuated electrophysiological signal from the sinoatrial node and the cardiac conduction system, which is manifested as a gradual increase in the amplitude of both P wave and QRS complex. It can be concluded from this study that most of the P-wave increase would be accompanied by an increase in QRS complex amplitude, while there were some patients in whom the QRS complex did not increase with a P-wave amplitude increase. Therefore, when positioning the catheter tip by IC-ECG, it is important not to determine the location of the catheter tip based solely on the ratio of P and R waves but to make a comprehensive judgment to prevent inaccurate positioning. In addition, the morphological changes in the QRS complex observed in this study might be an indicator of catheter ectopy because when the catheter tip deviates from the position of the superior vena cava, there may be a difference in ECG vector and depolarization direction, and the morphology of the QRS complex may change accordingly. However, no clinically significant conclusion has been formed due to the small sample size in this study.

4.6 | Effect of respiration on the negative P-wave amplitude

In clinical practice, we found that the P-wave amplitude in the same lead changed with respiration. At the beginning of the P wave, the negative wave was sometimes absent, making it difficult for us to determine the catheter depth. This phenomenon occurs because the catheter is not stationary in the superior vena cava. It moves with respiratory movement, the location of the catheter tip becomes shallower, and the negative P wave disappears when the inspiratory phase diaphragm moves downward, the location of the catheter tip becomes deeper and enters the right atrium when the expiratory phase diaphragm moves upward, and a negative P wave appears. The relationship between the length of the catheter in the expiratory and inspiratory phases and the negative P wave could be observed when the patient was asked to breathe calmly during positioning to reduce the impact of breathing on the positioning of the catheter tip so that the catheter tip could be located in a relatively appropriate interval to prevent the location of the catheter tip from being too deep. This consideration is also related to the fact that the patient is often in a calm breathing state when performing intravenous therapy, and the catheter tip is located deepest at the end of expiration.
4.7 | Special cases

Regarding special cases such as atrial fibrillation and atrial flutter, a total of 29 cases were included in this study, and only 14 cases of the catheter tips were in place, with a localization accuracy of 48.28%. Atrial fibrillation and flutter are a kind of active ectopic arrhythmia with fast frequency, manifested by the disappearance of the P wave on the body surface ECG. Atrial flutter is manifested by the same size fast and regular flutter wave without isotonic line (F wave); atrial fibrillation is manifested by an atrial fibrillation wave (f wave) with different sizes and directions, fast and irregular. When the catheter tip reached the junction of the superior vena cava and right atrium, the wave amplitude of atrial fibrillation f wave and atrial flutter F wave could be observed to be significantly increased, and the increased atrial fibrillation f wave and decreased atrial flutter F wave after withdrawing the catheter were consistent with the body surface ECG (Zhao, 2015). However, there are few studies on the catheter tip localization of patients with atrial fibrillation and atrial flutter, and there is no certain standard for localization judgment, so the accuracy of catheter localization is low in these cases. This study only objectively recorded the IC-ECG mapping of special cases without in-depth research, and a redesigned study protocol is needed for such patients to explore further.

4.8 | Interference waves

There were five cases of interference waves in this study, four patients had catheters in place, and one had a catheter position that was too deep, with an accuracy rate of 80%. The baseline of the interference wave was unstable, and the waveform was serrated, affecting the observation of the negative P wave. In five patients (four critically ill patients), the occurrence of interference wave may be related to muscle tremors caused by the dry and tense skin of the patients, which also related to the alternating current interference of ventilators, monitors, ultrasonic probes, and other instruments and equipment (Yao and Zhang, 2018). It has been pointed out that IC-ECG is highly susceptible to interference from the external environment, among which the length of the guidewire and the site through which the guidewire passes can affect the stability of ECG images (Qin and Feng, 2015). In this study of interference wave cases, all five patients had a catheter placement length of more than 39 cm. In the positioning of catheter tip by ECG in critically ill patients, it was essential to assess in advance, eliminate patients’ concerns, clean their skin, and reduce the possible interference from various instruments.

4.9 | Inadequacy of chest X-ray image-guided positioning

A chest X-ray image is still the gold standard for PICC catheter tip positioning in China, but the shortcomings of chest X-ray image-guided positioning cannot be ignored. Changes in posture and breathing can affect the accuracy of catheter tip positioning. The standard chest X-ray is taken with the patient in a standing position, with the limbs forward and holding their breath after a deep inspiration. The diaphragm descends to a greater extent, which makes the position of the catheter tip relatively shallow. Foreign literature studies have shown that there is an error of 2 cm between the position of the catheter tip in the standing and lying positions. The center line’s position of the radiography machine during filming also affects positioning accuracy, with the catheter position becoming shallower if the centerline is shifted down and deeper if the centerline is shifted up. There are also disadvantages of chest X-ray image-guided positioning such as radiographic injury, positioning lag, and poor visualization (Sun et al., 2017; Zhang et al., 2016), so intracavitary electrocardiography is highly feasible as an alternative to chest X-ray for PICC tip positioning.

The meta-analysis study by Yintian Liu et al. showed that the IC-ECG-guided localization method did not differ from the chest X-ray image-guided localization method in confirming whether the catheter tip was in place. The integration of catheter tip placement and localization could be realized. This technique had obvious advantages in determining the catheter tip position, and it suggested that characteristic P waves could replace chest X-ray (Liu et al., 2017), and most of the literature in recent years also supports the above theory. However, there is no accurate criterion for the relationship between ECG mapping changes and the inferior, superior vena cava, and the junction of the superior vena cava and the right atrium. This study was conducted to compare the consistency of various mapping changes in P waves and QRS complex with chest X-ray images and concluded that the negative wave amplitude of the negative–positive bidirectional wave of the P wave was more instructive for whether the catheter tip position was optimal than the proportion of positive P-wave amplitude in the R wave. Although there is much literature on IC-ECG studies, the data on specific P-wave mapping changes compared with chest X-ray images are not clearly defined and should be further investigated. In addition, there were restrictions to the use of chest X-ray comparison in this study because of the limitations of chest X-ray image-guided positioning, and further exploration of other localization methods such as comparison of CT and IC-ECG should be undertaken to find a comprehensive and better method of catheter tip localization for the benefit of the majority of patients.

CONFLICT OF INTEREST
The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS
DH and ZY designed this study. YX and ZY contributed to the data collection, performed the data analyses, interpreted the data, and wrote the manuscript. All contributions critically revised the final manuscript.

ETHICAL APPROVAL
This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of Shijiazhuang people’s Hospital.
DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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