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Research article

Development and validation of a nomogram for predicting difficult radial artery cannulation in adult surgical patients

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ABSTRACT

Background: Radial artery cannulation is an invasive procedure commonly performed in patients in the perioperative time, in the intensive care unit, and in other critical care settings. The current study aimed to explore the preoperative risk factors associated with difficult radial artery cannulation and develop a nomogram model for adult patients undergoing major surgery. This nomogram may optimize preoperative clinical decision-making, thereby reducing the number of puncture attempts and preventing associated complications.
Methods: This was a single-center prospective cohort study. Between December 2021 and May 2022, 530 adult surgical patients were enrolled. The patients were randomized into the training and validation cohorts at a ratio of 8:2. Radial artery cannulation was performed before the induction of anesthesia. Univariate and multivariate logistic regression analyses were performed to identify variables that were significantly associated with difficult radial artery cannulation. These variables were then incorporated into the nomogram. The discrimination and calibration abilities of the nomogram were assessed.
Results: One hundred and seventy-three (41.7 %) patients in the training cohort had difficult radial artery cannulation. Based on multivariate analysis, the independent risk factors were wrist circumference, anatomical abnormalities, BMI <18.5 kg/m^2, grade II hypertension, hypotension, and history of chemotherapy and stroke. The concordance indices were 0.765 (95 % confidence interval [CI]: 0.719–0.812) and 0.808 (95 % CI: 0.725–0.890) in the training and validation cohorts, respectively. The calibration curve showed good agreement between the actual and predicted risks.
Conclusions: A preoperative predictive model for difficult radial artery cannulation in adult patients undergoing surgery was developed and validated. This model can provide reliable data for optimizing preoperative clinical decision-making.

1. Introduction

Arterial cannulation for continuous hemodynamic monitoring [1] and frequent arterial blood gas analysis [2] is commonly performed in the emergency departments, intensive care units (ICUs), and operating rooms [3,4]. Common sites for arterial cannulation include the radial artery (89 %), femoral artery (7.1 %), and brachial artery (2.6 %) [5]. The radial artery has a superficial course and

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collateral circulation via the ulnar artery. The radial artery is commonly used for cannulation because of the absence of complications [6]. Recently, the radial artery has become the preferred site for percutaneous coronary intervention [7–9].

Despite the guidelines and best-practice recommendations regarding the advantages of ultrasound-guided radial artery cannulation, the traditional blind palpation method is still widely used [10–16]. The success rate of blind cannulation depends on the operator's technique and the patient's vascular condition. The mean internal diameter of the radial artery in adults is 2.2 ± 0.4 mm. Therefore, localization and subsequent cannulation can occasionally be challenging and require multiple attempts [17]. Repeated cannulation attempts can lead to pain [18], hematoma formation, radial artery spasm [9], and wasted resources such as time [6]. Moreover, the success rate of cannulation decreases with subsequent attempts [17,19]. Furthermore, repeated attempts may lead to an extremely unpleasant experience for both patients [18] and operators and may reduce the operator's confidence. Several strategies have been used to address the difficulty of radial artery cannulation. Some methods, including sublingual [20] or subcutaneous [21] nitroglycerin [6,22] and flow-mediated dilatation (FMD) [8], can cause radial artery dilation [23] and improve the palpability of the radial artery pulse. Additionally, ultrasound-guided radial artery cannulation is associated with a high first-attempt success rate and a low number of attempts [1,10–16,24].

Therefore, a simple and noninvasive method for estimating difficult radial artery cannulation is preferred. This is similar to preoperative evaluation of the airways, which aims to identify potentially critical situations, allowing clinicians to prepare a B-plan or other techniques or devices. This increases the success rates and reduces the risk of complications. Currently, data on the predictors of difficult radial artery cannulation in patients undergoing surgery are limited. Therefore, this study aimed to examine the incidence of and predictors of difficult radial artery cannulation. A nomogram to predict difficult radial artery cannulation was developed and validated in this study.

2. Methods

2.1. Study design

This single-center, prospective, observational study was approved by the ethics committee of Affiliated Hospital of Jiaxing University (LS2021-KY-406) and written informed consent was obtained from all subjects participating in the trial. The trial was registered prior to patient enrollment at Chinese Clinical Trial Register (ChiCTR2100054616).

Anesthesiologists with >5 years of experience in blind cannulation performed radial artery cannulation. To avoid the effects of anesthetic drugs on the radial artery, the procedure was conducted before anesthesia induction without any premedication before puncture. Upon arriving in the operating room, an electrocardiogram was connected to the patients. Subsequently, a pulse oximeter was placed on the puncture hand, and a noninvasive blood pressure monitoring device was placed on the nonpuncture side. A modified Allen's test was conducted on the puncture hand to confirm ulnar artery patency. Radial artery puncture was performed in the patients with positive results. The arm on the puncture side was externally rotated during extension. A small pillow was placed under the hyperextended wrist. The right radial artery was punctured routinely. The anesthesiologist used the traditional pulsation palpation approach to locate the radial artery and determine its approximate anatomical direction. The ventral surface of the left index finger was palpated, and the part of the radial artery with the strongest pulsation was fixed. After skin disinfection, 0.2 ml of 1 % lidocaine was administered subcutaneously using a 1 ml syringe with a 26 G needle at the site with the strongest radial pulsation. An angiocatheter needle (a 20 G, 45 mm, polyurethane catheter, BD Arterial Cannula) was inserted into the artery at an angle of approximately 30°–45° to the skin over the styloid process in the right hand. After confirming blood reflux in the catheter hub, the needle tail was depressed and pushed 2–3 mm forward. If blood reflux persisted, the catheter was advanced into the radial artery and connected to the transducer.

The first successful attempt was defined as the successful cannulation of the radial artery after the first insertion of the angiocatheter. Cannulation was considered successful if an arterial waveform was confirmed on the monitor. Failure attempts were defined as other conditions, including subcutaneous angle adjustment and needle retraction. If the artery was not catheterized during the initial attempt, firm pressure was applied to the site for a few minutes. A second attempt was then made. In patients with three unsuccessful cannulations, puncture was performed under ultrasound guidance using an in-plane approach.

2.2. Patients

The sample size was calculated using 10 events per variable. We enrolled 530 patients who underwent elective major surgery requiring radial arterial blood pressure monitoring between December 2021 and May 2022 at the Affiliated Hospital of Jiaxing University (Zhejiang, China). The inclusion criteria were patients aged 18 years or older, those requiring radial artery cannulation, and those with American Society of Anesthesiologists physical status I–III. The exclusion criteria were insufficient dual blood supply to the hand, as represented by a negative modified Allen's test, local infection, and history of local surgery.

Finally, 518 patients were included in the study and randomly divided into training (80 %) and validation (20 %) cohorts. The patients in the training cohort were used to develop the nomogram model, whereas those in the validation cohort were used to validate the generated nomogram.

2.3. Definition of variables and outcomes

Based on clinical observations and existing studies [1,3,25,26,27], 25 factors have been found to be associated with the risk of difficult radial artery cannulation. These included wrist circumference (cm); shoe size; age; sex; height; weight; BMI (<18.5, 18.5–24, 24–28, and >28 kg/m^2); body surface area; grade I, II, and III hypertension; hypotension (preoperative systolic blood pressure of <90 mmHg); hyperlipidemia; coronary heart disease; diabetes; arrhythmia; chronic renal insufficiency; anatomical abnormalities; history of smoking, stroke, and chemotherapy; and peripheral vascular disorders. The puncture conditions were recorded in the operating room, and the anatomy of the punctured hand was determined using preoperative ultrasonography. Anatomical abnormalities included radial artery tortuosity, vascular branch variation, and a radial-ulnar artery ring. Wrist circumference was measured proximal to the radial styloid before puncture. The shoe size was self-reported. Data on the other influencing factors were collected from the electronic medical records system.

The analysis primarily aimed to identify the risk factors associated with difficult radial artery cannulation, defined as first-attempt failure, and to establish a model for predicting the incidence of difficult radial artery cannulation.

Table 1
Characteristics of the participants.

Variables	Training cohort (n = 415)	Validation cohort (n = 103)	*P* value
Wrist circumference	16.1 ± 1.0	16.4 (1.5)	0.081
Shoe size	39 (4)	40 (3)	0.410
Height	163 (10)	165 (10)	0.190
Weight	62 (15)	63.8 ± 10.1	0.677
BSA	1.6 ± 0.2	1.7 ± 0.2	0.400
Sex			
Male	231 (55.7 %)	62 (60.2 %)	0.253
Female	184 (44.3 %)	41 (39.8 %)	
Anatomical abnormality			
Yes	44 (10.8 %)	14 (13.6 %)	<0.001
No	370 (89.2 %)	89 (86.4 %)	
BMI (kg/m^2)			
<18.5	46 (11.1 %)	9 (8.7 %)	0.001
18.5–24	200 (48.2 %)	47 (45.6 %)	0.062
24–28	137 (33.0 %)	39 (37.9 %)	0.655
>28	32 (7.7 %)	8 (7.8 %)	0.805
Hypertension			
Grade I	105 (25.3 %)	32 (31.1 %)	0.014
Grade II	75 (18.1 %)	25 (24.3 %)	<0.001
Grade III	41 (9.9 %)	10 (9.7 %)	0.101
Hypotension			
Yes	35 (8.4 %)	8 (7.8 %)	0.001
No	380 (91.6 %)	95 (92.2 %)	
Hyperlipidemia			
Yes	147 (35.4 %)	41 (39.8 %)	0.439
No	268 (64.6 %)	62 (60.2 %)	
CHD			
Yes	17 (4.1 %)	3 (2.9 %)	0.143
No	398 (95.9 %)	100 (97.1 %)	
DM			
Yes	53 (12.8 %)	11 (10.7 %)	0.244
No	362 (87.2 %)	92 (89.3 %)	
Arrhythmia			
Yes	121 (29.2 %)	24 (23.3 %)	0.098
No	294 (70.8 %)	79 (76.7 %)	
Renal insufficiency			
Yes	20 (4.8 %)	4 (3.9 %)	<0.001
No	395 (95.2 %)	99 (96.1 %)	
History of smoking			
Yes	31 (7.5 %)	9 (8.7 %)	0.432
No	384 (92.5 %)	94 (91.3 %)	
History of chemotherapy			
Yes	35 (8.4 %)	8 (7.8 %)	0.008
No	380 (91.6 %)	95 (92.2 %)	
Peripheral vascular disorders			
Yes	62 (14.9 %)	16 (15.5 %)	0.150
No	353 (85.1 %)	87 (84.5 %)	
History of stroke			
Yes	28 (6.7 %)	3 (2.9 %)	0.001
No	387 (93.3 %)	100 (97.1 %)	
Year			
<70	273 (65.8 %)	67 (65.0 %)	0.556
≥70	142 (34.2 %)	36 (35.0 %)	

Abbreviations: BSA, body surface area; BMI, body mass index; CHD, coronary heart disease; DM, diabetes mellitus.

2.4. Statistical analysis

Patients were divided into two groups according to the presence or absence of one or more radial artery cannulation difficulties. Categorical variables are presented as numbers and percentages, and continuous variables are presented as the mean ± standard deviation or median (interquartile range [IQR]). Categorical variables were compared using the chi-squared test or Fisher's exact test, as appropriate. Continuous variables were compared using the *t*-test or the Mann–Whitney *U* test. A univariate logistic regression analysis was performed to assess the importance of each variable in predicting difficult radial artery cannulation in the training cohort. Odds ratios (ORs) and 95 % confidence intervals (CIs) were determined. All variables with a *P* value of <0.1 in the univariate logistic regression were included in the multivariate logistic regression. In the multivariate analysis, variables were selected via a backward elimination process based on Akaike's information criterion. A nomogram model was developed using the "rms" R package (R software, version 4.2.0, R Development Core Team, New Zealand) using the independent risk factors identified based on multiple regression. The C-index was used to evaluate the predictive accuracy and discriminative power of the nomogram. Next, the nomogram was subjected to 1000 bootstrap resamples for internal validation. Receiver operating characteristic curve analysis was used to calculate the optimal cutoff value determined by maximizing the Youden index. A calibration curve was used to compare the actual and predicted risks. Decision curve analysis was performed to evaluate the clinical usefulness of the nomogram. A *P* value of <0.05 was considered significant. All analyses were performed using the Statistical Package for the Social Sciences software (version 25.0; IBM Corporation, Armonk, NY, the USA) and R version 4.2.0. This report was based on the transparent reporting of a multivariate prediction model for individual prognosis or diagnosis guidelines [28].

3. Results

3.1. Characteristics of the participants

A total of 530 patients were enrolled in this study. However, only 518 patients met the inclusion criteria and were included in the final analysis. Subsequently, 415 and 103 patients were assigned to the training and validation cohorts, respectively. Table 1 shows the demographic characteristics of the training cohort. A total of 173 (41.7 %) patients in the training cohort had difficulty in cannulating the radial artery.

Table 2
Univariate logistic regression analysis of difficult radial artery cannulation based on preoperative data in the training cohort.

Variables	OR (95 % CI)	*P* value
Wrist circumference	0.842 (0.693–1.022)	0.081
Shoe size	0.961 (0.879–1.051)	0.385
Height	0.982 (0.957–1.008)	0.167
Weight	0.996 (0.977–1.015)	0.644
BSA	0.589 (0.172–2.014)	0.399
Sex	1.258 (0.848–1.867)	0.253
Anatomical abnormality	3.998 (2.030–7.875)	<0.01
BMI (kg/m^2)		
<18.5	2.963 (1.560–5.630)	0.001
18.5–24	0.688 (0.465–1.019)	0.062
24–28	0.909 (0.600–1.379)	0.655
>28	1.096 (0.529–2.268)	0.805
Hypertension		
Grade I	0.557 (0.348–0.889)	0.014
Grade II	4.417 (2.562–7.614)	<0.01
Grade III	1.710 (0.895–3.268)	0.104
Hypotension	3.383 (1.609–7.109)	0.001
Hyperlipidemia	1.174 (0.782–1.764)	0.439
CHD	2.060 (0.768–5.523)	0.151
DM	1.408 (0.790–2.510)	0.245
Arrhythmia	1.433 (0.935–2.196)	0.098
Renal insufficiency	6.064 (1.990–18.474)	0.002
History of smoking	1.341 (0.644–2.791)	0.433
History of chemotherapy	2.566 (1.255–5.250)	0.010
Peripheral vascular disorders	1.486 (0.865–2.553)	0.152
History of stroke	4.638 (1.925–11.175)	0.001
Year	1.131 (0.750–1.705)	0.556

Abbreviations: BSA, body surface area; BMI, body mass index; CHD, coronary heart disease; DM, diabetes mellitus; OR, odds ratio; CI, confidence interval.

3.2. Preoperative predictors of difficult radial artery cannulation

Table 2 shows the results of the univariate logistic regression analysis of the clinical characteristics of the training cohort. Univariate analysis identified 18 preoperative risk factors associated with difficult radial artery cannulation, including wrist circumference (odds ratio [OR] = 0.842, 95 % confidence interval [CI]: 0.693–1.022; $P = 0.081$), anatomical abnormality (OR = 3.998, 95 % CI: 2.030–7.875; $P < 0.01$), BMI (<18.5 kg/m^2 – OR = 2.963, 95 % CI: 1.560–5.630, $P = 0.001$; 18.5–24 kg/m^2 – OR = 0.668, 95 % CI: 0.465–1.019, $P = 0.062$), hypertension (grade I – OR = 0.557, 95 % CI: 0.348–0.889, $P = 0.014$; grade II – OR = 4.417, 95 % CI: 2.562–7.614, $P < 0.01$), hypotension (OR = 3.383, 95 % CI: 1.609–7.109; $P = 0.001$), arrhythmia (OR = 1.433, 95 % CI: 0.935–2.196; $P = 0.098$), renal insufficiency (OR = 6.064, 95 % CI: 1.990–18.474; $P = 0.002$), and history of chemotherapy (OR = 2.566, 95 % CI: 1.255–5.250; $P = 0.010$) and stroke (OR = 4.638, 95 % CI: 1.925–11.175; $P = 0.001$). Multivariate analysis was performed using all variables with P values of <0.1. The results showed that wrist circumference (OR = 0.637, 95 % CI: 0.494–0.821; $P < 0.01$), anatomical abnormality (OR = 5.531, 95 % CI: 2.594–11.796; $P < 0.01$), BMI of <18.5 kg/m^2 (OR = 4.023, 95 % CI: 1.687–9.593; $P = 0.002$), grade II hypertension (OR = 3.961, 95 % CI: 2.121–7.399; $P < 0.01$), hypotension (OR = 3.740, 95 % CI: 1.570–8.910; $P = 0.003$), and history of chemotherapy (OR = 3.700, 95 % CI: 1.690–8.098; $P = 0.001$) and stroke (OR = 4.145, 95 % CI: 1.554–11.051; $P = 0.004$) were independently and significantly associated with difficult radial artery cannulation (Table 3).

3.3. Development and validation of the nomogram for predicting difficult radial artery cannulation

These independently associated risk factors were used to establish a nomogram for difficult radial artery cannulation (Fig. 1). The risk of difficult radial cannulation was estimated by calculating the total score for each patient using the nomogram. In the training cohort, the C-index was 0.765 (95 % CI: 0.719–0.812) and 0.77 through 1000 bootstrapping validations. Additionally, in the validation cohort, the C-index was 0.808 (95 % CI: 0.725–0.890). Based on these results, the model had a good discrimination ability. According to the maximum Youden index, the optimal cutoff value for the prediction probability of the nomogram was 0.45. The sensitivity and specificity were 63.0 % and 78.9 % in the training cohort and 64.4 % and 84.1 % in the validation cohort, respectively. Furthermore, the calibration curves demonstrated acceptable model calibration with good consistency between the observed and predicted probabilities of patients with difficult radial artery cannulation in both datasets (Fig. 2 A and B). Fig. 3 (A and B) shows the decision curves of the nomogram for predicting difficult radial artery cannulation in both cohorts. Decision curve analysis was performed to assess the net benefit of different clinical decisions with a certain threshold probability.

4. Discussion

This single-center prospective cohort study developed and validated a novel predictive model for difficult radial artery cannulation that may improve clinical decision-making. The results showed that seven factors might be associated with difficult radial artery cannulation in adult surgical patients, including wrist circumference, anatomical abnormality, BMI of <18.5 kg/m^2, grade II hypertension, hypotension, and history of chemotherapy and stroke. Through verification, the nomogram established in this study effectively predicted patients with and without difficult radial artery cannulation.

The radial artery is preferred for catheterization. Although the radial artery is easy to palpate, standard pulse guidelines have discriminative limitations. Furthermore, multiple attempts can be made; however, associated complications can develop [6,25]. The first-attempt success rate can be as low as 15%–56 % [24,26]. In China and other countries, there is no uniform protocol or standard for preoperative prediction of difficult radial artery cannulation. The independent predictors of transradial percutaneous coronary intervention failure reportedly include weight of ≤65 kg, cardiogenic shock, endotracheal intubation, creatinine level of >133 μmol/L, and hypertension [29]. Our study showed that the risk factors for difficult radial artery cannulation were low body weight (BMI of <18.5 kg/m^2), grade II hypertension, and preoperative hypotension. The subcutaneous fat layer of patients with BMI of <18.5 kg/m^2 is

Table 3
Multivariate logistic regression analysis of difficult radial artery cannulation based on preoperative data in the training cohort.

Variables	OR (95 % CI)	P value
Wrist circumference	0.637 (0.494–0.821)	<0.01
Anatomical abnormality	5.531 (2.594–11.796)	<0.01
Hypotension	3.740 (1.570–8.910)	0.003
History of chemotherapy	3.700 (1.690–8.098)	0.001
BMI (kg/m^2)		
<18.5	4.023 (1.687–9.593)	0.002
18.5–24	1.255 (0.750–2.100)	0.388
Hypertension		
Grade I	0.829 (0.481–1.430)	0.501
Grade II	3.961 (2.121–7.399)	<0.01
Arrhythmia	1.211 (0.730–2.008)	0.459
History of stroke	4.145 (1.554–11.051)	0.004
Renal insufficiency	3.356 (0.941–11.964)	0.062

Abbreviations: BMI, body mass index; OR, odds ratio; CI: confidence interval.

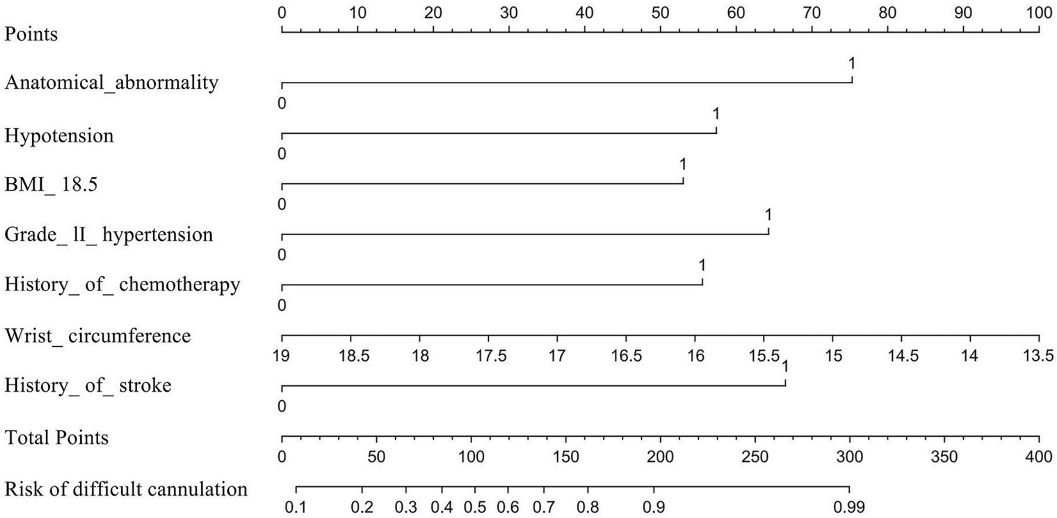

Fig. 1. Nomogram for predicting difficult preoperative radial artery cannulation in adult surgical patients. When using the nomogram, find the position of each variable on the axis and the vertical corresponding point. The points for all variables were then summed up to determine the predicted probability of difficult radial artery cannulation on the bottom axis. For anatomical abnormality, hypotension, BMI of <18.5 kg/m^2, grade II hypertension, and history of chemotherapy and stroke, 1 represents yes, and 0 represents no. Abbreviations: BMI, body mass index.

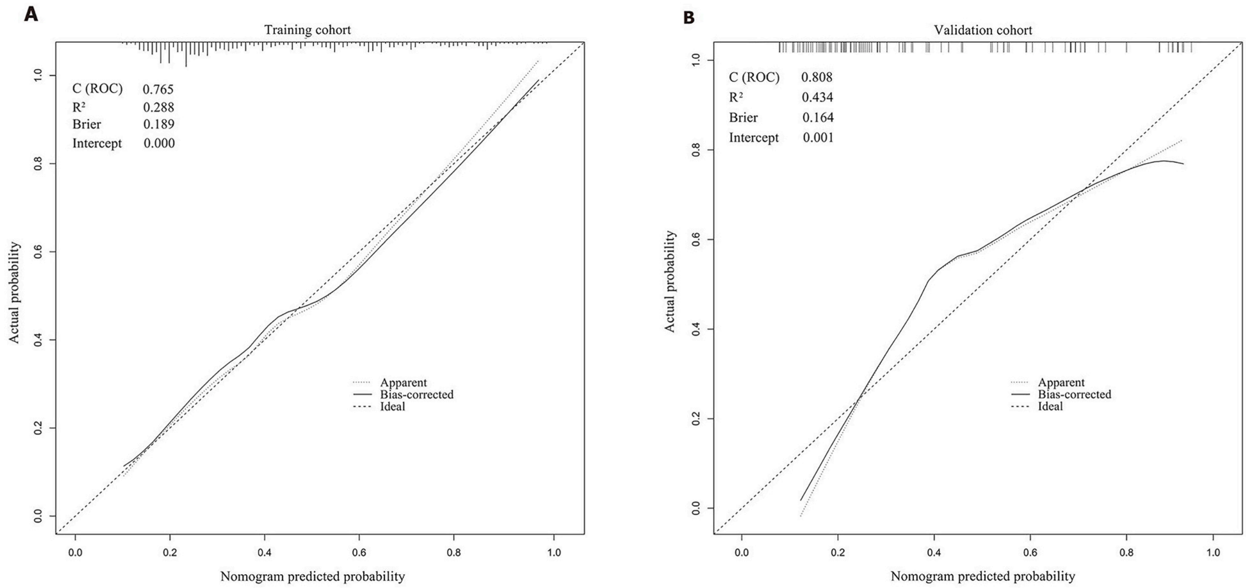

Fig. 2. Calibration curves of the nomogram. A: Calibration plot for predicting difficult radial artery cannulation in the training cohort. B: Calibration plot for predicting difficult radial artery cannulation in the validation cohort. The diagonal dotted line represents a perfect prediction by an ideal model. The solid line indicates the performance of the nomogram. The lines closer to the diagonal area represent better predictions.

thin; therefore, their skin and arteries can easily slide during puncture. Therefore, puncturing can be challenging. Another possible reason is that patients with a low BMI have a small radial artery diameter [7,29,30], which is an issue during radial artery intervention. The arteries in patients with morbid obesity may be difficult or impossible to palpate [27]. However, in this study, BMI >28 kg/m^2 was not a risk factor, probably because few patients with obesity were included.

Hypertension deteriorates the vascular compliance of the radial artery and may affect normal vascular anatomy, which can cause cannulation failure. However, it is unclear why only grade II hypertension was associated with more puncture attempts, probably because different grades of hypertension have varying effects on the radial artery. Li et al. showed that patients in ICUs with hypotensive shock had a high failure rate after their first radial artery puncture [10]. In patients with hypotension or shock [31], peripheral vascular perfusion is insufficient, the radial artery blood flow is reduced, and the pulse is weak and fast. Arterial pulsations are challenging to palpate using the traditional palpation approach; thus, puncturing can be challenging [3]. Kantor et al. revealed that

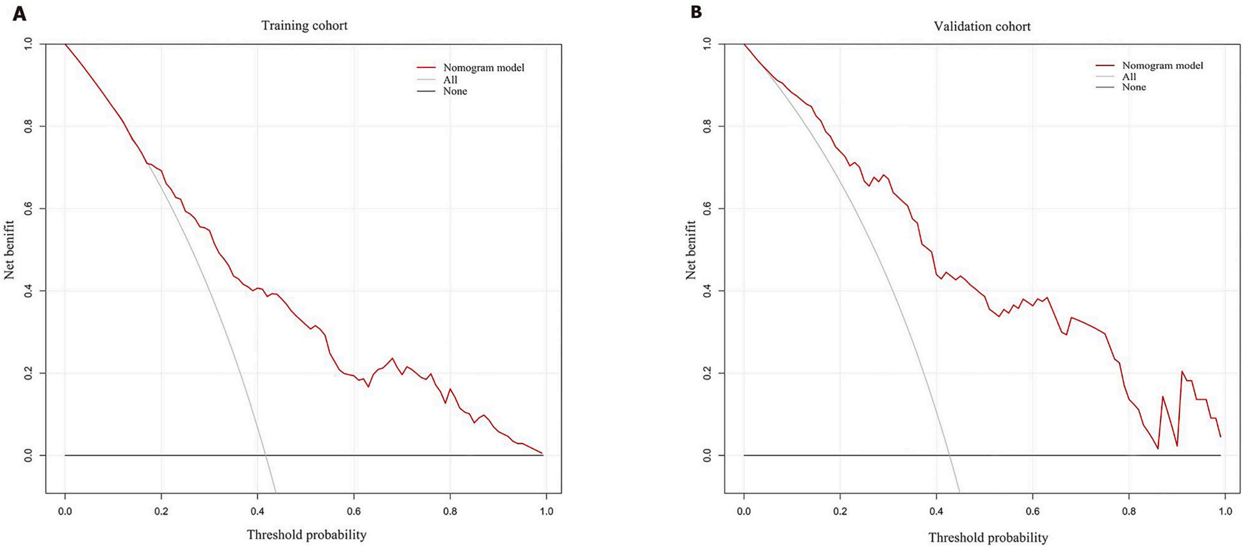

Fig. 3. Decision curve analysis of the nomogram. The grey and black lines indicate patients with positive or negative radial artery cannulation difficulty, respectively. The red lines indicate the net payoff of the nomogram at different threshold probabilities. The net clinical benefit was calculated as the true-positive rate minus the weighted false-positive rate. A: Decision curve analysis of difficult radial artery cannulation in the training cohort. B: Decision curve analysis of difficult radial artery cannulation in the validation cohort.

low body weight and systolic blood pressure were associated with increased puncture difficulty in critically ill children. However, these difficulties decreased with the use of ultrasonography [32]. Li et al. revealed that in patients with shock in the ICU, the first-puncture success rates were 42 % with palpation and 80 % with ultrasound guidance [10]. After screening for difficult radial artery catheterization, alternative techniques can be considered to facilitate successful cannulation.

In this study, renal function abnormalities were a significant factor in the univariate analysis, but not in the multivariate analysis. This finding was different from that of Abdelaal [29], possibly because our sample size was extremely small, and differences were not significant. The presence of abnormal radial artery branches is a risk factor for difficult radial artery cannulation in children undergoing surgery [1]. This finding is consistent with those of the present study. The patients' radial artery anatomy was evaluated with ultrasonography before puncture. The results showed that radial artery cannulation was less successful in patients with anatomical abnormalities. White et al. published a study on the predictors of difficult radial artery cannulation in adults [26]. They revealed that preoperative hypotension and vascular tortuosity were significant risk factors, consistent with our findings. The anatomical abnormality rate was 10.8 %, similar to that reported by Jung [1] (19.7 %). In patients with anatomical abnormalities, the catheter may not be successfully passed into the artery despite significant blood return during the initial puncture. Another study revealed that patients with radial artery branches had significantly smaller arterial diameters [1], which may explain the difficulty in cannulating these patients.

Wrist circumference can be easily measured and may be a good alternative to measuring hand size. This study found that wrist circumference was an independent risk factor for difficult radial artery cannulation. Aykan [7] and Kotowycz [30] revealed that wrist circumference is an independent predictor of radial artery diameter during transradial percutaneous coronary intervention. Patients with smaller wrist circumference had smaller radial artery diameters, which may have contributed to cannulation difficulty. The mean internal diameter of the radial artery in adults is 2.2 ± 0.4 mm [33]. The external diameter of the 20-gauge catheter used in this study was approximately 1.1 mm, which was smaller than the radial artery diameter in general patients. Furthermore, a history of chemotherapy and stroke were independent risk factors for difficult radial artery catheterization. In terms of systemic effects, chemotherapeutic drugs can significantly stimulate blood vessels, thereby causing arterial stiffness, decreased elasticity, and compliance. Moreover, chemotherapeutic drugs are associated with the risk of radial artery spasm during puncture, which affects subsequent puncture attempts. The reason why a history of stroke is associated with more puncture attempts remains unclear. However, one possible explanation is that the radial arteries of these patients are more sensitive to the development of spasms.

One hundred and seventy-three patients in the training cohort underwent difficult radial artery cannulation. Our strict definition of difficult cannulation (with subcutaneous angle adjustment also considered an attempt) appears to be associated with a high failure rate. During radial artery cannulation, success of the first-attempt is critical. Subsequent attempts after failed attempts could become more challenging with a weak or even absent pulse caused by an arterial spasm or hematoma [34]. The radial artery is at risk of vasospasm during cannulation attempts due to its α1-adrenoceptor and thick tunica media [35]. Transient vasospasms occur in 57 % [6] of adults after radial artery cannulation. Jang reported that the success rate of the second attempt at the selected radial artery after vasospasm was extremely low [6].

A predictive model for difficult radial artery cannulation can help operators identify patients at high risk of cannulation failure prior to the first puncture attempt. These patients can then undergo interventions to improve their first-puncture success rates. Several studies have shown that topical or systemic nitroglycerin [6,22] can increase the radial artery internal diameter in children and adults, thereby improving the success rate of cannulation. In addition, ultrasound guidance [1,10,24] reduces first-attempt failures, cannulation attempts, and procedure-related complications in anesthesia, critical care, and emergency medicine. However, if nitroglycerin is administered prophylactically, adverse reactions such as hypotension may develop. Similarly, if each patient underwent ultrasonography, the procedure time would have increased. In addition, not all hospitals have adequate ultrasound equipment, and not all operators can perform ultrasonography [26]. The application of predictive models can prevent these issues and decrease the rates of cannulation failure and the associated morbidity.

The current study has some limitations. First, the sample size was relatively small. In the future, large-scale studies should be performed to evaluate the reliability of this study. Second, the data analyzed in this study were collected from patients at a single institution. Hence, it may be difficult to generalize these results to patients in other institutions with different populations. Data from other institutions are needed to further validate the reliability of the model. Third, children were not included in this study; only adults were included. Therefore, these findings may not apply to children. Fourth, ultrasound radial artery cannulation was not performed in this study, and we will carry out a subsequent study. Further research is needed to determine whether the use of alternative techniques in patients with a high probability of difficult radial artery cannulation can improve the first-attempt success rates.

5. Conclusion

A preoperative predictive model for difficult radial artery cannulation in adult patients undergoing surgery was developed and validated. Our predictive model, which used seven preoperative risk factors, could facilitate the early identification of patients at high risk of difficult radial artery cannulation. Furthermore, the model may provide reliable data for optimizing preoperative clinical decision-making.

Funding

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Availability of data and materials

The datasets supporting the conclusions of this article are included within the article.

Ethics approval and consent to participate

This study was approved by the ethics committee of Affiliated Hospital of Jiaxing University (LS2021-KY-406) and was registered with the Chinese Clinical Trials Registry (ChiCTR2100054616) before any patient enrollment. All participants provided a written informed consent before enrollment.

Consent for publication

All authors are agreed for publication.

CRediT authorship contribution statement

Sheng-yan Wang: Writing – original draft, Formal analysis, Conceptualization. **Qing Qiu:** Funding acquisition, Data curation. **Xu Shen:** Writing – review & editing, Validation, Software, Methodology. **Qi-hong Shen:** Writing – review & editing, Software, Conceptualization.

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.

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