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Research article

Development and validation of a nomogram for predicting the placement of nasointestinal tubes in critically ill patients based on abdominal radiography: A single-center, retrospective study

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A R T I C L E I N F O

Keywords:
Nasointestinal tube
Critically ill patients
Abdominal radiography
Nomogram

A B S T R A C T

Background: Enteral nutrition administered via the nasointestinal tube (NET) is a prevalent nutritional modality among critically ill patients, and abdominal radiographs hold significant value in accurately ascertaining the precise positioning of the NET subsequent to its placement. Therefore, we propose an innovative approach to construct a clinical prediction model based on NET's configuration within the gastrointestinal tract in abdominal radiography. This model aims to enhance the accuracy of determining the position of NETs after their placement.

Methods: Patients admitted to the intensive care unit of Zhejiang Provincial People's Hospital between October 2017 and October 2021 were included to constitute the training cohort for retrospective analysis, and nomogram was constructed. Consecutively enrolled patients admitted to the same hospital from October 2021 to October 2023 were included as the validation cohort. The training cohort underwent a univariate analysis initially, followed by a multivariate logistic regression approach to analyze and identify the most appropriate model. Subsequently, nomogram was generated along with receiver operator characteristic curves, calibration curves, and decision curves for both the training and validation cohorts to evaluate the predictive performance of the model.

Results: The training and validation cohorts comprised 574 and 249 patients, respectively, with successful tube placement observed in 60.1 % and 76.3 % of patients, correspondingly. The predictors incorporated in the prediction maps encompass the "C-shape," the height of "inverse C-shape," showing the duodenojejunal flexure, and the location of the head end of the NET. The model demonstrated excellent predictive efficacy, achieving an AUC of 0.883 (95 % CI 0.855–0.911) and good calibration. Furthermore, when applied to the validation cohort, the

Abbreviations: ICU, intensive care unit; NET, nasointestinal tube; BMI, body mass index; AGI, acute gastrointestinal injury; Apache, Acute Physiology and Chronic Health Evaluation; SOFA, Sequential Organ Failure Assessment; NRS, Nutritional Risk Screening; CRRT, continuous renal replacement therapy; IC-shape, inverse C-shape; DF, duodenojejunal flexure; ROC, receiver operator characteristic; AUC, the area under ROC curve.

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nomogram exhibited strong discrimination with an AUC of 0.815 (95 % CI 0.750–0.880) and good calibration.

Conclusion: The combination of abdominal radiography and NET's configuration within the gastrointestinal tract enables accurate determination of NET placement in critically ill patients.

1. Introduction

Nutritional therapy plays a crucial role in the management of critically ill patients [1,2], who have a statistically significant risk of malnutrition ranging from 40 to 50 % [3–5]. It is important to consider any critically ill patient admitted to the intensive care unit (ICU) for more than 48 h as being at risk of malnutrition [6,7]. This heightened vulnerability not only increases the likelihood of multi-organ dysfunction but also leads to prolonged hospitalization, elevated morbidity rates, and increased mortality [8–10]. Therefore, enteral or parenteral nutrition is commonly employed in clinical practice to administer nutritional therapy to patients. Major clinical practice guidelines concur that enteral nutrition via tube feeding currently represents the preferred method of nourishing critically ill patients. In cases where oral administration is not feasible, enteral nutrition should be initiated within 48 h [7]. Currently, with nasogastric tube feeding is the preferred enteral route [11]; however, for patients at high risk of aspiration or with intolerance to gastric feeding, international guidelines recommend the post-pyloric feeding route [7,12]. Based on relevant data, blind placement of nasointestinal tube (NET) exhibits a success rate ranging from 20 % to 90 % [13–16], rendering it the current favored technique for tube placement. However, accurately determining the position of a NET after placement remains a challenging issue for clinicians. Currently, abdominal radiography [17] is widely regarded as the preferred method, followed by ultrasound [18], electromagnetic navigation [19], and abdominal computerized tomography imaging [20] due to considerations of accuracy and cost-effectiveness.

Abdominal radiography exhibits high specificity and sensitivity in detecting gas and foreign bodies, rendering them valuable for diagnosing gastrointestinal perforation [21], intestinal obstruction [22], and foreign body ingestion [23]. The NET is clearly visualized on X-ray, and its course shape within the gastrointestinal tract accurately reflects the anatomical shape of the digestive system. It is through precise abdominal radiography that clinicians determine the precise location of the NET. However, the determination of NET position by abdominal radiography still has limitations. Firstly, assessment accuracy is reduced in patients with anatomical variations [24,25]. Secondly, the position is mostly determined based on gastrointestinal anatomy shape and accurately estimating whether the head end of the NET passes through pylorus on X-ray is difficult [16]. Thirdly, multiple abdominal radiography examinations increase patient exposure to radiation [26]. Fourthly, clinicians mostly determine NET location empirically without a recognized systematic assessment method [27].

Nomogram drawing is an essential step in constructing a prognostic model, which exhibits significant predictive efficacy for disease prognosis and the occurrence of outcome events [28]. The retrospective and prospective cohort study conducted by Hu L et al. [29] demonstrated that the primary diagnosis, Acute Physiology and Chronic Health Evaluation (Apache) II score, and acute gastrointestinal injury (AGI) grade were significant predictors for successful NET placement, as evidenced by the development of a nomogram and subsequent external validation. This model is primarily utilized for predicting preplacement success rates; however, there remains uncertainty regarding the determination of postplacement position, particularly when employing x-ray methodology for evaluation.

Therefore, we propose an innovative approach to develop a clinical prediction model based on the NET's configuration within the gastrointestinal tract as visualized in abdominal radiography, aiming to enhance the accuracy of determining NET position after placement.

2. Methods

2.1. Study design and patients

We retrospectively collected data on 883 cases of NET placement from the ICU at Zhejiang Provincial People's Hospital between October 1, 2017 and October 1, 2023. Inclusion criteria: 1. Patients with a high risk of aspiration or gastric feeding intolerance [7]. 2. Patients with gastrointestinal function that did not improve despite the use of gastrointestinal prokinetic agents [7]. 3. Patients undergoing their first-time placement of NETs. 4. Age ≥18 years. Exclusion criteria: 1. Patients who underwent gastrointestinal surgery. 2. Patients who had endoscopic placement of NETs. After excluding 60 patients, a total of 574 patients who fulfilled the inclusion criteria were ultimately included in the training cohort from October 1, 2017 to September 30, 2021. The validation cohort comprised of 249 patients from the same hospital between October 1, 2021 and October 1, 2023 based on the aforementioned criteria.

2.2. Ethics statement

The study protocol was approved by the Ethics Committee of Zhejiang Provincial People's Hospital and informed consent waivers were obtained (QT2024087).

2.3. Standard procedure for blind NET placement and judgment of location

The NET (model NT111, spec 12) used in our center is produced by Zhejiang Jiancheng Medical Technology CO., LTD., and it is of the same model as the Corflo NET made by corpark company in America. The maximum scale length of the NET is 140 cm. Metoclopramide 10 mg was administered intravenously to boost gastrointestinal peristalsis prior to the blind placement of NET [30]. The NET placement procedure was as follows: before NET placement, the patient position was adjusted (step 1). The placement depth was roughly measured according to the body surface landmarks of the patient (step 2). Make sure the NET is in the stomach (step 3). NET keeps moving forward (step 4). Adjust appropriately when resistance is encountered (step 5). The standardized procedure carried out at our center was originated from previously published protocols, with slight modifications made to improve its applicability and effectiveness [31,32]. Abdominal radiography was performed by the radiologist at the patient's bedside, and the ICU physicians evaluated the results. The gold standard for determining the location of the NET for all patients is established based on abdominal computerized tomography (step 6). The detailed NET placement process is shown in Fig. 1.

2.3.1. Data collection

Baseline data were obtained from the electronic medical record system for the following patient characteristics: age, gender, body mass index (BMI), clinical presentation, serum albumin levels, ICU-related scores, such as Apache II score, Sequential Organ Failure Assessment (SOFA) score, and Nutritional Risk Screening (NRS) 2002 score, administration of sedative analgesic medications, use of vasoactive medications, continuous renal replacement therapy (CRRT), admission to the ICU to time of initiation of enteral nutrition (either nasogastric tube or post-pyloric feeding tube), and time of placement of the NET to time of initiation of post-pyloric feeding. The following elements of the imaging were documented, including the "C-shape," the height of the "inverse C-shape (IC-shape)," showing the duodenojejunal flexure (DF), and the location of the head end of the NET, by imaging the NET in the gastrointestinal tract in the electronic medical record system. The evaluation of the above imaging was conducted collaboratively by two ICU physicians who possess expertise in standardized interpretation of radiographs. In instances where a disagreement arose between the two physicians, a third physician was consulted to render a final judgment.

2.4. Definition of outcome

The term "C-shape" describes the configuration of the NET as it traverses the bulbous, descending, and horizontal segments of the duodenum on abdominal radiography. The term "IC-shape" describes the configuration of the NET as it traverses the fundus, body, and antrum of the stomach on abdominal radiography. The height of the "IC-shape" corresponds to the number of vertebrae encompassed within the IC-shape" configuration observed on abdominal radiography. The DF refers to the configuration of the NET as it enters the jejunum through the ascending segment of the duodenum on abdominal radiography. The head end of the NET is defined as its position appearing on abdominal radiography either within or outside the contour of the stomach (Fig. 2).

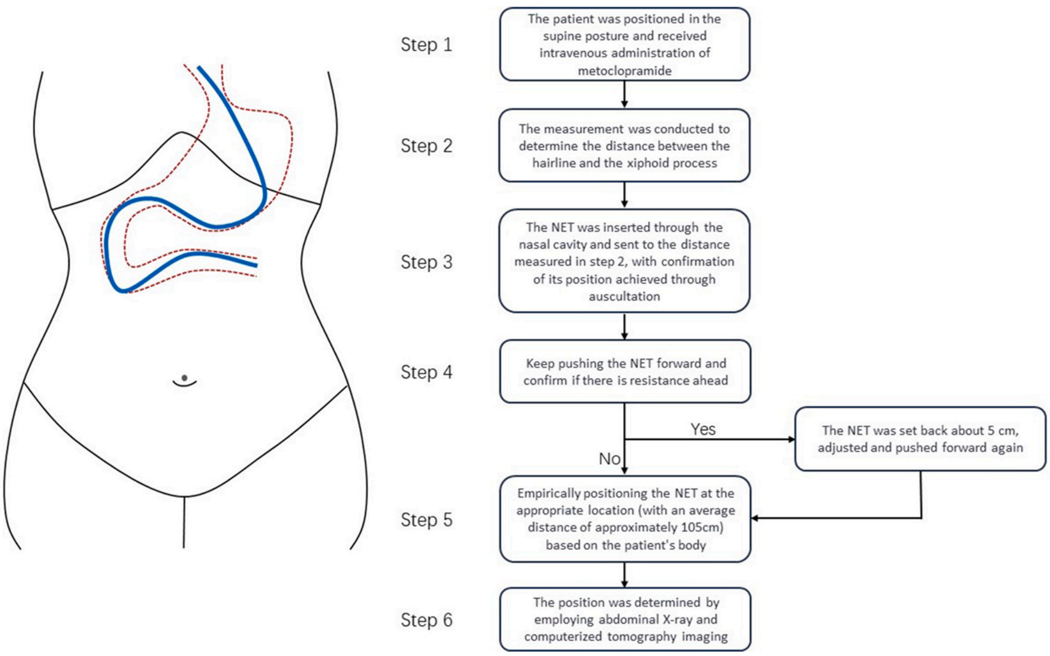

Fig. 1. Simplified diagram and flow chart of NET placement. NET, nasointestinal tube.

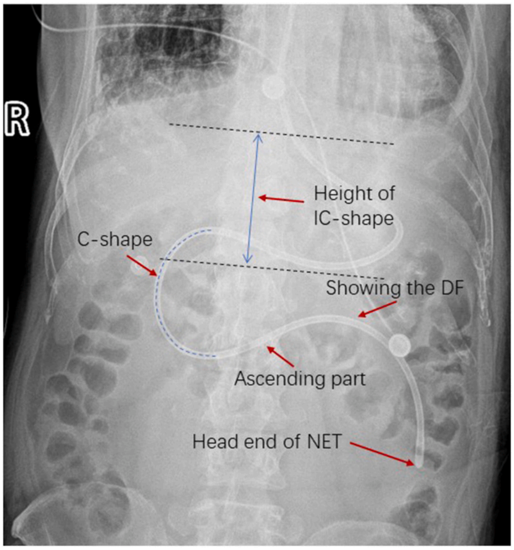

Fig. 2. NET's configuration under the abdominal radiography. The blue color double arrow solid line indicates the height of the IC-shape, its apex being the horizontal line through the cardia, and its lowest point being the horizontal line through the NET at the lower edge of in the stomach (theoretically equal to the level of the lower edge of the stomach). The blue dashed line indicates the C-shape, which theoretically represents the duodenal bulb, descending part, and horizontal part. IC-shape, inverse C-shape; DF, duodenojejunal flexure; NET, nasointestinal tube.

2.5. Development and assessment of the nomogram

Outcome variables were evaluated through multivariate logistic regression analysis, with univariate $P < 0.1$ as the entry criterion. Subsequently, a nomogram was constructed to predict the association between positional accuracy and outcome variables following the NET placement. It is a valuable tool because it visually represents the predicted probability of 0–100, and the total number of points assigned to each covariate corresponds to the predicted probability of successful placement of the patient according to different patient clinical characteristics. Disregarding statistical significance, the variable exhibiting the highest absolute value of beta will be assigned a score of 100 on the scale, while the remaining variables will receive scores proportionate to their effect size. The cumulative score is obtained by summing up individual scores for each predictor. The success rate of NET placement can be estimated by projecting a vertical line from the axis representing the total number of data points. The model's accuracy, sensitivity, and specificity in predicting tube placement success were evaluated using receiver operating characteristic curves (ROC), the area under the ROC curve (AUC), and

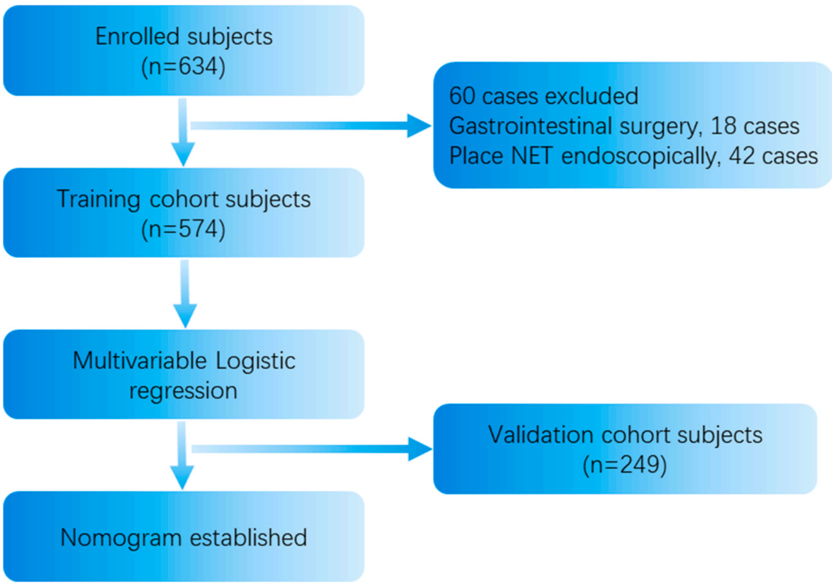

Fig. 3. Flow chart. NET, nasointestinal tube.

the concordance index (C-index). Nonparametric bootstrapping was conducted on the training and validation cohort, followed by the creation of calibration curves to evaluate the concordance between actual observations and predictions generated by the nomogram. Decision curve analysis (DCA) quantifies the net benefit of nomogram clinical applications at various threshold probabilities, thereby introducing a novel approach to assess predictive model performance. DCA combines the mathematical simplicity of accuracy measures, such as sensitivity and specificity, with the clinical applicability of decision analytic methods.

2.6. Statistical analyses

The data were analyzed using IBM SPSS Statistics v.25.0 (IBM Corp., Armonk, NY, USA). All data were expressed as mean ± standard deviation or median (interquartile range) based on normality tests. Unpaired t-tests, Mann-Whitney U-tests, or Fisher's exact tests were used as appropriate when performing univariate analysis. The outcome variables with $P < 0.1$ in the univariate analysis were included in the multivariate analysis model within the training cohort. In univariate analysis, there was no correction for multiple testing. Therefore, results should be interpreted with caution. Subsequently, the results were analyzed and visualized using various software packages including R language 4.3.1 rms (version 4.3.2), pROC (version 4.3.3), calibrate (version 4.3.3), ggplot2 (version 4.3.3), and dcurves (version 4.3). A significance level of p-value <0.05 was considered for determining statistically significant differences between groups (two-tailed).

3. Result

After excluding 60 patients (18 with routine gastrointestinal surgery and 42 with endoscopic NET placement), a total of 574 patients were included in the training cohort (Fig. 3). Within this cohort, the median age was 70 (57–80) years, with male patients accounting for 71.6 % (n = 411). Successful placements of NETs were achieved in 345 cases, representing a rate of 60.1 %. The training cohort was divided into successful and failed tube placement groups, and in terms of nutrition, NRS-2002 scores was 4.06 ± 1.39 in the successful group compared with 4.23 ± 1.55 in the failure group, which were not statistically different. Similarly, in critical illness-related scores, the Apache II score and SOFA score were 20.05 ± 7.17 and 8.07 ± 3.68 in the success group, respectively, while they were 19.61 ± 6.91 and 7.31 ± 3.58 in the failure group (Table 1). The frequency of cases in the successful group, where the NET

Table 1
Patient characteristics and results of the univariate analysis in training cohort.

Characteristic	Overall (n = 574)	Success (n = 345)	Failure (n = 229)	P-value
Age (years)	70 (57–80)	71 (57–80)	69 (56–80)	0.573
Sex, n (%)				0.508
Male	411 (71.6)	243 (70.4)	168 (73.4)	
Female	163 (28.4)	102 (29.6)	61 (26.6)	
Body mass index (kg/m^2)	22.92 ± 4.36	23.19 ± 4.24	22.52 ± 4.53	0.071
Clinical presentation, n (%)				
Sepsis	42 (7.3)	20 (5.8)	22 (9.6)	0.102
Septic shock	27 (4.7)	17 (4.9)	10 (4.4)	0.842
Severe pneumonia	137 (23.9)	80 (23.2)	57 (24.9)	0.689
Hypertension	258 (44.9)	150 (43.5)	108 (47.2)	0.393
Diabetes	94 (16.4)	58 (16.8)	36 (15.7)	0.818
Respiratory support way, n (%)				0.804
Mechanical ventilation	459 (80.0)	272 (78.8)	185 (80.8)	
High-Flow oxygen therapy	87 (15.1)	55 (16.0)	34 (14.8)	
Others	28 (4.9)	18 (5.2)	10 (4.4)	
Serum albumin (g/dL)	30.5 (27.7–33.3)	30.4 (27.5–33.2)	30.6 (28.0–33.7)	0.157
Use of sedatives, n (%)	452 (78.7)	264 (76.5)	188 (82.1)	0.119
Use of a vasopressor, n (%)	198 (34.5)	116 (33.6)	82 (35.8)	0.592
Renal replacement therapy, n (%)	108 (18.8)	57 (16.5)	51 (22.3)	0.102
Apache II score	19.87 ± 7.06	20.05 ± 7.17	19.61 ± 6.91	0.466
SOFA score	7.95 ± 3.64	8.07 ± 3.68	7.31 ± 3.58	0.346
NRS-2002 score	4.13 ± 1.46	4.06 ± 1.39	4.23 ± 1.55	0.165
NET placement depth (cm)	106.87 ± 5.07	106.97 ± 4.96	106.71 ± 5.23	0.542
Time from ICU admission to the start of enteral feeding (days)	1 (0–2)	1 (0–2)	1 (0–2)	0.509
Time from NET placement to the start of post-pyloric feeding (days)	1 (0–2)	0 (0–1)	2 (1–4)	<0.001
Outcome				
C-shape	317 (55.2)	277 (80.3)	40 (17.5)	<0.001
The height of IC-shape	2.87 ± 1.23	2.64 ± 1.12	3.25 ± 1.31	<0.001
NET's head position	300 (52.3)	263 (76.2)	31 (16.2)	<0.001
Showing the DF	202 (35.2)	183 (53.0)	19 (8.3)	<0.001
Complication				
Trachea and lung damage	0 (0.0)	0 (0.0)	0 (0.0)	1.000
Perforation of the digestive tract	0 (0.0)	0 (0.0)	0 (0.0)	1.000

Apache, Acute Physiology and Chronic Health Evaluation; SOFA, Sequential Organ Failure Assessment; NRS, Nutritional Risk Screening; IC-shape, inverse C-shape; NET, nasointestinal tube; DF, duodenojejunal flexure.

exhibited a “C-shape,” showing a DF, and had its head positioned outside the gastric contour on abdominal radiography, was significantly higher compared to the unsuccessful group ($p < 0.001$), indicating a statistically significant difference. Moreover, the height of “IC-shape” on abdominal radiography was 2.64 ± 1.12 in the successful group and 3.25 ± 1.31 in the unsuccessful group ($P < 0.001$). Additionally, a comparison of baseline data was conducted between the training and validation cohorts, revealing statistically significant differences in age ($P = 0.047$), vasoactive drug use ($P = 0.003$), CRRT ($P = 0.043$), Apache II score ($P = 0.046$), SOFA score ($P = 0.030$), and tube placement success ($P < 0.001$). However, no significant differences were observed between the two cohorts in terms of outcome variables (Table 2).

3.1. Nomogram development

In the univariate analysis of the training cohort outcome variables, four variables (namely “C-shape,” the height of “IC-shape,” showing the DF, and NET’s head end location) were included in a multivariate logistic retrospective model based on their statistical significance ($P < 0.1$). The findings demonstrated that the presence of a “C-shape” (OR 5.901, 95 % CI 3.492–9.972), the height of “IC-shape” (OR 0.830, 95 % CI 0.689–1.000), showing the DF (OR 2.124, 95 % CI 1.100–4.103), and NET’s head end location (OR 4.199, 95 % CI 2.418–7.294) were significant factors influencing the successful placement of the tube (Fig. 4). To construct the predictive model, we assigned four factors influencing the success of tube placement to the training cohort, and each factor was given a specific score based on its impact on tube placement success. Utilizing the rms package in R software, we generated a visual nomogram representing the predictive model (Fig. 5).

3.2. Nomogram validation

In the model constructed for the training cohort, the C-index was determined to be 0.883, while the AUC value was estimated at 0.883 (95 % CI 0.855–0.911). Similarly, in the validation cohort model, a C-index of 0.816 and an AUC value of 0.815 (95 % CI 0.750–0.880) were obtained (Fig. 6A and B). The calibration curve showed that bias-corrected lines for the training and validation cohorts overlap well with the ideal line (Fig. 7A and B). DCA illustrates the net clinical benefit that can be realized at different risk thresholds (Fig. 8A and B). The threshold range for DCA is derived from the training cohort and validation cohort based on the sensitivity and specificity of the model. Interventions were performed exclusively on patients whose assessed risk fell within this threshold range, resulting in a superior net benefit compared to intervening in all or none of the patients.

Table 2
Patient characteristics and results of the univariate analysis between training cohort and validation cohort.

Characteristic	Training cohort (n = 574)	Validation cohort (n = 249)	P-value
Age (years)	70 (57–80)	68 (58–76)	0.047
Sex, n (%)			0.405
Male	411 (71.6)	177 (68.7)	
Female	164 (28.4)	78 (31.3)	
Body mass index (kg/m^2)	22.92 ± 4.36	23.35 ± 4.01	0.181
Clinical presentation, n (%)			
Sepsis	42 (7.3)	22 (8.8)	0.479
Septic shock	27 (4.7)	7 (2.8)	0.255
Severe pneumonia	137 (23.9)	59 (23.7)	1.000
Hypertension	258 (44.9)	125 (50.2)	0.172
Diabetes	94 (16.4)	44 (17.7)	0.685
Respiratory support way, n (%)			0.810
Mechanical ventilation	459 (80.0)	194 (77.9)	
High-Flow oxygen therapy	87 (15.1)	39 (15.7)	
Others	28 (4.9)	16 (6.4)	
Serum albumin (g/dL)	30.5 (27.7–33.3)	30.6 (27.8–33.4)	0.276
Use of sedatives, n (%)	452 (78.7)	191 (76.7)	0.552
Use of a vasopressor, n (%)	198 (34.5)	60 (24.1)	0.003
Renal replacement therapy, n (%)	108 (18.8)	32 (12.9)	0.043
Apache II score	19.87 ± 7.06	18.90 ± 6.15	0.046
SOFA score	7.95 ± 3.64	7.41 ± 3.09	0.030
NRS-2002 score	4.13 ± 1.46	4.00 ± 1.24	0.221
NET placement depth (cm)	106.95 ± 4.69	106.87 ± 5.07	0.819
Time from ICU admission to the start of enteral feeding (days)	1 (0–2)	1 (1–2)	0.355
Time from NET placement to the start of post-pyloric feeding (days)	1 (0–2)	1 (0–2)	0.254
Outcome			
C-shape	317 (55.2)	153 (61.4)	0.107
The height of IC-shape	2.89 ± 1.23	2.80 ± 1.14	0.355
NET’s head position	300 (52.3)	146 (58.6)	0.094
Showing the DF	202 (35.2)	101 (40.6)	0.157
NET successfully placed	345 (60.1)	190 (76.3)	<0.001

Apache, Acute Physiology and Chronic Health Evaluation; SOFA, Sequential Organ Failure Assessment; NRS, Nutritional Risk Screening; IC-shape, inverse C-shape; NET, nasointestinal tube; DF, duodenojejunal flexure.

Variables	Beta	SE	z	OR(95%CI)	p
C-shape					
N				Reference	
Y	1.775	0.268	6.630	5.901(3.491,9.972)	0.000
The heigh of IC-shape	−0.186	0.095	1.965	0.830(0.689,1.000)	0.049
The position of NET head					
N				Reference	
Y	1.435	0.282	5.095	4.199(2.418,7.294)	0.000
Showing the DF					
N				Reference	
Y	0.753	0.336	2.243	2.124(1.100,4.103)	0.025

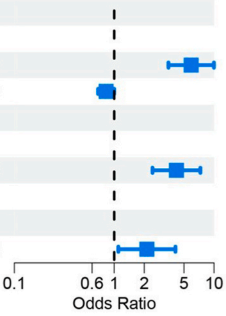

Fig. 4. Results of multivariate logistic regression analysis of the training cohort and forest plot of individual variables. Factors with an odds ratio >1.0 are associated with successful NET placement. CI, confidence interval; IC-shape, inverse C-shape; NET, nasointestinal tube; DF, duodenojejunal flexure. N (the position of NET head), the head of NET was inside the stomach contour. Y (the position of NET head), the head of NET was outside the stomach contour.

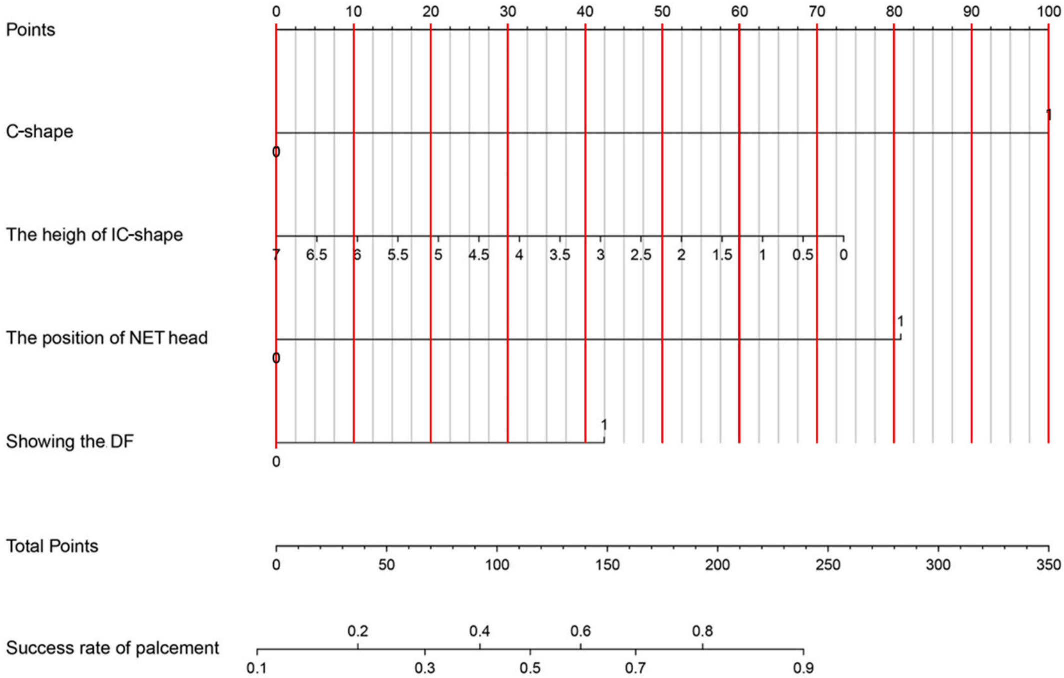

Fig. 5. Nomogram predicting the probability of success of NET placement. To obtain the nomogram-predicted probability, locate patient values on each axis. Draw a vertical line to the point axis to determine how many points are attributed for each variable value. Sum the points for all variables. Locate the sum on the total point line to assess the individual probability of successful NET placement. IC-shape, inverse C-shape; NET, nasointestinal tube; DF, duodenojejunal flexure; 1, Yes; 0, No.

4. Discussion

In this study, we demonstrated that the presence of "C-shape," the height of "IC-shape," showing the DF, as well as NET's head end location were identified as independent risk factors for successful tube placement. Furthermore, multiple logistic regression analysis confirmed these aforementioned variables to be independent predictors of successful tube placement. Based on these findings, we have developed a clinically useful nomogram for predicting the positional accuracy of NET placement in critically ill patients. To the best of our knowledge, this study represents the pioneering effort in developing a predictive model for abdominal radiography to investigate the determinants of NET placement success and subsequently translating the model into clinical practice, enabling clinicians to accurately assess NET positioning.

The success rate of blind NET placement has been reported to range from 20 % to 90 % based on previous studies [13–16]. In our center, the training cohort achieved a success rate of approximately 60 %, while the validation cohort demonstrated a higher success rate of 76.3 %. The nomogram demonstrates that the presence or absence of a "C-shape" on the abdominal radiography significantly

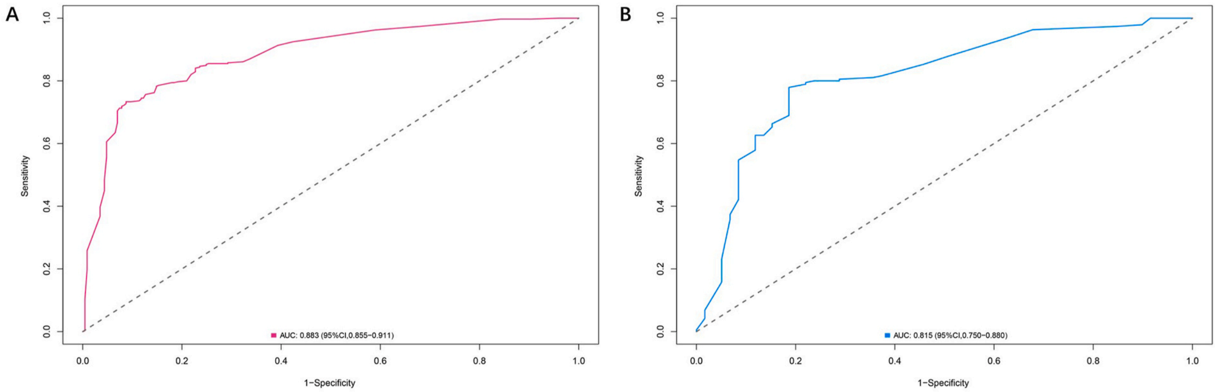

Fig. 6. ROC curve. ROC curve and AUC of the nomogram. Training cohort (A) and validation cohort (B). ROC, receiver operating characteristic; AUC, the area under ROC curve.

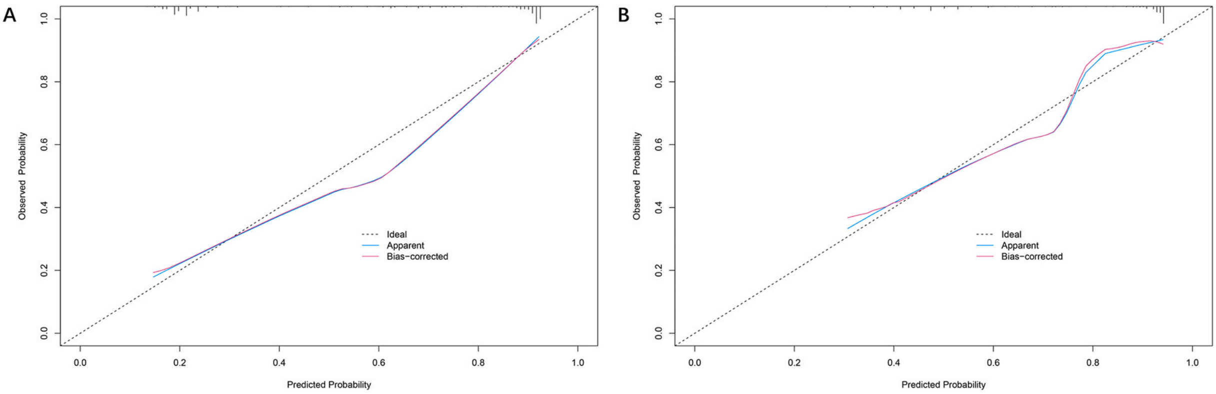

Fig. 7. Calibration curve. Calibration curve of the nomogram. Calibration curves of the successful NET placement in training cohort (A) and validation cohort (B). The dotted line represents the ideal reference line where the predicted probability matches the observed probability. The apparent curve in blue refers to the average predicted value of the response variable based on the calibration model without any adjustments for bias. The bias-corrected curve in red takes into account any systematic errors or biases in the calibration model by adjusting the apparent mean. The greater the degree of overlap between the two solid and the ideal reference line, the higher the level of prediction accuracy. NET, nasointestinal tube.

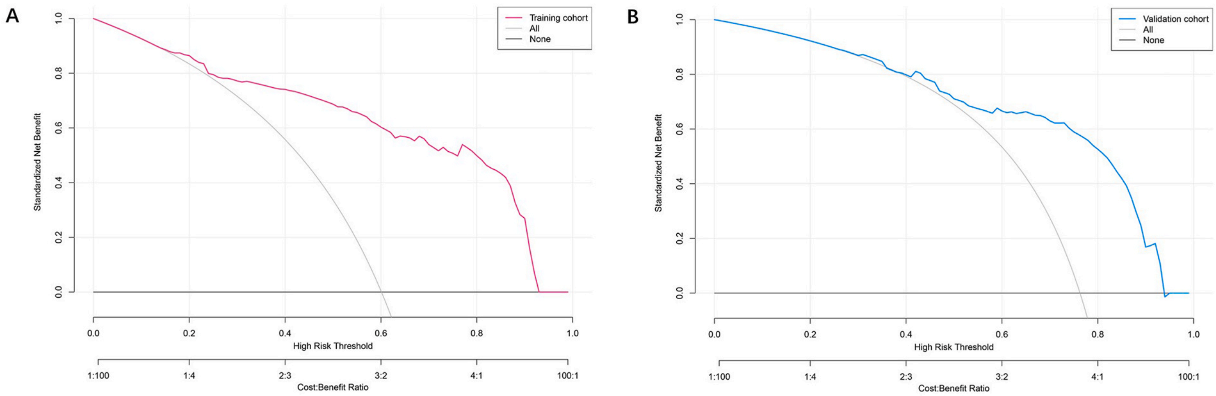

Fig. 8. DCA curve. DCA curve of the nomogram. DCA curve of the successful NET placement in training cohort (A) and validation cohort (B). DCA, decision curve analysis; NET, nasointestinal tube.

influences the efficacy of tube placement, with patients exhibiting a “C-shape” increasing the odds of success by 490 % compared to those without. Yamamichi N et al. [33] showed that patients without “C-shape” are more prone to barium retention compared to those with. They categorized the gastroduodenum into four distinct morphological types: V type (within the stomach), V-H type (in the proximal half of the duodenal bulb), H-V type (in the distal half of the duodenal bulb), and H type (in the descending portion of the duodenum). The duodenal bulb is observed to be positioned higher than the pyloric orifice on barium contrast imaging, and patients with a medial deviation (absence of “C-shape”) are more prone to experiencing barium retention compared to those with a lateral deviation ("C-shape”). Our findings align with Yamamichi N’s observation, as the duodenum typically originates on the right side of the pyloric opening in accordance with normal anatomical positioning [34]. Consequently, this facilitates smoother placement of NETs and is evident in abdominal radiography displaying a distinct “C-shape” contour formed by the bulbous, descending, and horizontal segments of the duodenum. In contrast, in patients whose abdominal radiographs do not exhibit a “C-shape,” the duodenal origin is biased towards the medial aspect of the body, rendering NET advancement more challenging and resulting in an increased rate of placement failure within the same position and angle of view.

The concept of the IC-shape was initially proposed by our research team, representing the anatomical configuration formed by the NET traversing through the gastric fundus, body, and antrum [34]. Moreover, the number of vertebrae encompassed within this “IC-shape” indirectly correlates with the overall length of the stomach. Based on this premise, we introduced the concept of vertebral height as a quantitative measure for assessing the overall length of the stomach. The study conducted by Kurisawa K et al. [14] demonstrated a significant correlation between the successful placement of NETs and their corresponding gastric and spinal levels observed on x-ray imaging, with the critical position identified as the L1-L2 spinal level. A recent study conducted by this research group demonstrated that the optimal cutoff point for accurately predicting a failed initial attempt at gastric greater curvature, based on computed tomography imaging, was identified caudal to the spine at L2-L3 [20]. The findings of our study align closely with two previous studies, as we observed a significant difference in the height of “IC-shape” between the groups with successful and unsuccessful tube placements. Notably, the unsuccessful group exhibited significantly higher “IC-shape” heights compared to the successful group, indicating that these patients had longer stomachs and belonged to the category of hook-type or weak-type stomachs based on gastric typing [35]. The presence of the duodenal suspensory ligament renders the pylorus relatively fixed, while the long stomach contributes to an increased curvature, thereby posing challenges in NET placement. This was also demonstrated by our findings that as the height of the “IC shape” increased, its efficacy in predicting whether the NET was in place decreased.

Similarly, we investigated whether the presence of DF on abdominal radiography independently influenced the success of tube placement and effectively incorporated it into our predictive model. Anatomically [34], it can be deduced that the distance from the tip of the nose to the beginning of the jejunum in a typical adult human is approximately 110–120 cm. In our study, the average depth of tube placement among patients was measured at 106.87 ± 5.07 cm in training cohort. Due to variations in body size among patients, some individuals (47 % in the success group) did not exhibit DF on abdominal radiographs, while a small proportion (8.3 %) in the failure group showed DF primarily due to imaging interpretation errors (folded in the stomach and had a shape similar to that of the DF). However, the multiple logistic regression analysis results revealed that this factor retained its status as an independent risk factor for determining location. Additionally, the visualization of the DF serves as an indirect indicator of NET placement depth and reduces the risk of tube re-move into the stomach due to intestinal peristalsis. Previous studies have reported instances of positional shifting of NET after several days of feeding, attributed to inadequate insertion depth [17,36]. Therefore, it is recommended that the head end of the NET be placed at a distal end of the ligament of Treitz [37], thereby minimizing the potential for aspiration and pneumonitis when exceeding beyond the fourth portion of the duodenum [38].

The visualization of the stomach contour on abdominal radiographs may be limited due to inherent constraints. However, by considering the anatomical positioning within the human body and assessing the display of the gastric bubble, an approximate assessment of the stomach contour can be made, enabling determination of the positional relationship between the NET’s tip and the stomach contour. It has been reported that over 1.2 million nasogastric tubes are annually inserted in the United States, with approximately 1.3%–2.4 % blindly placed entering the trachea and causing lung injury in about 0.3%–0.7 % of cases [39–41]. Similarly, in an analysis of 9931 patients with NET placement, Sparks DA et al. [42] reported a 1.9 % incidence of misplacement and a 0.36 % incidence of pneumothorax. In addition to this, another rare complication that should not be overlooked is gastrointestinal perforation during NET placement. Fakih H et al. [43]presented a case report describing the presence of an ectopic NET within the abdominal cavity. The head end of the NET was identified in the right upper quadrant of the gastric contour on abdominal radiography, and its location was confirmed by abdominal computerized tomography imaging. Our study demonstrated that the positioning of the NET’s head end outside the gastric contour independently influences the success of NET placement. Additionally, it was observed that None of the included patients had a NET inserted into the trachea; however, solely relying on abdominal radiography for diagnosis may fail to rule out gastrointestinal perforation, which is a shortcoming of it. Therefore, follow-up with abdominal computerized tomography imaging is recommended to accurately determine the presence or absence of gastrointestinal perforation. The positioning of the head end of the NET outside the gastric contour strongly suggests its presence in the small intestine rather than circling and winding through the stomach [44].

Our study was validated by abdominal computerized tomography imaging, which accurately identified the precise location of the NET and effectively excluded any possibility of its entry into the trachea or perforation into the abdominal cavity based on abdominal radiography. Currently, there is no standardized international criterion for the interpretation of abdominal radiography in relation to NET placement. Our study is based on a comprehensive understanding of gastrointestinal anatomy and the visualization of NET on abdominal radiography. We aim to develop a predictive model that will assist clinicians in accurately assessing the position of NET after tube placement. Firstly, due to the patient population’s specificity in ICU, abdominal computerized tomography has inherent limitations for most research centers. Consequently, bedside abdominal radiography remains a crucial modality for determining the location of NETs. Secondly, based on abdominal radiography findings, clinicians can make preliminary assessments of the location of the NET using these predictors, thereby reducing the time required to initiate post-pyloric feeding. Thirdly, employing a nomogram based on abdominal radiography enables clinicians to make quantitative assessments of the location of NETs, thereby enhancing the precision of diagnostic judgments. However, the study had some limitations First, due to the retrospective, single-center observational design, indication bias had to be taken into account, which may have affected the results of the study. Second, the predictive model employed in this study was specifically applicable for assessing success after NET placement and relied on the availability of abdominal radiography, rendering it unsuitable for pre-placement prediction. Third, compared with the validation cohort, the patients included in the training cohort had characteristics such as older age and more severe diseases, and the predictive model constructed differed somewhat from the model constructed in the validation cohort, but the overall predictive efficacy of both was still better. Fourth, the included patients may have abnormal gastrointestinal anatomy, vertebral compression and scoliosis, etc., and the model is not adapted to such patients. Fifth, due to the large number of included variables, multiple testing correction was not performed before multivariate analysis, which may increase the chance of false positives.

5. Conclusion

The combination of abdominal radiography and NET's configuration within the gastrointestinal tract enables accurate determination of NET placement in critically ill patients.

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Ethics approval and consent to participate

This study was approved by the Institutional Review Board and the Ethics Committee of the of Zhejiang Provincial People's Hospital, which complies with the Declaration of Helsinki (ethics approval number: QT2024087, Date of approval: April 30, 2024). Patient consent was waived since this is a retrospective study.

Consent for publication

Not Applicable.

Data availability statement

The data generated in this study can be shared after a reasonable request to the corresponding author.

CRediT authorship contribution statement

Zihao Zheng: Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Siyu Tang:** Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation. **Ziqiang Shao:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation. **Hanhui Cai:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation. **Jiangbo Wang:** Writing – review & editing, Formal analysis, Data curation. **Lihai Lu:** Writing – review & editing, Formal analysis, Data curation. **Xianghong Yang:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Investigation. **Jingquan Liu:** Writing – review & editing, Supervision, Resources, Project administration.

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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