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Clinical application of intracavitary electrocardiogram localization combined with ultrasound in central venous catheterization in critically ill patients

An observational study

Zhenfei Pan, MB[a], Jinqiang Zhu, MB[b], Zhenzhen Jiang, MB[b], Lili Chen, MB[b,*]

Abstract

To explore the clinical application value of intracavitary electrocardiogram (ECG) localization combined with ultrasound in central venous catheterization in critically ill patients. A total of 103 patients who were treated in the intensive care unit of our hospital from October 2020 to June 2023 were selected as the study subjects, and according to the differences in their central venous catheter placement methods, they were divided into study group (n = 52, receiving ultrasound combined with intracavitary ECG localization for catheterization) and control group (n = 51, receiving routine catheterization). The differences in the catheter placement accuracy, catheter depth, catheter placement duration, incidence of catheter-related complications, length of stay, and hospitalization expenses between the 2 groups were compared. The analysis utilizing X-ray for catheter tip positioning indicated that the catheter tip placement rate was higher in the study group than in the control group, and the catheter tip malposition rate was lower than in the control group ($P < .05$). There was no statistical significance in the catheter depth between study group and control group ($P > .05$), and the catheter placement duration of study group was significantly lower than that of control group, with statistical significance ($P < .05$). One case of partial catheter blockage, one case of catheter-related bloodstream infection, and one case of phlebitis were observed in study group, with an overall incidence of complications of 5.77% (3/52), which was significantly lower than 21.57% (11/51) of control group ($P < .05$). The length of stay and hospitalization expenses in study group were significantly lower than those in control group, with statistical significance ($P < .05$). The combined use of ultrasound and intracavitary ECG localization in critically ill patients undergoing central venous catheterization can help increase the success rate of catheter placement, shorten the catheter placement duration, reduce the incidence of various catheter-related complications, and also reduce the length of stay and hospitalization expenses.

Abbreviation: ECG = electrocardiogram.

Keywords: central venous catheterization, complications, Intracavitary ECG localization, success rate of catheter placement, ultrasound

1. Introduction

The central venous catheter is placed through the subclavian vein, internal jugular vein, or femoral vein, with its tip positioned in the superior vena cava or inferior vena cava.[1] It is currently widely used in the intensive care unit and serves as a crucial lifeline for critically ill patients.[2,3] The 2016 American Society for Parenteral and Enteral Nutrition guidelines recommend that the tip of a central venous catheter inserted through the upper body should be positioned in the lower segment of the superior vena cava or near the junction of the superior vena cava and right atrium, while the tip of a central venous catheter inserted through the lower body should be located above the diaphragm in the inferior vena cava.[4] At present, central venous catheterization in clinical practice is mainly performed using blind punctures of the subclavian vein or internal jugular vein, which is prone to complications such as catheter tip malposition during catheterization, and it is difficult to ensure that the catheter can be put in place at one time each time. Existing literature reports that the incidence of catheter malposition is about 2.3% to 76.0% abroad and 3.7% to 40% domestically, most of which is catheter malposition in internal

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jugular vein.[5] Although clinical skills gradually mature with increasing experience, deviation of the catheter tip from the ideal position may inevitably occur due to the individual differences in patients.[6]

The accurate positioning of the central venous catheter tip is of great significance in reducing complications such as catheter-related phlebitis, venous thrombosis, and bloodstream infections, and ensuring the safety of intravenous therapy for patients.[7,8] Currently, the commonly used confirmation is chest radiograph localization after catheter placement. However, this confirmation needs to be carried out after the end of the catheter placement procedure. Even if there is tip malposition, the sterile aids for puncture have been discarded, making it difficult to adjust catheter and increasing the risk of infection, and there are drawbacks such as delay, cost and radiation, which hinder the adoption of electrocardiogram (ECG) catheter tip confirmation.[9] In recent years, both domestic and foreign scholars have conducted research on real-time monitoring methods of catheter tip position during catheterization, and various methods such as electromagnetic navigation, central venous pressure positioning, cough-induced movement positioning, and esophageal ultrasound positioning have been continuously explored, but most of the above-mentioned methods focus on the placement of peripherally inserted central venous catheter, with limited attention to the accuracy of the tip position of central venous catheters.[10]

Intracavitary ECG localization technique refers to connecting the central venous catheter or guidewire to the electrocardiographic monitor through the electrocardiographic lead wires, and the position of the catheter tip is determined based on the characteristic change of the ECG P-wave of lead II during catheter placement, allowing for integrated catheter placement and localization.[11] However, the single intracavitary ECG localization technique can only identify that the catheter tip is not in the superior vena cava, and cannot determine which blood vessel the tip has misplaced to, and if combined with ultrasound examination for exploration of the blood vessels, it will assist the operator in redirecting the catheter to the correction position.[12] The above serves as the theoretical basis for this study, and through adopting grouping and comparison, it was found that the intracavitary ECG localization technique combined with ultrasound can indeed effectively reduce the incidence of central venous catheter tip malposition during placement. The details are now described below.

2. Materials and methods

2.1. General data

A total of 103 patients who were treated in the intensive care unit of our hospital from October 2020 to June 2023 were retrospectively selected as the study subjects, and according to the differences in their central venous catheter placement methods, they were divided into study group (n = 52, receiving ultrasound combined with intracavitary ECG localization for catheterization) and control group (n = 51, receiving routine catheterization). In the study group, there were 38 males and 14 females, with a mean age of (57.48 ± 19.11) years, and in the control group, there were 37 males and 14 females, with a mean age of (60.71 ± 14.35) years. There was no significant difference in the baseline data of the patients in the 2 groups ($P > .05$), exhibiting good comparability. The study was reported to the Ethics Committee of The First People's Hospital of Wenling for approval (approval number KY-2022-1018-01). Informed consent was waived by the Ethics Committee of The First People's Hospital of Wenling due to the retrospective nature of this research.

Inclusion criteria: patients who aged ≥ 18 years; patients who required central venous catheterization; and patients with central venous catheter placement in the superior vena cava.

Exclusion criteria: patients who did not agree with themselves or their family members, or who were uncooperative; patients with relative contraindications for CVC placement, such as thrombosis or coagulation disorders; patients with heart disease, pacemakers, post-cardiac surgery, or other conditions that may affect the P-wave; and patients with ECG abnormalities.

2.2. Catheter placement methods

The included patients were divided into a control group and a study group, with steps 1, 4 and 6 in the control group and steps 1 to 6 in the study group.

Steps: The patient were placed in supine position; The ECG monitor was opened and set to lead II, the lead III ECG (white, black, red) was connected, the surface baseline ECG was stored or printed; A pre-catheterization vascular assessment was performed using ultrasound; The central venous catheter was inserted by blind puncture to the predetermined length following standard procedure; The exposed length of the guidewire was adjusted to align it with the inner opening of the catheter. The white lead wire and electrode were removed and attached to the far end of the guidewire. The changes in the P-wave on the ECG were observed. If there were variations in the P-wave, the position of the catheter and guidewire was simultaneously adjusted to the optimal location. If no variations in the P-wave occurred, ultrasound was used to explore the internal jugular vein, external jugular vein, axillary vein, and subclavian vein, ruling out any anomalies and adjusting the tip of the catheter to the optimal position; and The patient was assisted in undergoing a bedside chest X-ray to determine the position of the catheter tip.

2.3. Observation indicators and evaluation standard

Chest X-ray images were used to mark various veins and record the position of the catheter tip.

Axillary vein: between the lateral margin of the thoracic cavity and the lateral margin of the first rib;

Internal jugular vein: superior margin of clavicle upward;

Subclavian vein: medial axillary vein, above the inferior margin of the medial end of the clavicle

Cephalic vein: below the inferior margin of the medial end of the clavicle and above the superior margin of the beginning of the right main bronchus;

Superior vena cava upper segment: within one posterior rib height range of the right main bronchus from the superior margin of the beginning of the right main bronchus to the right main bronchus;

Superior vena cava middle segment: overlapping with the position of the right main bronchus;

Superior vena cava lower segment: within a range of 2 vertebral units below the level of the right main bronchus and below the inferior margin of the tracheal carina;

CAJ: within a range of 1.5 to 2 vertebral units (vertebrae + intervertebral discs) below the inferior margin of the tracheal carina.

2.4. Accuracy indicator of catheter tip placement

X-ray showed that the tip of the catheter was located in the lower segment of the superior vena cava, indicating that the catheter tip was in place. The catheter tip placement rate = the number of catheters with the tip located in the lower segment of the superior vena cava/the total number of catheters included in the group × 100%.

2.5. Malposition indicator of catheter tip

X-ray showed that the catheter tip was located outside the superior vena cava. The catheter tip malposition rate = number

Table 1

Difference analysis of general clinical data between the 2 groups (mean ± SD)/[n (%)].

Clinical data		Study group (n = 52)	Control group (n = 51)	Fisher/χ^2/t	P
Gender	Male	38	37	0.004	.952
	Female	14	14		
Average age (years)		57.48 ± 19.11	60.71 ± 14.35	1.635	0.163
Vascular location	Jugular V	3	8	2.655	.103
	Subclavian V	49	43		
Vascular site	Left	0	1	1.030	.310
	Right	52	50		
Number of catheter lumens	Double	17	12	1.069	.301
	Single	35	39		

of catheter cases with catheter tips located outside the superior vena cava/total number of catheters included in the group × 100%.

2.6. Catheter depth and catheter placement duration in 2 groups

The catheter depth referred to the distance from the puncture point to the tip of the catheter, and the catheter placement duration was the duration from puncture needle insertion to catheter fixation.

2.7. Catheter-related complications in 2 groups

The incidence of partial catheter blockage, deep vein thrombosis, catheter-related bloodstream infection and phlebitis in the 2 groups were analyzed.

2.8. Length of stay and hospitalization expenses between the 2 groups

The length of stay and hospitalization expenses of the 2 groups were counted, and the difference between the 2 groups was compared.

2.9. Quality control

In order to reduce the influence of work experience and operation level on the study, the central venous catheterization of the patients included in this study was done by the same medical practitioner with the qualification of puncture in the intensive care ward, and the ECG export was also done by the same registered nurse with the qualification of specialist nurse of venous therapy at the provincial level in Zhejiang. Data collection was conducted by 2 individuals working together, and any errors and omissions identified during the data entry process were promptly verified and corrected in original data.

2.10. Statistical methods

The data were verified to be correct and then imported into the SPSS 19.0 (Armonk, NY: IBM Corp.) for statistical analysis. The normally distributed measurement data were presented as (mean ± standard deviation), and the independent sample t test was conducted. Counting data were presented as frequency/percentage, and the chi-square test was used. In the chi-square test, if the total sample size (n) was greater than or equal to 40, but one of the expected counts $1 \leq T < 5$, the continuity correction chi-square test was used; if the expected count was less than 1 or the total sample size was less than 40, the Fisher exact probability method was employed. All statistical analyses were based on two-sided hypothesis tests. $\alpha = 0.05$ was used as the test level.

Table 2

Comparison of catheter tip in place in 2 groups of patients [n (%)].

Group	Cases	Cases with catheter tip in place	Cases with catheter tip not in place
Study group	52	50	2
Control group	51	15	36
Fisher/$^{-2}$	–	51.954	
P	–	.000	

3. Results

3.1. Difference analysis of general clinical data between the 2 groups

General clinical data of the 2 groups of patients such as gender, average age, vascular location, vascular site, number of catheter lumens, etc. were included, and intergroup comparison was implemented, which showed no statistically significant difference between the 2 groups of patients in the above data ($P > .05$), suggesting good comparability of the 2 groups of patients, as shown in Table 1.

3.2. Comparison of catheter positioning accuracy in 2 groups of patients

X-ray was used to determine the position of the catheter tip, and the analysis showed that the study group exhibited a higher catheter tip placement rate and a lower catheter tip malposition rate compared to the control group ($P < .05$), as shown in Tables 2 and 3; Figures 1 and 2.

3.3. Comparison of catheter depth and catheter placement duration in 2 groups

There was no statistical significance in the catheter depth between study group and control group ($P > .05$), and the catheter placement duration of study group was significantly lower than that of control group, with statistical significance ($P < .05$), as shown in Table 4; Figure 3.

3.4. Comparison of catheter-related complications in 2 groups

One case of partial catheter blockage, one case of catheter-related bloodstream infection, and one case of phlebitis were observed in study group, with an overall incidence of complications of 5.77% (3/52), which was significantly lower than 21.57% (11/51) of control group ($P < .05$), as shown in Table 5; Figure 4.

3.5. Comparison of length of stay and hospitalization expenses in 2 groups

The length of stay and hospitalization expenses in study group were significantly lower than those in control group, with statistical significance ($P < .05$), as shown in Table 6; Figure 5.

4. Discussion

In 2021, The General Office of the National Healthcare Commission of China issued the "Notice on the Improvement Targets of National Healthcare Quality and Safety for 2021," in which the document explicitly stated that in order to improve the quality and safety of healthcare, two of the main targets were namely to "reduce the incidence of intravascular catheter-associated bloodstream infections and "improve the standardized prevention rate of venous thromboembolism,"[12] and the achievement of these two major targets was inextricably linked to the accuracy of the tip position of central venous catheters. To ensure the safety of intravenous treatment for patients, the tip position of the central venous catheter is critical, and the methods and timing for positioning the tip of the central venous catheter vary according to technological advancements and national conditions.[13] At present, post-catheterization X-ray positioning is still the gold standard for central venous catheter tip positioning. However, this positioning method can only be applied after catheterization and is not suitable for use during catheterization. It is also inconvenient for critically ill patients, pregnant women, and other special patients, and if catheter repositioning is required, it may increase the risk of catheter-related infections for patients and can result in increased financial burden due to the need for secondary examinations or failed adjustment.[14,15] Although many studies have explored how to improve the success rate of central venous catheter placement, there are still some defects or deficiencies, and insufficient attention has been paid to the accuracy of the tip position of central venous catheter.

This study analyzed the clinical value of intracavitary ECG localization combined with ultrasound in central venous catheterization in critically ill patients by adopting a grouping and comparison method. The analysis utilizing X-ray for catheter tip positioning indicated that the catheter tip placement rate was higher in the study group than in the control group, and the catheter tip malposition rate was lower than in the control group ($P < .05$), suggesting that ultrasound combined with intracavitary ECG localization could indeed significantly improve the accuracy of central venous catheter puncture. The authors of this article analyzed that the traditional methods of catheter placement measurement can only rely on the external measurements of catheter length, and factors such as the patient's body size, the operator's experience, measurement methods, and the patient's vascular direction can all have an impact on the accuracy of the catheter placement, leading to the occurrence of catheters being inserted too deep or too shallow.[16] Mariyaselvam et al[17] pointed out that nearly 32% of the 59 cases studied had operator error, resulting in failed catheterization and a low success rate. In this study, the intracavitary ECG localization technique was applied to the patients in study group, which has the advantages of simple operation and

Table 3

Comparison of catheter tip malposition in 2 groups of patients (n).

Group	Cases	Cases with malposition of catheter tip	Cases without malposition of catheter tip
Study group	52	1	51
Control group	51	16	35
Fisher/$^{-2}$	–	15.882	
P	–	.000	

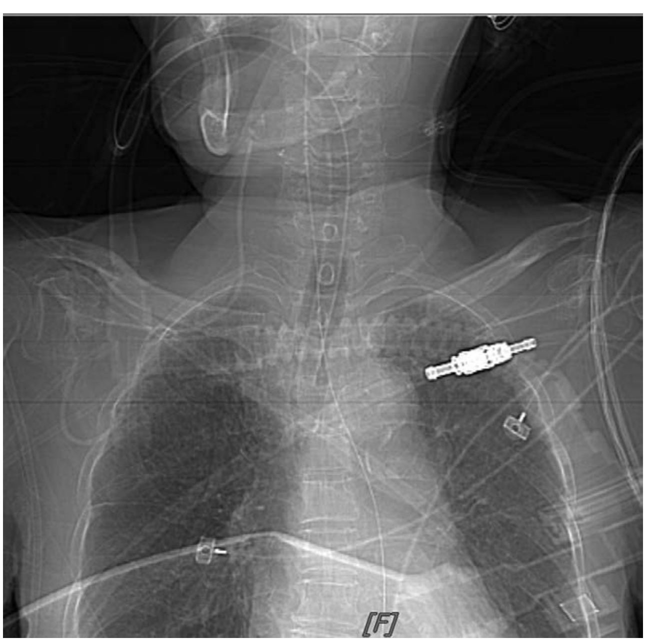

Figure 1. Typical catheter malposition X-ray 1. Patient A, female, 85 years old, cerebral infarction (right temporo-occipital lobe), acute respiratory failure, puncture in subclavian V, catheter placement depth 14 cm, malpositioned location: internal jugular V.

Table 4

Comparison of catheter depth and catheter placement duration in 2 groups (mean ± SD).

Group	Case	Catheter depth (cm)	Catheter placement duration (min)
Study group	52	15.73 ± 1.00	23.26 ± 4.01
Control group	51	15.51 ± 1.25	25.69 ± 3.96
t	–	0.988	3.094
P	–	.326	.003

Figure 2. Typical catheter malposition X-ray 2. Patient B, male, 55 years old, traumatic subarachnoid hemorrhage with scalp avulsion injury, puncture in subclavian V, catheter placement depth 17 cm, malpositioned location: subclavian V.

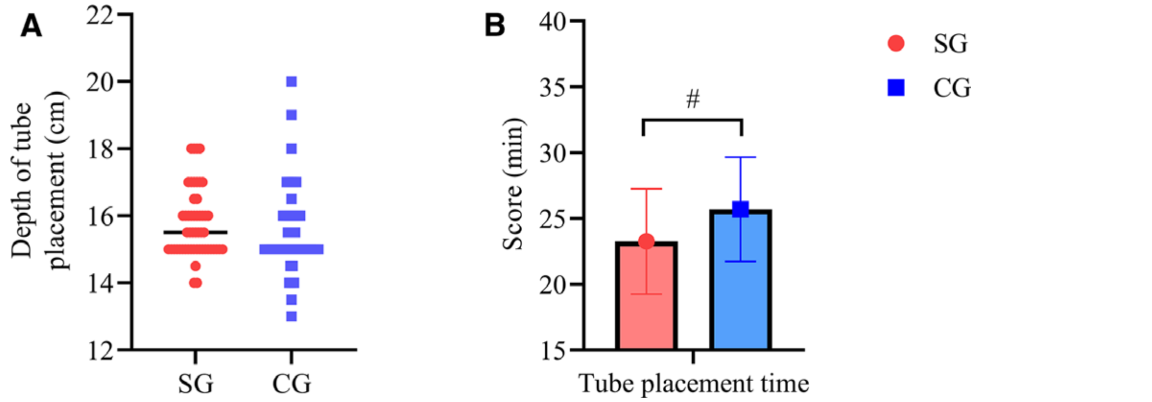

Figure 3. Comparison of catheter depth and catheter placement duration in 2 groups. There was no statistical significance in the catheter depth (A) between study group and control group ($P > .05$), and the catheter placement duration (B) of study group was significantly lower than that of control group, with statistical significance ($P < .05$). #Statistical significant difference.

Table 5

Comparison of catheter-related complications in 2 groups [n (%)].

Group	Case	Partial catheter blockage	Deep venous thrombosis	Catheter-related bloodstream infection	Phlebitis	Total
Study group	52	1 (1.92)	0 (0.00)	1 (1.92)	1 (1.92)	3 (5.77)
Control group	51	2 (3.92)	3 (5.88)	2 (3.92)	4 (7.84)	11 (21.57)
χ^2	–	–	–	–	–	5.472
P	–	–	–	–	–	.019

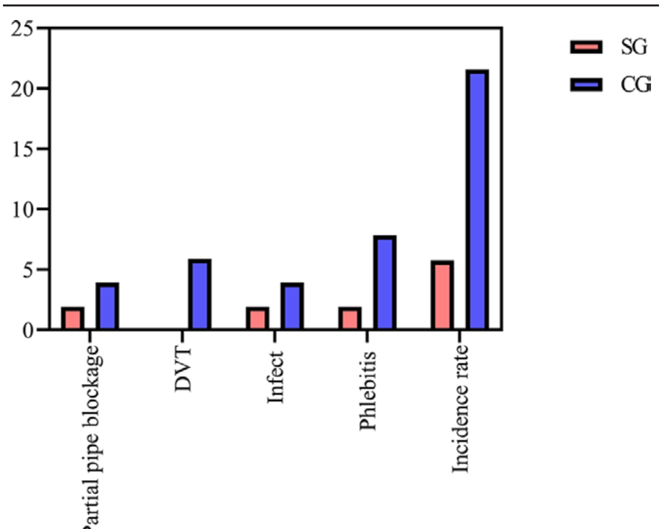

Figure 4. Comparison of catheter-related complications in 2 groups. The total incidence of complications in study group was 5.77% (3/52), significantly lower than 21.57% (11/51) in control group ($P < .05$).

short learning cycle, and it is also suitable for special populations such as pregnant women, critically ill patients, children, and individuals with limited mobility, in a coma, or requiring fluid replacement therapy.[18] The comparison of this study also showed that ultrasound combined with intracavitary ECG localization technique is valuable in improving the accuracy of catheterization.

In addition, this study also compared the differences in catheter depth and catheter placement duration between the 2 groups, and the results showed that the catheter placement duration of patients in study group was significantly lower than that of patients in control group, and the differences in catheter depth between the 2 groups were not significant.

Table 6

Comparison of length of stay and hospitalization expenses in 2 groups (mean ± SD).

Group	Case	Length of stay (d)	Hospitalization expenses (ten thousand yuan)
Study group	52	12.36 ± 2.65	4.56 ± 0.51
Control group	51	14.22 ± 2.04	4.79 ± 0.44
t	–	3.986	2.449
P	–	.000	.016

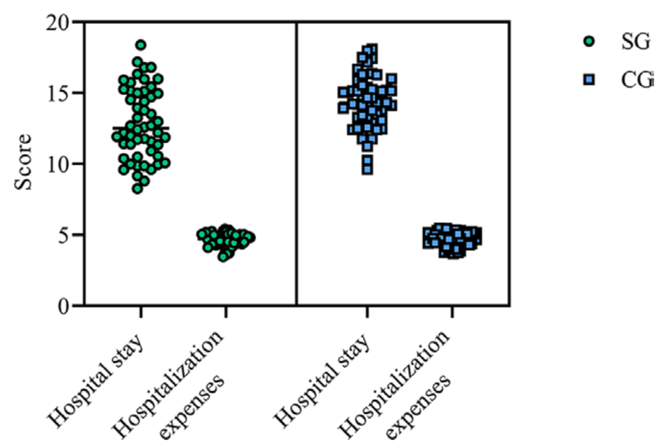

Figure 5. Comparison of length of stay and hospitalization expenses in 2 groups. The length of stay and hospitalization expenses in study group were significantly lower than those in control group, with statistical significance ($P < .05$).

The authors of this study analyzed that in the traditional catheterization process, in order to speculate on the effect of catheterization, the operator needs to continuously observe the changes in the patient's ECG waveform and speculate the catheterization condition based on the ECG waveforms, which is a severe test for the operator and also requires a lot of time.[19] As for the ultrasound combined with intracavitary ECG confirmation carried out in the patients of study group in this study, the intracavitary ECG localization technique was used to detect the position of the catheter tip and guide the operator to adjust the catheterization scheme, and ultrasound examination was employed to detect any ectopic blood vessels around the catheter placement site, providing clear guidance to the operator for the correct path of catheter delivery; the combination of the two techniques provided a straightforward and concise approach for the operator, significantly shortening catheter placement duration.[20]

In this study, the comparison of the incidence of catheter-related complications between the 2 groups of patients suggested that ultrasound combined with intracavitary ECG localization technique could significantly reduce the incidence of catheter-related complications. Previous studies have confirmed that complications such as phlebitis and infections are prone to occur during the central venous catheterization process,[21,22] and the reasons for this are related to factors such as the operator's catheterization skill, catheter type, catheterization site, and the number of punctures. In this study, there was no statistically significant difference in the general clinical data between the 2 groups of patients. Moreover, both groups underwent visual procedures performed by the same group of physicians and nurses, thus excluding operator-related factors. Therefore, the significant reason for the difference in the incidence of complications between the 2 groups of patients in this study was the difference in the catheterization methods. The authors of this study analyzed that the reason for the higher incidence of complications in control group was the frequent readjustment of the catheter during catheter placement process, causing mechanical damage to the patients' vascular endothelium, and at the same time, the endothelial injury induced a coagulation reaction, leading to various complications.[23] The comparison of length of stay and hospitalization expenses between the 2 groups of patients in the study confirmed that the combination of ultrasound and intracavitary ECG localization techniques could shorten patients' length of stay and lower their hospitalization expenses, which is of positive significance for building a harmonious doctor-patient relationship.

5. Conclusions

The combined use of ultrasound and intracavitary ECG localization in critically ill patients undergoing central venous catheterization can help increase the success rate of catheter placement, shorten the catheter placement duration, reduce the incidence of various catheter-related complications, and also reduce the length of stay and hospitalization expenses.

Author contributions

Conceptualization: Zhenfei Pan, Lili Chen.
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