

Establishment and verification of prediction model on failure factors of radial arterial puncture in patients with heart failure

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Abstract: Objective: This paper aims to establish a prediction model for the failure factors of radial arterial puncture in patients with heart failure and verify its effectiveness.

Method: 969 patients from the internal medicine department of Dujiangyan Hospital of Traditional Chinese Medicine from July 2019 to July 2021 were divided into a training set (n=700, 72.5%) and a validation set (n= 269, 27.5%) using the leave-one-out (LOO) method. Logistic regression was used to select the risk factors of failure of the first needle of radial artery puncture in patients with heart failure, and the corresponding prediction model was established. The ROC curve was drawn and the effectiveness of the model was verified.

Results: Logistic regression showed that increased heart rate, rapid respiration, decreased mean arterial pressure, and decreased plasma albumin were independent risk factors for radial artery puncture failure in patients with heart failure. The probability of radial artery puncture failure was calculated as $8.010 + 0.025 \times \text{Heart rate} + 0.086 \times \text{Respiratory rate} - 0.070 \times \text{Means arterial pressure} - 0.232 \times \text{Plasma albumin}$. The area under the ROC curve (AUC) was 0.823 in the training set and 0.765 in the verification set. The Hosmer-Lemeshow test showed that the prediction model had good stability. The maximum value of the Jordan index of the model was 0.524, the optimal critical value of the corresponding prediction probability was 0.658, the sensitivity was 84.7%, and the specificity was 67.8%.

Conclusion: The prediction model based on regression analysis has a moderate predictive power for the radial arterial puncture in patients with heart failure and can assist clinical decisions, reduce patient pain, and save medical consumable expenses.

Keywords: heart failure; radial arterial puncture; prediction model; regression

Due to the aging of the population and the rise of chronic diseases among middle-aged and elderly people, the incidence and mortality of heart failure (HF) have also increased. Heart failure is a complex clinical symptom caused by various factors such as cardiac structure, function, and myocardial damage ^[1]. Even if the guideline provides standardized drug therapy, the disease still has a high hospitalization rate ^[2]. Radial artery puncture is a routine clinical operation

for patients with heart failure, as it is necessary to detect blood gas analysis and place arterial catheters to observe arterial blood pressure ^[3]. However, the arterial puncture is an invasive operation, and repeated puncture can easily lead to complications such as increased puncture difficulty, pain and anxiety in patients, local bleeding at the puncture site, subcutaneous hematoma and vasospasm, reduced treatment compliance, and increased cost of disposable puncture needles. Therefore, it is important to emphasize the success rate of the first radial artery puncture.

Previous literature on risk factors of patients with failed radial artery catheterization and prediction model construction ^[4] analyzed the factors affecting the success of radial artery catheterization in coronary angiography ^[5]. In this study, some predictive factors were proposed by reference to the article. Combined with the clinical characteristics of patients with heart failure, a predictive model of the factors causing the failure of the first radial artery puncture was established and verified.

Data and methods

Research object

According to the sample size calculated by the logistic independent variable event method ^[6], 969 inpatients (hereinafter referred to as inpatients) in the internal medicine department of Dujiangyan Traditional Chinese Medicine Hospital from July 2019 to July 2021 were included in the study.

Inclusion criteria:

Patients older than 18 years

Identified as heart failure patients by radial artery puncture for the first time after admission, combined with their symptoms, signs, laboratory examinations, and cardiac ultrasound.

Exclusion criteria:

Severe ICU cases

Shock cases

Sudden death cases

Cases of operation failure due to patient's refusal to puncture

Cases with incomplete data

Data Collection and Screening of Early Warning Indicators

The nursing records, inspection results, imaging data, and medical record data of the first radial artery puncture of the patients included in the study were obtained from the HIS case system of the hospital. Statistical methods such as frequency distribution, t-test, chi-square test, correlation analysis, and logistic regression were used to screen predictors that may lead to puncture failure. These predictors included age (in years), sex (male/female), indoor temperature (in Celsius), body temperature (in Celsius), heart rate (in times/min), brain natriuretic

peptide (in pg/mL), atrial fibrillation (yes/no), respiration (in times/min), mean arterial pressure (in mmHg), plasma albumin (in g/L), and edema (yes/no).

Standardized operation of radial artery puncture

The patient should lie flat, with the forearm on the puncture side straight and the side facing upwards. A pulse pillow or sandbag should be placed under the wrist. The most obvious fluctuation of the distal radial artery should be taken as the puncture point. The middle finger should gently press the artery, and the index finger should be placed on the artery side to prevent the artery with obvious sclerosis from sliding to the operator's side during the puncture process. A disposable artery puncture needle should be used, with an inclined plane of $25^{\circ}\sim 45^{\circ}$, and the needle tip should face the patient's end. The angle of the needle can be adjusted according to the blood return situation. If at least 2ml of arterial blood is found to enter the needle tube during the first needle puncture, it is considered that the first needle puncture is successful, otherwise, it is defined as the first needle puncture failure.

Establishment and verification of prediction model

969 patients were divided into training groups ($n=700$, 72.5%) and validation groups ($n=269$, 27.5%)^[7] by using Matlab2020a based on the LOO method. The risk factors leading to failure of first needle arterial puncture in heart failure were screened from the training group using the logistic regression method to build a prediction model. The data from the training group and validation group were substituted into the model to analyze :1. the measured and predicted values of the failure rate of the first needle puncture; 2. Sensitivity, specificity, receiver operating characteristic curve (ROC curve), and area under ROC curve (AUC) were obtained to further evaluate the effectiveness of the model; 3. The Hosmer Lemeshow test was conducted for the logistic model, and the best critical value was obtained according to the principle of "the highest Yodon index"^[8].

Statistical methods

SAS9.4 software was used for data analysis^[9]. The measurement data conforming to the normal distribution were expressed by mean $\pm$ standard deviation, and the comparison between groups was performed by t-test; The skewness distribution is expressed by the median M (quartile) [M (QL, QU)], and the inter-group comparison is performed by Wilcoxon rank sum test; Counting data were expressed by cases or percentages, and chi-square test was used for comparison between groups; Logistic regression analysis was used to build a prediction model, draw ROC curve and correction curve, and observe AUC evaluate model effectiveness. The significance level was set as 0.05 (bilateral), and $P<0.05$ was statistically significant^[10].

Outcome

Baseline comparison of the training group and validation predictor (**Table 1**)

There was no statistically significant difference between the two groups in terms of relevant predictors ($P > 0.05$). The data of the two groups were homogeneous and comparable. The validation group can be used to verify the predictive efficacy of the new model ^[8].

Table 1. Baseline comparison between the training group and validation group

Variable	training group	validation group	Z/t/ χ^2	P value
	(700 cases)	(269 cases)		
Age(years old, $\bar{x} \pm s$)	76(34, 98)	68(34, 98)	-1.050	0.294
Gender (case,%)			0.059	0.808
Male	386(55.1)	146(54.3)		
Female	314(44.9)	123(45.7)		
Indoor temperature($^{\circ}$,M)	21(9,28)	21(10, 27)	-0.391	0.969
Body temperature($^{\circ}$,M)	36.5(35.8, 38.1)	37.2(35.8, 38.3)	-1.353	0.176
Heart rate(10 bpm,M)	115(50, 190)	113(50, 189)	-0.034	0.973
BNP(pg/ml, $\bar{x} \pm s$)	1014.18 $\pm$ 34.79	945.49 $\pm$ 52.52	-1.267	0.205
Atrial fibrillation (case,%)			0.133	0.715
Non-atrial fibrillation	458(65.4)	172(63.9)		
Atrial fibrillation	242(34.6)	97(36.1)		
Respiratory rate (bpm, M)	26(19,36)	28(22,36)	-0.945	0.344
Mean arterial pressure (mmHg, $\bar{x} \pm s$)	86.73 $\pm$ 0.45	87.06 $\pm$ 0.68	-0.521	0.602
Plasma albumin (g/L, $\bar{x} \pm s$)	36.51 $\pm$ 0.14	36.33 $\pm$ 0.24	-0.482	0.630
Edema (case,%)			0.016	0.899
Non-edema	468(66.8)	181(67.3)		
Edema	232(33.2)	88(32.7)		

Constructing prediction model by regression method. The results of single factor regression analysis showed that heart rate, atrial fibrillation, mean arterial pressure, plasma albumin, and edema were related to the failure of first needle puncture of arterial puncture in patients with heart failure ($P < 0.05$) (**Table 2**). Combined with the P value of each factor and odds ratio (OR) multivariate logistic regression, it was suggested that heart rate, respiration, mean arterial pressure and plasma albumin were independent risk factors for failure of the first needle of arterial puncture. A logistic regression model was constructed based on the step-

wise regression method: $P=1/(\exp(\text{logit})+1)$; $\text{logit}=8.010+0.025 \times \text{Heart rate}+0.086 \times \text{Respiratory rate}-0.070 \times \text{Mean arterial pressure}-0.232 \times \text{Plasma albumin}$ (Table 3).

Table 2. Regression analysis of predictors of arterial puncture failure

variable	Single-factor regression analysis			Multivariate regression analysis		
	OR	Wald	P value	OR	Wald	P value
age	0.992	1.411	0.234	0.997	0.125	0.723
Gender	0.937	0.144	0.704	1.083	0.147	0.701
Indoor temperature	0.983	1.001	0.316	1.000	0.000	0.996
Body temperature	0.965	0.036	0.848	0.885	0.275	0.599
Heart rate	0.976	52.056	0.000	0.978	29.43	0.000
BNP	1.000	0.357	0.549	1.000	0.539	0.462
Atrial fibrillation	0.510	14.802	0.000	0.704	2.431	0.118
Respiratory rate	0.910	17.077	0.000	0.920	9.309	0.002
Mean arterial pressure	1.064	51.715	0.000	1.071	45.051	0.000
Plasma albumin	1.243	76.238	0.000	1.258	60.87	0.000
Edema	0.423	23.866	0.000	0.741	1.904	0.167

Table 3. Stepwise regression analysis of predictors of radial artery puncture failure

Incorporating variables	Estimated value	Standard error	Wald	P value	OR	95% confidence interval
Constant term	8.010	1.5281	27.475	0.000	—	—
Heart rate	0.025	0.003	39.074	0.000	0.975	[0.968,0.983]
Respiratory rate	0.086	0.027	10.385	0.001	0.918	[0.872,0.967]
Mean arterial pressure	-0.070	0.009	49.677	0.000	1.073	[1.052,1.094]
Plasma albumin	-0.232	0.028	66.607	0.000	1.261	[1.193,1.333]

Validation of prediction model (Table 4, Figure 1). The data of the training group and the verification group were substituted into the new model. With the failure of arterial puncture as the state variable and the prediction probability as the test variable, the ROC curves of the two groups were drawn; The AUC of the training group was 0.823, and the AUC of the test group was 0.765, indicating that the prediction efficiency of the model was moderate. Based on the calibration curves of the training group and the verification group with the number of groups of 15, as shown in Figure 2, combined with the results of the Hosmer Lemeshow test, the prediction model has good stability, in which the P values of the training group ($P=0.654$) and the verification group ($P=0.225$) are greater than 0.05, so there is no significant difference between the prediction and the actual situation. The maximum value of the Yodon index of the model is 0.524, the optimal critical value of the corresponding prediction probability is 0.658, the sensitivity is 84.7%, and the specificity is 67.8%.

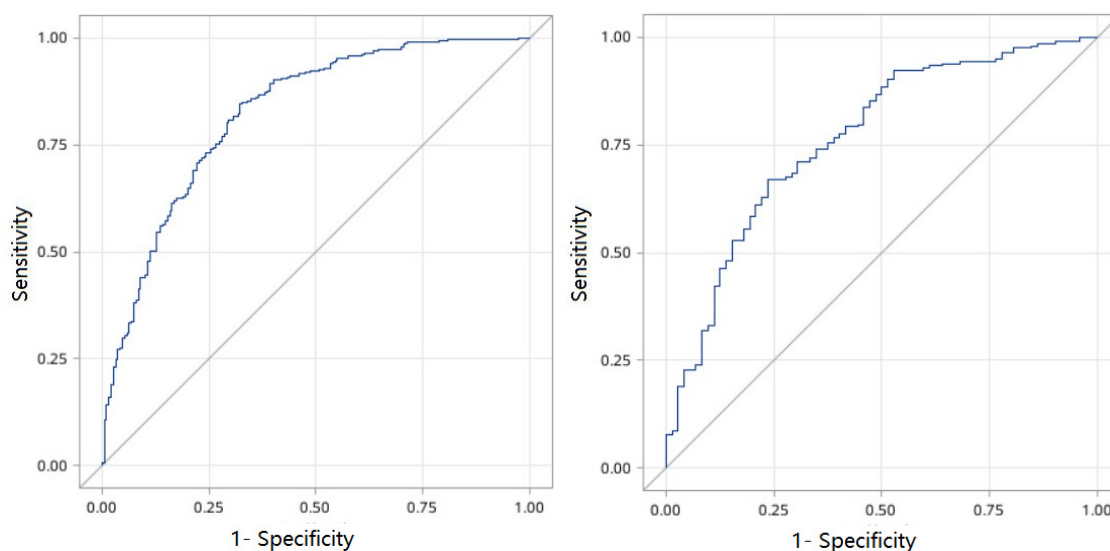


Figure 1. A: ROC curve of training group;

B: ROC curve of validation group

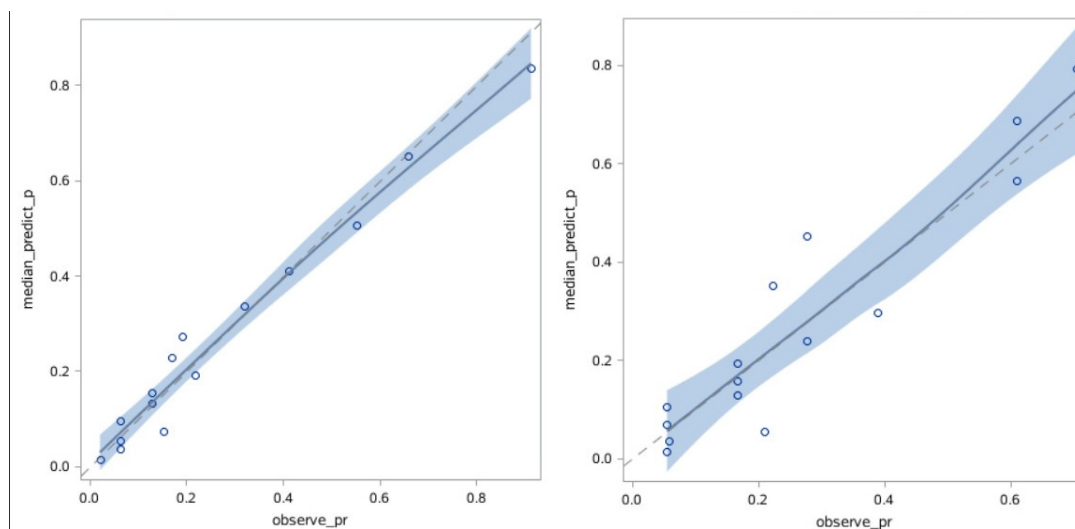


Figure 2. A: Calibration curve of training group

B: Calibration curve of validation group

Table 4. Predictive ability of prediction model for arterial puncture failure of patients with heart failure in the training group and verification group

group	AUC	95%CI	P value	Sensitivity(%)	Specificity(%)	Accuracy(%)
Training Group	0.823	0.787~0.859	0.000	82.5	71.5	80.57
Validation group	0.765	0.706~0.833	0.000	82.6	62.5	78.44

Discussion

In recent years, radial artery catheterization technology has been continuously optimized, such as ultrasound-guided radial artery catheterization^[5]. However, it is difficult to perform blood gas analysis or arterial pressure monitoring for patients with heart failure in the ward and use ultrasonic positioning for radial

artery catheterization. Traditional puncture technology is more popular in clinical practice. Although the medical unit has also conducted repeated and regular training on radial artery puncture operation for medical staff, there is still a high failure rate of the first radial artery puncture in clinical work, so it is necessary to further explore the factors of puncture failure and establish a prediction model and verify the effectiveness of the model.

Risk factors for failure of radial artery puncture in patients with heart failure

Heart rate The study data analysis showed that the OR value of heart rate was 0.975, its 95% confidence interval was [0.968,0.983], and the P value was <0.05, indicating that a faster heart rate was an independent risk factor affecting the success rate of puncture. Increasing the heart rate within a certain range can increase the cardiac output, but when the heart rate is higher than 180 times/minute, the cardiac output will decrease ^[11]. When atrial fibrillation is combined, this result is significant, so patients with excessive heart rate (including rapid atrial fibrillation) will increase the difficulty of puncture.

Mean arterial pressure: The research data suggest that the average arterial pressure OR value is 1.073, its 95% confidence interval is [1.052,1.094], and the P value is <0.05, suggesting that the reduction of blood pressure is an independent risk factor affecting the success rate of puncture. The concentric output of blood pressure, effective blood volume, and peripheral resistance are all related ^[12]. It can be understood that the difficulty of arterial puncture in patients with heart failure with low blood pressure increases.

Plasma albumin: The study data analysis showed that the OR value of plasma albumin was 1.261, its 95% confidence interval was [1.193, 1.333], and the P value was <0.05, indicating that the reduction of plasma osmotic pressure was an independent risk factor affecting the puncture success rate. Plasma albumin is one of the important factors to maintain plasma osmotic pressure. Heart failure patients are prone to malnutrition and hypoproteinemia due to gastrointestinal congestion and reduced absorption of nutrients ^[13]. The plasma albumin decreased, and the subcutaneous tissue fluid at the puncture site increased accordingly, which increased the difficulty of the puncture

Respiratory rate: The study data analysis shows that the OR value of respiration is 0.918, its 95% confidence interval is [0.872,0.967], and the P value is 0.001, indicating that the increase of respiratory rate is an independent risk factor affecting the success rate of puncture. Clinically, due to the respiratory distress caused by cardiopulmonary diseases, the patient will take a semi-recumbent position or end sitting position to relieve the symptoms ^[14]. However, to cooperate with the arterial puncture, the patient has to lie flat, this position will increase the amount of blood returning to the heart and increase the patient's "sense of suffocation", so that the patient's muscle tension, including the puncture site, will increase involuntarily, or the body will twist, thus increasing the difficulty of ar-

terial puncture.

The significance and clinical application of the prediction model The model can be used for pre-clinical operation evaluation. For patients with a high risk of radial artery puncture failure, can directly select the femoral artery with a relatively large vascular lumen as the first puncture point to avoid increasing the pain of patients.

The subject is a regression study. The prediction factors have not included the relevant indicators of radial artery elasticity and subcutaneous fat at puncture points, and the sample size of the included study is small, so there is no external verification result, which affects the promotion of this prediction model ^[15]; This study uses the random split method to obtain the training group and the validation group. Compared with other split methods, such as k-fold cross-validation, it may produce some errors ^[16]; SAS software was used for data processing, and the visibility of prediction model lines was not displayed ^[17].

In the future, prospective research will be carried out to include multicenter and large-scale case data analysis. Further, we will screen predictive factors such as indicators of the degree of arteriosclerosis, or evaluate the success rate of radial artery puncture according to the principles of traditional Chinese medicine pulse, and optimize the development and validation of the model; We will also select different methods to split data and set up training group and verification group to build corresponding models and verify ^[18]; In addition to internal verification, external verification is added to further evaluate model effectiveness ^[19]; We will use R language to build a visual display of models, such as APP/ Web, Nomogram, etc. ^[20]; We will improve the sensitivity and specificity of the prediction model, and provide a better reference for clinical decision-making of individual operation.

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