Heliyon 10 (2024) e29158

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Risk factors and prediction model construction for peripherally inserted central catheter-related infections

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ARTICLE INFO

Keywords:
Peripherally inserted central catheter
Catheter-related infection
Prediction model

ABSTRACT

Objective: To establish a predictive modeling for the risk of bloodstream infection associated with peripherally inserted central catheter (PICC).
Methods: Patients receiving PICC treatment in Shenzhen People's Hospital from June 2020 to December 2020 were retrospectively enrolled and divided into the infection group and the non-infection group according to the presence and absence of PICC-related infections. Then, relevant clinical information of patients was collected and the predictors of PICC-related infection were screened by the least absolute shrinkage and selection operator regression (LASSO) model. Besides, multivariate logistic regression was used to analyze the influencing factors of PICC-related infection, A nomogram was constructed based on the results of the multivariate analysis. Ultimately, a receiver operating characteristic (ROC) curve was plotted to analyze the application value of influencing factors to predict PICC-related infections.
Results: A total of 505 patients were included, including 75 patients with PICC-related infections (14.85%). The main pathogen was gram-positive cocci. The predictors screened by LASSO included age >60 years, catheter movement, catheter maintenance cycle, insertion technique, immune function, complications, and body temperature ≥37.2 °C before PICC placement. Multivariate logistic regression analysis showed that independent risk factors of infections related to PICC included age >60 years [odds ratio (OR) = 1.722; 95% confidence interval (CI) = 1.312–3.579; *P* = 0.006], catheter movement (OR = 1.313; 95% CI = 1.119–3.240; *P* = 0.014), catheter maintenance cycle >7 days (OR = 2.199; 95% CI = 1.677–4.653; *P* = 0.000), direct insertion (OR = 1.036; 95% CI = 1.019–2.743; *P* = 0.000), poor immune function (OR = 2.322; 95% CI = 2.012–4.579; *P* = 0.000), complications (OR = 1.611; 95% CI = 1.133–3.454; *P* = 0.019), and body temperature ≥37.2 °C before PICC placement (OR = 1.713; 95% CI = 1.172–3.654; *P* = 0.012). Besides, the area under the ROC curve was 0.889.
Conclusion: PICC-related infections are associated with factors such as age >60 years, catheter movement, catheter maintenance cycle, insertion technique, immune function, complications, and body temperature ≥37.2 °C before PICC placement. Additionally, the LASSO model is moderately predictive for predicting the occurrence of PICC-related infections.

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https://doi.org/10.1016/j.heliyon.2024.e29158
Received 26 October 2023; Received in revised form 28 March 2024; Accepted 2 April 2024
Available online 3 April 2024

1. Introduction

Peripherally Inserted Central Catheter (PICC) refers to catheters introduced through peripheral veins, allowing direct access to larger veins near the heart. Such a process minimizes direct contact between medication and the arm's vascular network [1,2]. Besides, the rapid blood flow within these larger veins facilitates rapid dilution of medications, thereby reducing the potential for irritation to blood vessels and the risk of body damage from repeated vein punctures and significantly enhancing clinical efficiency [1,3,4]. PICC is widely used in clinical practice due to its characteristics such as simple operation, safety, long indwelling time and easy observation. Additionally, PICC is principally applied in the rescue of critically ill patients, chemotherapy for malignant hematological diseases and malignant tumors, as well as parenteral nutrition for patients with severe pancreatitis, intestinal fistula or gastrointestinal tract and critically ill newborns [5,6].

As an invasive medical operation, PICC is prone to induce adverse complications such as catheter blockage, infection and mechanical phlebitis due to improper care. Of them, catheter-related bloodstream infection is the most prominent problem [7]. Catheter-associated infections not only prolong the hospital stays of patients, but also increase their mortality rate [8]. Therefore, timely identification of high-risk patients and correct nursing intervention measures are of great importance to prevent catheter-related infections and achieve better application of PICC in clinical practice. Several studies have been reported on the risk factors for infections related to PICC. For instance, PICC-related infections were most associated with hospital length of stay, ICU status, number of device lumens, previous PICC placement, the experience of operators, catheter retention time, PICC indwelling time, white blood cell count, a history of diabetes and immunity [9–12]. However, the current reports were limited to specific patients or specific infections, and there are few studies on the establishment of models to predict PICC-related infections. In this study, the risk factors of PICC-related infections were comprehensively analyzed, the predictive modeling was established, and the corresponding nursing intervention measures were discussed.

2. Research methods

2.1. Research subjects

Patients who received PICC placement in Shenzhen People's Hospital from June 1st, 2020 to December 1st, 2020 were retrospectively analyzed in this study. The included patients were divided into the infection group and the non-infection group based on whether they developed PICC-related infections. The inclusion criteria were as follows: (1) $>$ 18 years of age; (2) PICC treatment in the department of Shenzhen People's Hospital; (3) without signs of infection such as positive blood culture before catheter placement; and (4) signed informed consent. The exclusion criteria included (1) patients receiving PICC placement in other hospitals; (2) extubation within 48 h after PICC placement; (3) the body temperature $\geq$38 °C; (4) incomplete clinical data; (5) presence with secondary PICC-related infections which are defined as an infection occurring in the same patient after a previous infection episode, either with a different pathogen or after a gap of at least one month post-resolution of the primary infection; and (6) presence of PICC colonization which is defined as the presence of bacteria on the catheter tip without systemic signs of infection. Besides, this study was approved by the Ethics Committee of Shenzhen People's Hospital (201801187).

2.2. Clinical data

The clinical data of patients were collected, including age, gender, immune function, complications, body temperature during catheter placement, puncture technique, catheter type, fixation method, catheter movement, wound dressing change time, wound dressing, catheter retention time and catheter maintenance cycle.

In this study, poor immune function was a reduction in the capacity of the immune system of patients to fight infections and diseases, including congenital immunodeficiencies, acquired immunodeficiencies (HIV/AIDS), or patients who were receiving immunosuppressive treatments (chemotherapy or long-term corticosteroids use) [13]. Additionally, patients were considered to have poor immune function if they had laboratory markers indicative of immunosuppression (e.g., low white blood cell counts), a clinical history of frequent infections, or those who were assessed by physicians as immunocompromised [14]. Complications were defined as any adverse events or medical issues directly caused by PICC placement or its maintenance. The complications may include but are not limited to catheter-related bloodstream infections, thrombosis, mechanical phlebitis, catheter blockage or dislodgement. Besides, the complications are determined based on clinical diagnoses, imaging studies, or laboratory findings [15]. Catheter movement refers to the unintended displacement or offset of the PICC from its original insertion point. It is assessed based on clinical examination and patient reports, and is categorized as either present (yes) or absent (no) for each patient [16]. Such movement is significant because it may increase the risk of complications, including infection and mechanical irritation.

2.3. Placement of peripherally inserted central catheter

In this study, PICC placement was performed by three PICC nurses who had received professional theoretical and practical training. The catheter was purchased from Medical Components, Inc. (dba MedComp). The basilic vein was the preferred puncture site of PICC, followed by the median cubital vein, axillary vein and femoral vein. PICC operator referred to all personnel who have obtained PICC certification, received professional training and engaged in clinical work. PICC was placed under the laminar flow condition, and all PICC placements were carried out in the light of relevant standard procedures. After PICC placement, the catheter position was confirmed using an X-ray.

2.4. Diagnosis of catheter-related infections

The types of infection were defined according to the commonly used guidelines [17,18]. Briefly, a primary infection was the first infection episode in a patient in which the catheter was the source of bloodstream infection, with no other identifiable sources and no previous history of PICC-related infections. A secondary infection was defined as a subsequent infection in the same patient, characterized by different pathogens or by a gap of at least one month after the resolution of the primary infection. Colonization was defined as the presence of bacteria on the catheter tip without systemic signs of infection.

The procedure for diagnosing the infections [19] was as follows: First, a 5 cm catheter tip was seeded in a Columbia Blood Agar plate, a MacConkey Agar plate and nutrient broth (bacteria proliferation). Then, the catheter tip was rolled back and forth on the surface of the plates for culture. After 24 h of culture, the bacteria colony count ≥15 colony forming units/plate was positive. Subsequently, the purification and identification were carried out.

2.5. Statistical analysis

SPSS 26.0 was used for statistical analysis. Continuous variables satisfying normal distribution were expressed by mean ± standard deviation and the *t*-test was used for verification; while those failing to meet the normal distribution were represented by median or percentile and confirmed by Mann-Whitney *U* test. Categorical variables were expressed by frequency or rate and verified by χ^2 test. Additionally, R software (version 3.1.1) was adopted for statistical analysis. The least absolute shrinkage and selection operator (LASSO) was employed to screen suitable predictors. The non-zero coefficients and the screened predictors in the LASSO regression model were selected for multivariate logistic regression analysis. Then, a nomogram was constructed by assigning a weighted score to each independent influencing factor based on the results of the multivariate analysis. A receiver operating characteristic (ROC) curve was plotted to evaluate the predictive ability of the predictive modeling. $P < 0.05$ was considered statistical significance.

3. Results

3.1. Comparison of general baseline information between the infection and non-infection groups after PICC placement

Finally, a total of 505 patients were included in this study, including 75 patients with catheter-related infection (14.85%) and 430 patients without catheter-related infection (85.15%). The main pathogen was gram-positive cocci (Table 1). There was no significant difference between the two groups in terms of gender (female: 48% vs. 47.72%), wound dressing change time (>3 days: 57.33% vs. 60.40%), wound dressing (sterile cotton dressing: 57.33% vs. 53.86%), catheter type (Bard Groshong: 62.67 vs. 60.40%) and fixation method (adhesive tape: 21.33% vs. 23.37%). However, significant differences were observed in the indexes such as age (>60 years: 53.33% vs. 41.19%), insertion technique (direct insertion: 52.0% vs. 32.48%), catheter movement (yes: 10.67% vs. 5.94%), catheter retention time (>60 days: 72.00% vs. 51.49%), catheter maintenance cycle (>7 days: 32.00% vs. 21.59%), immune function (low: 85.33% vs. 32.48%), complications (yes: 69.33% vs. 32.48%) and body temperature during catheter placement (≥37.2 °C: 32.00% vs. 20.99%) ($P < 0.05$; Table 2).

3.2. Screening of predictors

The above indexes with statistical and clinical significance were enrolled into the LASSO regression model. The variable assignments of related indexes were shown in Table 3, and the number of corresponding variables screened by the LASSO regression model was displayed in Fig. 1A. Additionally, a risk factor classifier was established by the LASSO regression model. The screened predictors included age >60 years, catheter movement, catheter maintenance cycle, catheter insertion technique, immune function, complications, and body temperature before catheter placement ≥37.2 °C (Fig. 1B).

Table 1
Pathogens isolated from the tip of peripherally inserted central catheter.

Pathogens	Number of strains	Percentage (%)
Staphylococcus epidermidis	23	30.67
Staphylococcus aureus	14	18.67
Enterococcus	4	5.33
Klebsiella pneumoniae	10	13.33
Enterobacter cloacae	4	5.33
Pseudomonas aeruginosa	9	12.00
Acinetobacter baumannii	4	5.33
Candida albicans	7	9.33
Total	75	100

Table 2
Comparison between the two groups in general baseline information after peripherally inserted central catheter placement.

Items	Infection group (N = 75)	Non-infection group (N = 505)	X^2	P value
Age (year), n (%)				
>60 years	40 (53.33)	208 (41.19)	3.936	**0.047**
≤60 years	35 (46.67)	297 (58.81)		
Gender				
Female (%)	36 (48.00)	241 (47.72)	0.002	0.964
Male (%)	39 (52.00)	264 (52.28)		
Insertion technique, n (%)				
Direct, n (%)	39 (52.00)	164 (32.48)	10.942	**0.001**
Seldinger technique, n (%)	36 (48.00)	341 (67.52)		
Catheter type, n (%)				
Bard Groshong	47 (62.67)	305 (60.40)	0.141	0.707
Becton Dickinson (BD) B. Braun	28 (37.33)	200 (39.60)		
Catheter retention time, n (%)				
>60 days	54 (72.00)	260 (51.49)	11.069	**0.001**
≤60 days	21 (28.00)	245 (48.51)		
Fixation method, n (%)				
Adhesive tape	16 (21.33)	118 (23.37)	0.152	0.697
Fixator	59 (78.67)	387 (76.63)		
Catheter movement, n (%)				
Yes	8 (10.67)	30 (5.94)	1.673	0.196
No	67 (89.33)	475 (94.06)		
Catheter maintenance cycle, n (%)				
>7 days	24 (32.00)	109 (21.59)	4.009	**0.045**
≤7 days	51 (68.00)	396 (78.42)		
Wound dressing change time, n (%)				
>3 days	43 (57.33)	305 (60.40)	0.255	0.613
≤3 days	32 (42.67)	200 (39.60)		
Wound dressing, n (%)				
Sterile cotton dressing	43 (57.33)	272 (53.86)	0.317	0.573
Sterile transparent dressing	32 (42.67)	233 (46.14)		
Immune function, n (%)				
Normal	11 (14.67)	341 (67.52)	76.476	**0.000**
Low	64 (85.33)	164 (32.48)		
Complication, n (%)				
Yes	52 (69.33)	164 (32.48)	37.957	**0.000**
No	23 (30.67)	341 (67.52)		
Body temperature before PICC placement, n (%)				
≥37.2 °C	24 (32.00)	106 (20.99)	4.552	**0.033**
<37.2 °C	51 (68.00)	399 (79.01)		

PICC, peripherally inserted central catheter.

Table 3
Variable assignments.

Variables	Risk factors	Assignment
X1	Height	Continuous variables
X2	Body temperature before catheter placement	≥37.2 °C = 1, <37.2 °C = 0
X3	Catheter insertion technique	Direct insertion = 1, insertion with Seldinger technique = 0
X4	Body temperature after catheter placement	≥37.2 °C = 1, <37.2 °C = 0
X5	Multiple insertion	Yes = 1, no = 0
X6	History of diabetes	Yes = 1, no = 0
X7	Weight	Continuous variables
X8	Catheter maintenance cycle	>7 days = 1, ≤7 days = 0
X9	Age	Continuous variables
X10	Catheter movement	Yes = 1, no = 0
X11	BMI	Continuous variables
X12	Immunodeficiency	Yes = 1, no = 0
X13	Complications	Yes = 1, no = 0

BMI: Body mass index.

3.3. Logistic regression analysis

The analysis of the multivariate logistic regression model indicated that independent risk factors for catheter-associated infections including age >60 years [odds ratio (OR) = 1.722; 95% confidence interval (CI) = 1.312–3.579; $P = 0.006$], catheter movement (OR = 1.313; 95% CI = 1.119–3.240; $P = 0.014$), catheter maintenance cycle >7 days (OR = 2.199; 95% CI = 1.677–4.653; $P = 0.000$), direct

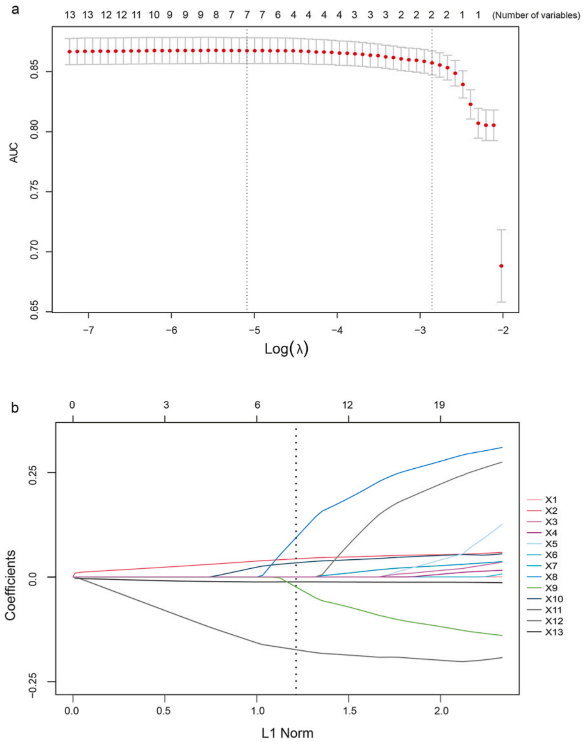

Fig. 1. Screening predictors of catheter-related infection after peripherally inserted central catheter placement by LASSO regression model A, Cross-validation results. The value between the two dotted lines was the range of positive and negative standard deviation of log (λ). The dotted line on the left indicated the value of harmonic parameter log (λ) when the model error was the smallest. When log (λ) = −5.1 was substituted, 7 variables were selected. B, LASSO coefficient profiles for 13 variables. Vertical lines were drawn at 10 times the value selected by cross-validation. With the decrease of λ value, both the compression degree of the model and the selections of the model for important variables increased. LASSO, least absolute shrinkage and selection operator.

insertion (OR = 1.036; 95% CI = 1.019–2.743; $P = 0.000$), poor immune function (OR = 2.322; 95% CI = 2.012–4.579; $P = 0.000$), complications (OR = 1.611; 95% CI = 1.133–3.454; $P = 0.019$), and body temperature ≥37.2 °C before PICC placement (OR = 1.713; 95% CI = 1.172–3.654; $P = 0.012$) (Table 4).

3.4. A nomogram of the risk of catheter-associated infections and the receiver operating characteristic curve analysis

A nomogram of the risk of catheter-associated infections was plotted using the seven risk factors obtained from the results of the multivariate logistic regression analysis. The highest score is 100 points, with the incidence rate of catheter-associated infections ranging from 0.1 to 0.9. The higher risks of occurrence were involved in the higher scores calculated from the sum of the distribution points for each high-risk factor in the nomogram (Fig. 2). The area under the ROC curve was 0.889 (95% CI: 0.771–0.839, $P < 0.001$), indicating that the LASSO regression predictive modeling was moderately predictive (Fig. 3).

Table 4
Independent risk factors of infections associated with peripherally inserted central catheter placement revealed by multivariate analysis.

Intercepts and variables	Prediction model		
	β	OR (95% CI)	*P*
Age >60 years	1.127	1.722 (1.312–3.579)	0.006
Catheter movement	0.409	1.313 (1.119–3.240)	0.014
Catheter maintenance cycle >7 days	1.130	2.199 (1.677–4.653)	0.000
Direct insertion	0.313	1.036 (1.019–2.743)	0.037
Poor immune function	1.924	2.322 (2.012–4.579)	0.000
Complications	0.505	1.611 (1.133–3.454)	0.019
Body temperature ≥37.2 °C before PICC placement	0.516	1.713 (1.172–3.654)	0.012

OR, odds ratio; CI, confidence interval; PICC, peripherally inserted central catheter.

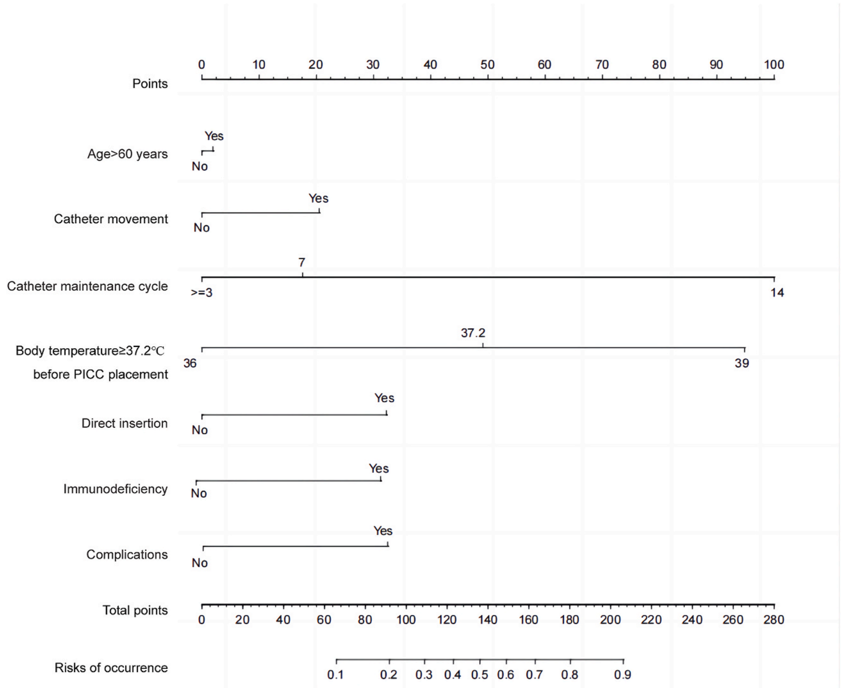

Fig. 2. A nomogram of the risk of catheter-associated infections.

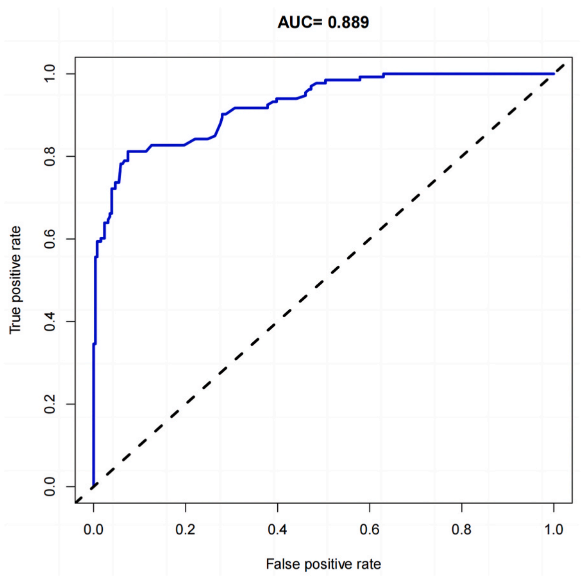

Fig. 3. Analysis of the receiver operating characteristic curve.

4. Discussion

Catheter-related infection, one of the most serious complications of PICC placement, is closely related to prolonged hospital stays, increased medical costs and ascending risk of death of patients [20]. At present, the clinical nursing has been improved in the selection of PICC materials, the qualification requirements of operators, the procedures and maintenance specifications of operation. However, there are still some patients with catheter-related infections [21,22]. Therefore, it is particularly important to evaluate the risk of infection in patients admitted to the hospital to receive PICC placement and predictably improve the nursing measures. This study explored the risk factors of catheter-related infections in patients undergoing PICC in Shenzhen People's Hospital. The results showed that the risk factors included age >60 years at admission, catheter movement, catheter maintenance cycle, catheter insertion technique, immune function, complications, and body temperature before catheter placement (≥37.2 °C). Besides, the area under the ROC curve in this study was 0.889. Such a result indicated a good level of predictive ability for the LASSO regression model in determining the risk factors for PICC-related infections. This result was significant because it not only provided a quantitative measure to support the effectiveness of the LASSO model in predicting PICC-related infections, but also highlighted the potential utility of the model in clinical settings. Additionally, such a result offered a tool to identify high-risk patients who might benefit from more intensive observation or preventive measures. Moreover, the outcomes of patients with catheter-related infections should be reported to the assigned nurses, so they could enhance their daily monitoring, and timely identify and address any abnormalities. Furthermore, high-risk patients should also be encouraged to provide timely feedback on any discomforts to reduce the incidence of PICC-related infections.

This study revealed that the main pathogens causing catheter-related infection were gram-positive cocci, such as *staphylococcus epidermidis* and staphylococcus aureus, second by gram-negative bacilli, such as pseudomonas aeruginosa and klebsiella pneumonia, Besides, the catheter-related infection can be caused by a small number of fungi including *candida albicans*. Notably, coagulase-negative *staphylococcus epidermidis* is the most common pathogen, inducing catheter-related infections. Staphylococcus, as a conditional pathogen, mainly infects individuals with implanted medical devices or low immune function. In addition, it is prone to cause catheter-related infection when the immune function of the patients is decreased [23]. Coagulase-negative staphylococci are generally considered non-pathogenic in healthy individuals, but they can become significant pathogens in certain clinical scenarios, The organisms can cause serious infections, especially in patients with implanted medical devices or those with decreased immune function [24]. In this study, we underscored the importance of not overlooking coagulase-negative staphylococci, especially in the context of catheter-related infections. Therefore, enough attention should be paid to the bloodstream infection caused by coagulase-negative staphylococci. Currently, some studies have reported a significant increase in the proportion of catheter-related infections induced by gram-negative bacteria possibly due to the irregular clinical use of antibiotics, the development of ultra-broad-spectrum drug-resistance-associated factors produced by gram-negative bacteria, an increase in the proportion of opportunistic pathogens, and a rapid increase in bacterial drug resistance [25,26]. Hence, in the process of invasive operation, the operating nurse should strictly follow the aseptic operation to avoid the invasion of cells through the skin tunnel, thereby controlling the inducement of infection. In addition, repeated insertion caused by unskilled operators may lead to damage to the inner wall of the blood vessels, subcutaneous tissue, and epidermal integrity. Such a process can increase the risk of bacterial invasive infection. A current study has pointed out that the insertion should not be performed again after three times of failures, otherwise, the incidence of complications will increase exponentially.

The physical condition was expressed by advanced age, poor immune function and numerous complications. The weakened self-defense mechanism and the body temperature ≥37.2 °C before catheter placement indicate that the patient has a potential infection. Therefore, the most direct and effective methods to reduce pathogen infection and reproduction were to provide patients with protection from infection, replacement, strict disinfection before nursing and the use of aseptic technology Currently, commonly used disinfectants for skin include 10% povidone iodine, 75% ethanol and 2% chlorhexidine [27]. Notably, chlorhexidine is the first choice for skin surface disinfection in such patients because the incidence of catheter-related infections can be reduced by 2% chlorhexidine. Additionally, the dressing area should be smaller than the disinfection area of the skin, generally 10 cm × 10 cm. After disinfection, it should be dried naturally to form a local barrier, thus reducing the irritation of insertion to the skin and making the dressing more reliable.

In this study, the catheter insertion technique is closely related to infection, and the use of the Seldinger technique can effectively reduce the incidence of infection. Besides, the catheter with a loose fixation and free access to the body can promote the formation of movable channels. Such channels can allow skin cells to enter the blood circulation along the catheter. Therefore, it is important for high-risk patients to be actively engaged in their treatment and promptly report any symptoms such as fever and pain. These symptoms might indicate an existing infection, so early detection and intervention can play a crucial role in managing the infection effectively. Such processes can minimize its impact and potentially reduce the severity and duration of PICC-related infections. Once catheter-related infections are discovered, the catheter should be pulled out immediately. Besides, appropriate antibiotics should be selected according to the drug sensitivity results. If the secretion increases or purulent secretion appears at the insertion site, the secretion can be cultured for bacteria. In addition, infrared rays can be used to irradiate the local infection area for about 2–3 times a day, with about 30 min each time. If the symptoms are not relieved or even aggravated after 2–3 days of treatment, the catheter should be removed immediately.

This study underlines the importance of continuous monitoring for infections in patients with PICC and the necessity of employing standardized definitions and protocols in clinical practice. Despite the interesting findings reported in our present study, it is also crucial to acknowledge the limitations of this study and the predictive modeling. The retrospective nature of the study is one of the important limitations. Such a limitation may be inherently biased due to the selection of patients and data collection methods. Additionally, the study was conducted in a single center, which may limit the generalizability of the findings in other settings. Furthermore, although the LASSO model provides a useful tool for risk prediction, it should not be considered infallible and must be used in conjunction with clinical judgment and other diagnostic tools.

5. Conclusion

Overall, our study highlights the significant correlation between PICC-related infections and various factors including patients age >60 years, catheter movement, the catheter maintenance cycle, insertion technique, immune function, complications, and body temperature ≥37.2 °C before PICC placement. Notably, the LASSO regression model was employed to demonstrate a moderate predictive capability for these infections, as indicated by an area under the ROC curve of 0.889. Additionally, further validation of the proposed prediction model should be performed, thus enhancing its reliability and applicability in diverse clinical settings.

Funding

None.

Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shenzhen People's Hospital (201801187). Written informed consent was obtained from the patients.

CRediT authorship contribution statement

Wei Li: Methodology, Conceptualization. **Jing Cao:** Methodology, Conceptualization. **Yu-luo Du:** Formal analysis, Data curation. **Yan-di Wen:** Formal analysis, Data curation. **Wei-xiang Luo:** Writing – original draft, Supervision, Investigation. **Xue-yan Liu:** Writing – review & editing, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Not applicable.

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