International Journal of Biology and Life Sciences
ISSN: 2957-9511 | Vol. 16, No. 2, 2026

Analysis of P-wave Morphology Changes and Related Influencing Factors during PICC Catheterization in Tumor Patients Using Intracavitary Electrocardiographic Monitoring Localization Technology

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Abstract: Objective To explore the changes in P-wave morphology during peripherally inserted central catheter (PICC) placement under intracavitary electrocardiographic (ECG) monitoring and analyze the related influencing factors. Methods A total of 180 patients who underwent PICC procedures at a tertiary cancer hospital in Shandong Province from December 2025 to May 2026 were selected as the study subjects. All patients underwent catheterization guided by intracavitary ECG monitoring, and their ECG monitor's lead II was observed to record characteristic high-spike P-waves, double-peaked P-waves, and the extraction rate and positioning accuracy of bidirectional P-waves. Univariate analysis of variance (ANOVA) and multivariate linear regression analysis were used to investigate the influencing factors of intracavitary ECG P-waves. Results All 180 patients completed PICC placement, and intracavitary ECG monitoring was performed after catheterization. The results indicated that the top two factors affecting intracavitary ECG P-wave changes were characteristic high-spike P-waves and bidirectional P-waves in lead II, accounting for 93.87% and 85% respectively. Univariate ANOVA revealed that patient height, gender, baseline P-wave amplitude, and catheterization site were associated with changes in intracavitary ECG P-waves ($P < 0.05$); multivariate linear regression analysis showed that patient baseline P-wave amplitude and catheterization site had significant effects on intracavitary ECG P-waves ($P < 0.05$). Conclusion The application of intracavitary ECG monitoring for PICC placement can reduce radiation hazards, is safe, low-cost, and holds positive significance and broad application prospects.

Keywords: P-wave Morphology; Intracavitary Electrocardiographic Monitoring Localization Technology; PICC; Tumor Patients.

1. Introduction

In recent years, the incidence rate of malignant tumors in China has shown a further upward trend. Due to high consumption, tumor patients require intravenous nutrition infusion, blood transfusion, and various irritant drugs. Central venous catheterization is commonly used in clinical practice [1].Compared with other venous access methods, peripherally inserted central venous catheters (PICC) have potential advantages such as longer indwelling time, lower cost, reduced risk of vascular and skin irritation, higher safety factor, convenient maintenance, and less patient pain, making them popular among tumor patients and medical professionals. PICC is a medium- to long-term catheter that is inserted into the central vein through peripheral venous puncture. Accurate positioning of its tip is crucial for preventing complications and ensuring treatment safety[2]. The positioning technology has evolved from traditional blind insertion confirmed by X-ray to real-time navigation with intracavitary electrocardiographic monitoring, significantly improving accuracy and safety. If the catheter tip does not reach the central vein, high-osmolar/irritant drugs (such as chemotherapy drugs) can easily cause serious complications such as phlebitis, vascular sclerosis, thrombosis, and arrhythmia. X-ray positioning requires postoperative verification, and if misplaced, secondary catheter adjustment is necessary, increasing the risk of infection. Intracavitary electrocardiographic monitoring technology allows for real-time adjustment by monitoring P-wave changes during surgery, achieving a one-time success rate of up to 98% [3]. This study selected 180 patients who underwent peripherally inserted central venous catheterization in a tertiary cancer hospital in Shandong Province from December 2025 to May 2026 for research, and explored and confirmed changes in P-wave morphology and related influencing factors during PICC catheterization under intracavitary electrocardiographic monitoring. The results are reported as follows.

2. Materials and Methods

2.1. General Information

From December 2025 to May 2026, 180 tumor patients who underwent peripherally inserted central catheter (PICC) placement in a tertiary cancer hospital in Shandong Province were selected as the study subjects. General patient information and catheterization-related data were collected.

Inclusion criteria: Electrocardiogram results indicate normal P waves; meet the indications for peripherally inserted central catheter (PICC); normal upper limb mobility; intact puncture skin; medical devices are intact and undamaged.

Exclusion criteria: patients with catheter malposition found by X-ray examination after catheterization; patients who have undergone neck radiotherapy or have neck diseases; patients with cardiac pacemakers or implantable defibrillators; patients with catheter tips not in the expected position.

2.2. Method

Operation method: Each patient was operated on by two or

more personnel. One nursing staff completed the catheterization procedure for the patient, while the other nursing staff strengthened the electrocardiogram (ECG) monitoring of the patient during catheterization and recorded the ECG details, including the P wave in lead II. After the above procedures were completed, the junction between the superior vena cava and the right atrium was clearly identified. Finally, the catheter position was further confirmed through chest X-ray examination.

Measurement tool: This study utilizes a self-designed questionnaire, which primarily includes information such as the patient's age, height, weight, gender, baseline heart rate, baseline P-wave amplitude, as well as details about the catheterization site, insertion length, catheter type, and the syringe used.

2.3. Observation Indicators

All patients completed electrocardiogram (ECG) testing, and the number of cases with characteristic high-spike P waves, double-peaked P waves, and bidirectional P waves was recorded in detail, along with an analysis of their accuracy.

2.4. Statistical Methods

Data analysis was conducted using SPSS 26.0. Descriptive statistics were presented as mean ± standard deviation, frequency, and percentage. Univariate analysis was performed using one-way ANOVA, while multivariate analysis was conducted using binary logistic regression analysis.

3. Results

3.1. General Information

Among the 180 patients who underwent catheterization, 119 were male and 61 were female. Age distribution: 8 aged 18-29 years, 22 aged 30-39 years, 48 aged 40-49 years, 71 aged 50-59 years, and 31 aged ≥60 years. Height distribution: 29 cases ≤160cm, 46 cases 161-165cm, 46 cases 166-170cm, and 59 cases ≥171cm. Weight distribution: 24 cases ≤50kg, 71 cases 51-60kg, 58 cases 61-70kg, and 27 cases >70kg. Baseline heart rate: 44 cases 60-70 beats/min, 79 cases 71-80 beats/min, 30 cases 81-90 beats/min, and 27 cases 91-100 beats/min. Catheterization length: 126 cases 30-40cm, and 54 cases 41-50cm. Catheterization site: 106 cases on the right side, and 74 cases on the left side.

3.2. Types and Composition Ratio of Diseases Treated in Patients with PICC Catheterization

All 180 patients who underwent PICC catheterization had solid or hematological malignancies. The top three types of malignancies were acute myeloid leukemia, lung cancer, and gastric cancer, with 84, 49, and 47 cases, respectively, accounting for 46.67%, 27.22%, and 26.11% of the total.

3.3. Morphological Changes and Composition Ratio of P Waves in Intracardiac Electrocardiogram during PICC Catheterization

All 180 patients completed PICC catheterization, and intracavitary electrocardiogram (IECG) detection was performed after catheterization. The results showed that the top two changes in P waves in IECG were characteristic high-spike P waves and bidirectional P waves in lead II, accounting for 86.25% and 66.25% respectively. Details are shown in Table 1.

Table 1. Changes in intracavitary electrocardiogram P-wave morphology and composition ratio during PICC catheter placement (n=180)

P-wave type	n	Percentage (%)
Characteristic tall peaked P-wave in lead II	169	93.87
Biphasic P-wave	153	85
Notched (bifid) P-wave appearing before tall peaked P-wave	78	43.33
Neither characteristic tall peaked P-wave nor biphasic P-wave could be elicited	12	6.67

3.4. One-way ANOVA for Patients with PICC Catheterization

The results indicated that the patient's gender, presence of characteristic P waves, and the site of catheterization were associated with changes in intracavitary electrocardiogram P waves ($P<0.05$), while the remaining factors showed no statistical significance ($P>0.05$). Details are provided in Table 2.

Table 2. Univariate analysis of variance (ANOVA) in catheterized patients (n=180)

Variable	F value	P value
Age	1.622	0.171
Height	2.696	0.056
Weight	0.365	0.779
Sex	5.143	0.023
Baseline heart rate	0.137	0.942
Presence of cardiac disease	1.431	0.278
Presence of normal electrocardiogram	11.37	0.053
Appearance of characteristic P-wave	4.121	0.039
Catheter placement site	8.54	0.049
Insertion length	1.978	0.677
Catheter type	1.146	0.741
Syringe type used	1.223	0.421

3.5. Multivariate Linear Regression Analysis of Patients with PICC Catheterization

Taking whether characteristic P waves are obtained during catheterization as the dependent variable, factors that are statistically significant in one-way ANOVA, namely patient height, gender, baseline P waves, and catheterization site, were subjected to multiple linear regression analysis. The results showed that the presence of baseline P waves and catheterization site were statistically significant ($P<0.05$). The assignment of values is shown in Table 3, and the linear regression analysis is shown in Table 4.

Table 3. Assignment of variables for multivariate analysis in catheterized patients

Independent variable	Assignment
Patient sex	Male = 0, Female = 1
Baseline P-wave amplitude	0.5-1.0 cm = 0, 1.0-1.5 cm = 1
Catheter placement side	Left = 0, Right = 1

4. Discussion

PICC is a widely used medical treatment measure in clinical medicine, mainly involving the placement of a central venous catheter into a peripheral vein of the patient. It is particularly extensively applied in the clinical treatment of

cancer patients[4]. Although X-ray imaging technology is a commonly used method for locating the tip of the PICC catheter, its imaging results serve as the "gold standard" for PICC catheter tip positioning[5].

Table 4. Multivariate linear regression analysis (n=180)

Variable	B	Standard Error	Beta	t	p	VIF	95% CI
Constant	-0.12	0.673	-	-0.18	0.857	-	-1.450 to 1.207
Sex	0.525	0.347	0.085	1.51	0.133	1.198	-0.161 to 1.210
Baseline P-wave amplitude	0.42	0.154	0.154	2.733	0.007**	1.202	0.117 to 0.723
Catheter placement site	1.189	0.369	0.192	3.224	0.001**	1.338	0.461 to 1.916

However, due to the poor physical condition of some patients, they cannot undergo repeated X-ray imaging examinations, and it is difficult for them to adapt to multiple adjustments of the PICC catheter tip position. Therefore, intracardiac electrocardiographic monitoring technology has been adopted as one of the main techniques for PICCcatheter tip positioning in clinical medicine, especially suitable for patients with advanced cancer, younger patients, or elderly patients with poor health. Compared to X-rays, intracardiac electrocardiographic monitoring allows for efficient catheter placement and positioning directly at the bedside using an electrocardiographic monitor. Even in cases of catheter malposition during clinical practice, adjustments can be made promptly under the monitoring of the electrocardiographic monitor, without requiring patients to be transferred to the imaging department for adjustments[6].

The results of this study are similar to those of Li Fang et al.[7]. Their study indicated that bimodal P waves can serve as a supplementary condition for diagnosing morphological changes in intracardiac P waves, thereby facilitating the improvement of catheter tip positioning accuracy. Bimodal P waves are indicative of the simultaneous reception of depolarization waves from both the left and right atria by the catheter's guidewire. They also serve as a marker indicating the catheter tip's entry into the entrance of the right atrium. Moreover, bidirectional P waves are the sole basis for indicating the catheter tip's position in the right atrium. The presence of bidirectional P waves indicates that the catheter tip is located between the lower part of the right atrium and the upper part of the right ventricle. However, the elicitation rate of bidirectional P waves is 85.00%, which cannot accurately determine the position of the catheter tip within the atria. Therefore, solely eliciting bidirectional P waves may lead to the catheter entering the ventricle or atrium too deeply, potentially damaging the patient's heart valves and causing arrhythmias. Additionally, bimodal P waves occur earlier than high-spike P waves and bidirectional P waves, and the appearance of high-spike P waves does not affect the elicitation of bimodal P waves. Therefore, the combination of high-spike P waves, bidirectional P waves, and bimodal P waves can better reflect the positioning conditions of the catheter tip entering the junction between the superior vena cava and the right atrium, thereby effectively improving the positioning accuracy[8].

In this study, female patients who exhibited characteristic P waves and those undergoing right-sided catheterization were more likely to obtain characteristic high-spike P waves, indicating that ECG-guided positioning has better applicability for different patients. The possible reason for this is that when the atria enlarge and conduction between the two atria becomes abnormal, characteristic P waves are less likely to appear. When the catheter is placed on the left side and enters the superior vena cava, it tends to form an angle with the superior vena cava, and the contact between the catheter and the venous wall can affect the observation of P waves. This is consistent with the research of Kremser[9], who believes that in the case of left-sided catheterization, the accuracy of ECG monitoring positioning is relatively low.

5. Conclusion

In summary, the presence of double-peaked P waves, bidirectional P waves, and characteristic high-spike P waves during electrocardiographic monitoring during PICC catheterization can serve as important indicators for locating the catheter tip. The combination of double-peaked P waves can accurately reflect the entry of the catheter tip into the superior vena cava. However, electrocardiographic monitoring is currently not regarded as the gold standard for diagnosing the position of the PICC catheter tip in China. This requires more clinical research data to support its importance, so that this technique can be better applied in clinical practice to serve patients.

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