RESEARCH ARTICLE

Development and clinical application of a risk prediction model for difficult post-pyloric feeding tube placement in neurocritical ill patients

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Post-pyloric feeding tube placement is a critical procedure for providing nutrition to neurocritical ill patients who are unable to feed orally. However, this procedure often presents challenges due to anatomical and physiological factors with blind bedside insertion attempts frequently failing. These failures can lead to complications including aspiration, injury, and delays in feeding, highlighting the need for improved predictive tools to guide clinical decision-making. This study developed and validated a risk prediction model for difficult post-pyloric feeding tube placement using routinely available bedside indicators to provide a quantitative basis for clinical decision-making and to reduce procedural complications. A retrospective cohort of 163 neurocritical ill patients was included, and clinical information was collected. Univariate and binary logistic regression analyses were conducted to develop the prediction model, which was validated internally using the bootstrap method and externally in an independent cohort of 86 patients. The results identified four independent predictors including past gastrointestinal history, acute physiology and chronic health evaluation II (APACHE II) score, maximum gastric residual volume (GRV) in the first 24 hours, and the number of blind bedside insertion attempts. The model demonstrated strong discrimination with an internal validation area under the receiver operating characteristic (ROC) curve (AUC) of 0.85 (95% CI: 0.79-0.91) and a Hosmer-Lemeshow goodness-of-fit test (P = 0.74). The external validation AUC was 0.82 (95% CI: 0.74-0.90) with P = 0.50. The optimal cutoff achieved sensitivity (Sen) ≥ 81% and specificity (Spe) ≥ 76%. The proposed model based on easily accessible bedside indicators showed excellent discrimination and calibration, which could guide individualized post-pyloric feeding tube placement strategies, thereby improving resource allocation and potentially reducing the failure rates and complications associated with this procedure.

Keywords: neurocritical care; post-pyloric feeding; difficult tube placement; risk prediction; logistic regression analysis.

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Introduction

Patients with neurocritical ill often suffer from traumatic brain injury, cerebrovascular accident, or severe infection, and are highly susceptible to a variety of systemic complications including altered consciousness, ventilator dependence, and gastrointestinal motility disorders. These patients are particularly vulnerable to malnutrition while in the intensive care unit (ICU), which can worsen their condition and prolong recovery [1-3]. Timely and adequate enteral nutrition plays a critical role in improving immune function, reducing infection rates, and shortening hospital stays of these patients [4, 5]. While conventional gastric feeding is common, it

carries significant risks including excessive gastric residue and aspiration pneumonia [6, 7]. To mitigate these risks, post-pyloric feeding, a procedure to place the tube beyond the pylorus into the duodenum, is recognized as a more effective strategy because it enhances nutrient tolerance and reduces gastric reflux [8, 9].

Despite the advantages, the success rate of blind bedside post-pyloric feeding tube placement is relatively low in neurocritical ill patients due to factors such as hemodynamic instability, anatomical abnormalities, and challenging procedural environments [10, 11]. Difficult post-pyloric feeding has been defined as any of the following situations, including excessive tube placement time with a single bedside blind attempt taking longer than 60 minutes, excessive number of attempts with the cumulative number of bedside blind attempts more than 2 times within 24 h and results in failure, imaging/endoscopy confirmed failure being indicated by radiographic or endoscopic findings showing that the tube tip does not pass the pylorus and in the antrum or pre-pyloric area, and need for adjunctive measures, where success has only been achieved after the above attempts failed and required the use of prokinetic drugs for ≥ 48 h, an electromagnetic guidance system, or direct endoscopic tube placement. Repeated attempts at tube placement increase the risk of complications such as tube entanglement, mucosal injury, and aspiration, while also placing additional strain on healthcare providers. Although assisted tube placement techniques such as endoscopic or electromagnetic navigation can improve success rates, they are limited by high costs, operator skill requirements, and lack of availability in critical care settings, particularly in primary care institutions or during public health emergencies [12, 13].

Given these challenges, there is an urgent need to develop a reliable, efficient method for predicting difficult post-pyloric feeding tube placement in neurocritical ill patients. This research aimed to develop a quantitative risk prediction model based on routine bedside variables to identify high-risk patients early in the procedure and guide decision-making in tube placement strategies. The study used retrospective cohort data and binary logistic regression to identify key factors that influenced the difficult post-pyloric feeding tube placement by employing the events per variable (EPV) principle and multiple validation strategies. The proposed model could enhance patient safety, optimize resource allocation, improve procedural outcomes, and contribute to more efficient and personalized care in critical care settings.

Materials and methods

Study subjects

The clinical data of 163 neurocritical ill patients consisted of 91 men and 72 women, aged from 29 to 56 years old, admitted to the ICU of the Second Affiliated Hospital of Soochow University (Suzhou, Jiangsu, China) between January 2021 and March 2024 were retrospectively collected. The patient's inclusion criteria included age over 18 years old, diagnosed with neurocritical illness including but not limited to severe traumatic brain injury, acute intracerebral hemorrhage, severe cerebral infarction with impaired consciousness, *etc*., undergoing the first endoscopic or bedside pernasal/oral post-pyloric enteral nutrition tube placement, no structural gastrointestinal diseases such as pyloric stenosis, gastrointestinal tumors, perforated ulcers observed on pre-procedure imaging of gastrointestinal ultrasound or CT. The exclusion criteria were previous gastrectomy, gastrointestinal reconstruction or other major gastrointestinal surgery, severe coagulation dysfunction with active bleeding or Prothrombin Time/International Normalized Ratio (PT/INR) 1.5 times over the normal value and could not be corrected in the short term, end-stage multi-organ failure with Sequential Organ Failure Assessment (SOFA) score larger than 12 or expected survival less than 48 h, severe gastrointestinal motility disorder with prokinetic drugs ineffective for more than 48 h, and missing key clinical or laboratory data rate larger than

10%. All procedures of this study were approved by the Institutional Review Board (IRB) of the Second Affiliated Hospital of Soochow University (Suzhou, Jiangsu, China) (Approval No. EC-AF(JD)-07/20240601).

Evaluation for difficult post-pyloric feeding

A self-developed general information questionnaire was used to systematically and comprehensively collect relevant data from neurological ill patients to assess the risk of intubation difficulties in the future. The questionnaire gathered demographic and basic information including age, body mass index (BMI), and past gastrointestinal history such as a gastric ulcer, gastrectomy, or reconstruction. It also assessed the severity of illness and neurological function based on the acute physiology and chronic health evaluation II (APACHE II) and Glasgow coma scale (GCS) scores. Gastrointestinal function status was evaluated through acute gastrointestinal injury (AGI) grading, the maximum gastric residual volume (GRV) within 24 h before the first tube placement, and whether prokinetic drugs had been used. Laboratory indicators including serum albumin levels and C-reactive protein (CRP) concentrations were then collected. The quality of the tube placement procedure was assessed by recording the number of bedside blind attempts and the duration of the first attempt at tube placement.

Data collection and statistical analysis

Data was collected from electronic medical records (EMR) for demographic and clinical information, ICU nursing records for vital signs and tube placement details, and imaging/ultrasound reports for tube localization. SPSS 27.0 (IBM, Armonk, New York, USA) was employed for statistical analysis. Kolmogorov-Smirnov test was used to exam continuous variables for normality. If data was normally distributed, they were presented as mean ± SD, and independent samples t-tests were applied. For non-normally distributed variables, medians and interquartile ranges were reported, and the Mann-Whitney U test was applied for comparison. Categorical variables were described as counts and percentages, while chi-square or Fisher's exact tests were used. A *P* value less than 0.05 was considered statistically significant difference. *P* values less than 0.5 from univariate analysis were included in the multivariate logistic regression (MLR) model. MLR analysis was performed using the stepwise (forward) regression method including variables with $P < 0.5$ from univariate analysis. Variables with independent predictive significance were retained, and their regression coefficients, odds ratios (OR), and 95% CI were reported. The prediction equation was then formulated as follows.

$$log\frac{p}{1-p} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \quad (1)$$

where p was the probability of difficult post-pyloric feeding. X_i was the i predictor.

Assessment of model performance

Model performance was assessed by plotting the receiver operating characteristic (ROC) curve and calculating the area under the curve (AUC) and its 95% CI. External validation was performed using data collected from 86 patients in the Second Affiliated Hospital of Soochow University (Suzhou, Jiangsu, China). The ROC analysis was repeated, and the internal and external validation results were compared to evaluate the robustness of the model.

Results

Patient baseline characteristics

Among the 163 neurocritical ill patients, 109 were in the successful feeding group and 54 in the difficult feeding group. Core evaluation indicators were compared and showed that there were statistically significant differences among the age, BMI, past gastrointestinal history, APACHE II score, maximum GRV in the first 24 hours, number of bedside blind attempts, and serum albumin between the groups ($P < 0.05$), while the remaining variables were not

Table 1. Baseline characteristics of patients.

Variables	Successful feeding group (n = 109)	Difficult feeding group (n = 54)	*P* value
Age (years)	55.4 ± 12.1	60.1 ± 13.0	0.040*
BMI (kg/m²)	22.8 ± 3.1	24.0 ± 3.5	0.035*
Past gastrointestinal history	15 (13.8%)	15 (27.8%)	0.025*
APACHE II score	17.9 ± 5.0	21.4 ± 5.6	< 0.001*
GCS score	8.6 ± 2.3	7.8 ± 2.7	0.046*
AGI Ⅰ-Ⅱ	95 (87.2%)	44 (81.5%)	0.309
Maximum GRV (mL) within 24 h before the first tube placement	132 ± 42	172 ± 56	< 0.001*
Prokinetic drug use	52 (47.7%)	32 (59.3%)	0.154
Serum albumin (g/L)	33.2 ± 4.2	31.5 ± 4.8	0.038*
CRP (mg/L)	23.8 ± 12.0	26.8 ± 13.9	0.129
Number of bedside blind attempts (times)	1.1 ± 0.4	1.3 ± 0.6	0.013*
Duration of first attempt at tube placement (min)	34.0 ± 11.5	38.1 ± 15.2	0.030*

Note: * indicated *P* < 0.05.

Table 2. Variable assignments.

Variables	Assignment coding
Age	≥ 65 = 1, < 65 = 0
BMI	≥ 24 kg/m² = 1, < 24 kg/m² = 0
Past gastrointestinal history	Yes = 1, No = 0
APACHE II score	≥ 20 = 1, < 20 = 0
Maximum GRV in the first 24 hours	> 150 mL = 1, ≤ 150 mL = 0
Number of bedside blind attempts	> 1 = 1, ≤ 1 = 0
Serum albumin	< 35 g/L = 1, ≥ 35 g/L = 0

statistically meaningful (*P* > 0.05) (Table 1).

MLR analysis of factors associated with feeding difficulty

The seven variables with statistically significant differences in the univariate analysis were dichotomized and then included in the MLR model (Table 2). After independent predictors selection using stepwise (forward) method, the multivariate analysis was conducted and revealed that past gastrointestinal history, APACHE II score, maximum GRV in the first 24 hours, and number of bedside blind attempts were the four independent predictors of difficult post-pyloric feeding (Table 3).

Development of the MLR prediction model

After the determination of four independent predictors, the regression coefficient (β) and OR values were also determined. The probability of a patient experiencing difficult post-pyloric feeding (*P*) was then calculated using the following formula.

$$logit(p) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 \quad (2)$$

where X_1, X_2, X_3, and X_4 were all assigned to 1 for past gastrointestinal history, APACHE II ≥ 20 points, maximum GRV in the first 24 hours > 150 mL, and number of bedside blind attempts > 1, respectively. After applying the estimated coefficients, the calculation formular was changed as below.

$$logit(p) = -2.10 + 1.10X_1 + 1.07X_2 + 1.16X_3 + 0.79X_4 \quad (3)$$

The probability was then calculated as follows.

$$p = \frac{e^{logit(p)}}{1+e^{logit(p)}} = \frac{e^{-2.10+1.10X_1+1.07X_2+1.16X_3+0.79X_4}}{1+e^{-2.10+1.10X_1+1.07X_2+1.16X_3+0.79X_4}} \quad (4)$$

Table 3. Results of MLR analysis.

Variables	β coefficient	OR (95% CI)	Wald χ^2	*P*
Age (≥ 65)	0.41	1.50 (0.70 - 3.20)	1.07	0.3
BMI (≥ 24 kg/m²)	0.34	1.40 (0.75 - 2.50)	1.14	0.28
Past gastrointestinal history	1.1	3.00 (1.40 - 6.50)	8.25	0.004*
APACHE II (≥ 20)	1.07	2.90 (1.50 - 5.65)	9.35	0.002*
Maximum GRV in the first 24 hours (> 150 mL)	1.16	3.20 (1.80 - 5.80)	12.94	< 0.001*
Number of attempts (> 1)	0.79	2.20 (1.25 - 3.90)	7.64	0.006*
Serum albumin (<35 g/L)	–0.11	0.90 (0.60 - 1.40)	0.20	0.65

Note: * indicated *P* < 0.05.

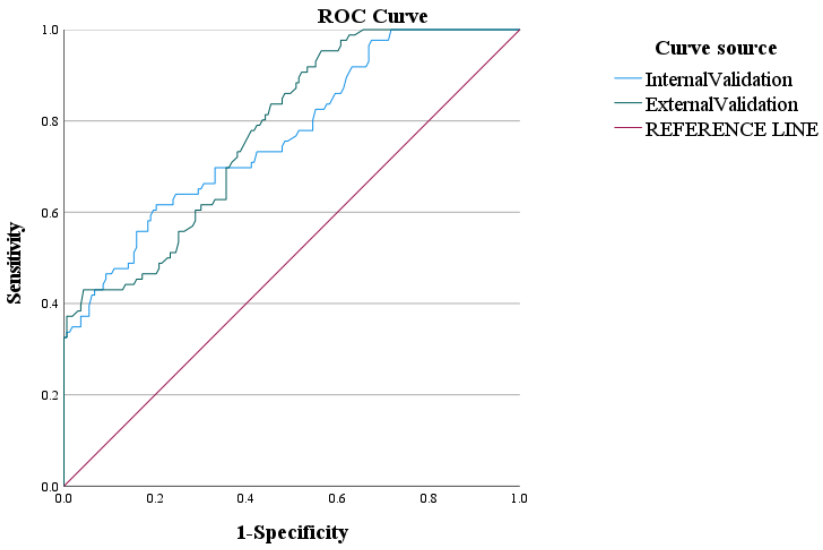

Figure 1. ROC curve of the model.

Application and validation of the risk prediction model

The model was validated using internal Bootstrap resampling with 1,000 replications and an external independent cohort of 86 patients. The internal validation (χ^2 = 5.12, df = 8, P = 0.74) and the external validation (χ^2 = 7.34, df = 8, P = 0.50) both suggested that there were no visible distinctions and statistically significant difference. Therefore, the proposed model fitted well with the observed data in both cohorts with no visible calibration bias. The ROC curve analysis showed that the internal validation (n = 163) had an AUC of 0.85 (95% CI: 0.79 - 0.91) with a sensitivity (Sen) of 82.5% and specificity (Spe) of 78.9% at the optimal cutoff value of 0.48, while the external validation (n = 86) demonstrated that the model had an AUC of 0.82 (95% CI: 0.74 - 0.90) with a Sen of 81.5% and Spe of 76.5% at the optimal cutoff value of 0.46 (Figure 1). These findings suggested that the model had excellent predictive performance both internally and externally with a high degree of discrimination in both cohorts. Further, the model showed good calibration as indicated by the non-significant Hosmer-Lemeshow test results. The high sensitivity (> 80%) and specificity (~ 80%) at optimal cutoff values further validated the model's effectiveness in identifying high-risk patients and minimizing false positives.

Discussion

This research proposed a risk prediction model for difficult post-pyloric feeding based on 163

neurocritical ill patients and validated the model using another externally independent cohort of 86 patients. Univariate analysis suggested that the difficult feeding group had significant differences from the successful group in terms of age, BMI, past gastrointestinal history, APACHE II score, maximum GRV in the first 24 hours, number of bedside blind attempts, and serum albumin. Analysis revealed that increased age and higher BMI might reflect multiple comorbidities and systemic stress in patients, potentially exacerbating gastrointestinal smooth muscle dysfunction and delaying tube advancement [17]. Previous ulcers or surgeries could lead to changes in pyloric structure, adhesions, or functional disorders, directly increasing the mechanical difficulty of tube placement [18]. Among nutritional and inflammatory indicators of albumin and CRP, low albumin levels suggested malnutrition or inflammatory consumption, which might be accompanied by gastric mucosal barrier disruption and gastroparesis [19]. Although CRP was not visible, its slightly higher trend indicated the potential impact of inflammation on gastrointestinal function. These distinctions emphasized that, in clinical assessment, routine vital signs should be monitored, while the patient's past gastrointestinal history and nutritional-inflammatory status should also be valued to provide a basis for early identification of high-risk individuals.

The MLR results identified four independent predictors including patient's congenital/past structural factors, severity of illness and overall physiological status (APACHE II), GRV, and mechanical indications during the procedure (attempt count). Past gastrointestinal history once again confirmed the visible obstructive effect of structural changes on tube advancement. APACHE II ≥ 20 indicated that the severity of illness was closely related to neurological dysfunction with higher scores often associated with hemodynamic instability and inadequate gastrointestinal perfusion, increasing the failure rate of tube placement [20]. Maximum GRV in the first 24 hours > 150 mL showed that GRV directly reflected impaired gastric emptying function and was an important physiological indicator for predicting the difficulty of bedside blind attempts [21]. Number of bedside blind attempts > 1 time suggested that continued attempts after the first failure were often unhelpful for success, reflecting a mismatch between the procedural environment and patient conditions, indicating that adjunctive techniques should be used in a timely manner. By combining those 4 predictors for comprehensive consideration, multidimensional risk assessment could be achieved.

The results of this study showed that the internal and external validations both exceeded 0.8, indicating that the model had good discrimination ability in different cohorts, while in terms of calibration, the Hosmer-Lemeshow test showed no statistically significant difference with no visible deviation, indicating that the predicted probabilities were in good agreement with the actual incidence rates. At the optimal cutoff values of 0.48/0.46, the Sen was > 80% and the Spe was close to 80%, which could be used for effectively screening high-risk patients in clinical practice while maintaining a low false alarm rate. The external validation cohort demonstrated only slightly decreased results, confirming that the model had a certain degree of transferability and potential for generalization. This proposed model used four indicators that were routinely available at the bedside to provide risk assessment before or early in the tube placement in low/medium/high three levels to guide the procedural strategy. High-risk cases were recommended to directly use endoscopy or electromagnetic navigation assistance to reduce repeated attempts, while medium-risk cases could first use prokinetic drugs and combined ultrasound monitoring, and low-risk cases could simply perform routine bedside blind insertion. Moreover, precise allocation of equipment and personnel for high-risk populations could avoid unnecessary procedural delays and complications, which also reduced complications caused by repeated procedures such as aspiration and nasopharyngeal injury and

improved the early nutritional achievement rate. This proposed model provided a basis for rapid bedside risk assessment and individualized tube placement strategies. However, as a single-center retrospective study, the threshold setting and variable selection might be influenced by the center's experience, and dynamic imaging or other physiological signals were not included in this study. Future research should expand the sample size and variable dimensions through prospective multicenter studies and integrate real-time electromagnetic navigation, quantitative gastrointestinal ultrasound indicators, and electronic health systems to develop intelligent decision-making tools and further enhance the model's applicability and accuracy.

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