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Ultrasonography and a novel combined prediction model for anticipating hypoxemia during painless gastroscopy

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Abstract. Over the years, the application of ultrasound as a non-invasive diagnostic tool has become increasingly widespread in clinical practice. Additionally, the incidence of hypoxemia is relatively high among patients undergoing painless gastroscopy. The primary objective of the present study was to predict the occurrence of hypoxemia in painless gastroscopy by measuring the anatomical parameters of the upper respiratory tract using ultrasound. The present single-center, prospective, observational study included 218 patients. Before anesthesia, basic information (age, sex, BMI) was collected. Preanesthetic ultrasound examined upper airway parameters, including distance from the skin to the hyoid bone (DSH), distance from the skin to the epiglottis (DSE), distance from the skin to the anterior commissure of the vocal cords (DSAC), tongue thickness (TT), hyoid-mental distance (HMD) and anterior condylar translation (ACT). Binary logistic regression was applied to identify independent predictors, and the predictive performance of each variable and a combined model was evaluated using the area under the receiver operating characteristic curve (AUC), calibration analysis and decision curve analysis (DCA). A total of 218 patients were analyzed in the present study. A binary logistic regression model identified BMI, DSH, DSE, DSAC, TT and ACT as the independent indicators associated with hypoxemia in painless gastroscopy. A novel combined predictive model equation was derived: logit(P)=1.053 x BMI + 1.363 x DSH + 1.658 x DSE + 1.839 x DSAC + 1.075 x TT-0.894 x ACT. The model demonstrated excellent discrimination with an AUC of 0.989, 95% CI: 0.979-0.999, significantly outperforming individual predictors (AUC range: 0.775-0.879). Calibration curves confirmed good agreement between predicted and observed risk, and DCA indicated clinical utility of the model. In conclusion, BMI, DSH, DSE, DSAC, TT, ACT and the novel combined predictive model incorporating aforementioned parameters are potentially valuable predictors fort the occurrence of hypoxemia in painless gastroscopy. This study was registered at the Chinese Clinical Trial Registry (trial registration no. ChiCTR2500109627; registered on 23 September 2025).

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Introduction

Painless gastroscopy is commonly used for diagnosing and treating gastrointestinal diseases (1). However, hypoxemia is a frequent complication with reported incidences ranging from 1.8 to 69% (2). This variation is influenced by factors such as sedation depth, patient risk profiles, oxygenation strategies and monitoring practices (3). Several factors contribute to the risk of hypoxemia, including respiratory depression caused by sedatives, pharyngeal airway obstruction, reduced chest wall compliance in obesity and airway obstruction from the endoscope (4). Severe or prolonged hypoxemia can lead to serious complications, such as myocardial ischemia, arrhythmias and cerebral hypoxia (5). As a result, assessing hypoxemia risk before the procedure is essential for enabling early interventions such as optimal patient positioning, airway management, tailored oxygen delivery and precise sedative titration, all of which improve procedural safety and patient outcomes.

Ultrasonography has become an important tool in clinical airway evaluation due to its real-time imaging capabilities, dynamic airway monitoring, and operator-independent measurements (6,7). Ultrasound can also capture dynamic airway changes under sedation, which are closely linked to desaturation during procedures (8). Consequently, ultrasound has gained prominence in pre-anesthesia difficult-airway assessment (9-10). A growing body of evidence supports the diagnostic utility of sonographic upper-airway parameters, such as distance from the skin to the hyoid bone (DSH), distance from the skin to the epiglottis (DSE), distance from the skin to the anterior commissure of the vocal cords (DSAC), tongue thickness (TT), hyoid-mental distance (HMD) and anterior condylar translation (ACT, a functional surrogate of mandibular mobility), for predicting difficult laryngoscopy or intubation (11-13). Notwithstanding these strengths, to the best of our knowledge, the direct application of airway ultrasound to predict hypoxemia during painless gastroscopy has been insufficiently explored, and robust, endoscopy-specific predictive models remain scarce.

The present study aimed to determine whether sonographic measurements can serve as reliable predictors of hypoxemia risk. We hypothesize that integrating multiple ultrasound parameters with clinical variables into a prediction model will offer a more accurate assessment, ultimately improving safety and guiding individualized oxygenation management during painless gastroscopy.

Materials and methods

Patient cohort and protocol. The present study was registered at the China Clinical Trial Registry (trial no. ChiCTR2500109627) on September 23 of 2025. The present study was reviewed and approved by the Medical Ethics Committee of Jiangnan University Medical Center (Wuxi, China; approval no. 2024Y329), and all participants gave informed consent. This prospective observational study was conducted at the Second People's Hospital (Wuxi, China) from October 2025 to January 2026. Consecutive adult patients aged 20-65 years who were scheduled for painless gastroscopy during the recruitment window were screened for eligibility. After confirming eligibility and obtaining written informed consent, 218 patients were enrolled. No interim analyses or protocol deviations that could affect patient safety or data integrity occurred during the study period.

Exclusion criteria were prespecified to minimize confounding from anatomical or physiological conditions that could independently alter airway dynamics. Patients were excluded if they had: Restricted neck movement (for example due to rheumatic disease, cervical masses or severe cervical spondylosis); upper respiratory tract anomalies or acute trauma (including maxillofacial trauma, cervical spine fractures or intraoral/airway masses); prior neck radiotherapy; single- or double-lumen tracheal intubation at presentation; known respiratory dysfunction (for example chronic respiratory failure, severe chronic obstructive pulmonary disease/asthma exacerbation or home oxygen use); or were pregnant. Where exclusion status was uncertain, supervising anesthesiologists adjudicated eligibility based on clinical records and examination.

After written informed consent was obtained, a standardized preoperative assessment was conducted by trained research staff using a predefined case report form. Demographic and anthropometric data included sex, age, body mass index (BMI, $kg \cdot m^{-2}$), neck circumference (measured at the level of the cricothyroid membrane at end-expiration) and sternomental distance (SMD; measured from the upper border of the manubrium to the mentum with the head fully extended and the mouth closed). All measurements were performed twice and averaged; if two readings differed by >5%, a third measurement was obtained and the median recorded. Comorbidities, medication history and prior anesthesia/sedation tolerance were documented to contextualize risk.

Upper-airway ultrasonography was performed using a GE ultrasound platform (GE HealthCare) equipped with a low-frequency convex probe and a high-frequency linear probe. Patients were positioned supine with the head in a neutral sniffing position; a thin pillow (3-5 cm) was used to align the external auditory meatus with the sternal notch when feasible. A liberal amount of gel was applied, and sonographers were instructed to use minimal transducer pressure to avoid compressing superficial soft tissues. The linear probe was the default for superficial structures; the convex probe was used in patients with large neck habitus or suboptimal acoustic windows. Measurements were acquired at end-expiration to reduce respiratory motion artifacts. Each parameter was measured three times, and the mean value was used for analysis.

The measured parameters are delineated as follows: i) DSH, distance in millimeters measured in a straight line from the cutaneous surface to the midline of the hyoid bone (Fig. 1); ii) DSE, distance in millimeters measured from the cutaneous surface to the middle axis of the highest part of epiglottis detected, through the thyrohyoid membrane (Fig. 1); iii) DSAC, distance in millimeters measured from the cutaneous surface to the midline of the anterior commissure of the vocal cords through the cricothyroid membrane (Fig. 1); iv) TT, the maximum vertical distance in millimeters measured from mylohyoid raphe to the surface of tongue (Fig. 2); v) HMD, distance in millimeters measured from the lower border of the mentum of the mandible to the upper border of the hyoid bone (Fig. 2); vi) ACT, distance that the anterior condyle moves horizontally after opening the mouth, measured in millimeters (Fig. 3).

After ultrasound assessment, all patients proceeded to painless gastroscopy under standardized sedation procedure. All patients received 5 μg sufentanil followed by propofol (1.5 mg/kg) over a time period of 60 sec. An endoscopist started examination when the MOAA/S score was ≤1 and the MOAA/S score was evaluated every 30 sec. A dose of 0.5 mg/kg propofol was administered when the MOAA/S score >1. Supplemental oxygen at 3 $l \cdot min^{-1}$ via standard nasal cannula was applied before induction.

Physiologic monitoring included continuous pulse oximetry (SpO_2), non-invasive blood pressure every 3-5 min, and electrocardiogram. Respiratory rate and chest excursion were observed throughout. An escalation algorithm for desaturation was predefined: i) Optimize head and neck position and reduce propofol infusion if SpO_2 trended downward; ii) initiate chin lift and/or jaw thrust for SpO_2 <90%; iii) increase oxygen flow to 5-8 $l \cdot min^{-1}$ and provide assisted ventilation via mask if recovery was not immediate; iv) for severe or persistent hypoxemia, suspend propofol infusion, perform bag-mask ventilation with 100% oxygen and insert an oral/nasopharyngeal airway as indicated. All hypoxemic events (threshold SpO_2 <90% for ≥10 sec) were prospectively recorded, including lowest SpO_2, duration, interventions and recovery time, using standardized forms by trained staff blinded to ultrasound measurements.

To ensure data quality, all measurements and intra-procedural events were double-entered into a secure database with real-time range checks. A 10% random sample of ultrasound images was re-evaluated by a senior reviewer; discrepancies >2 mm triggered consensus review and operator feedback.

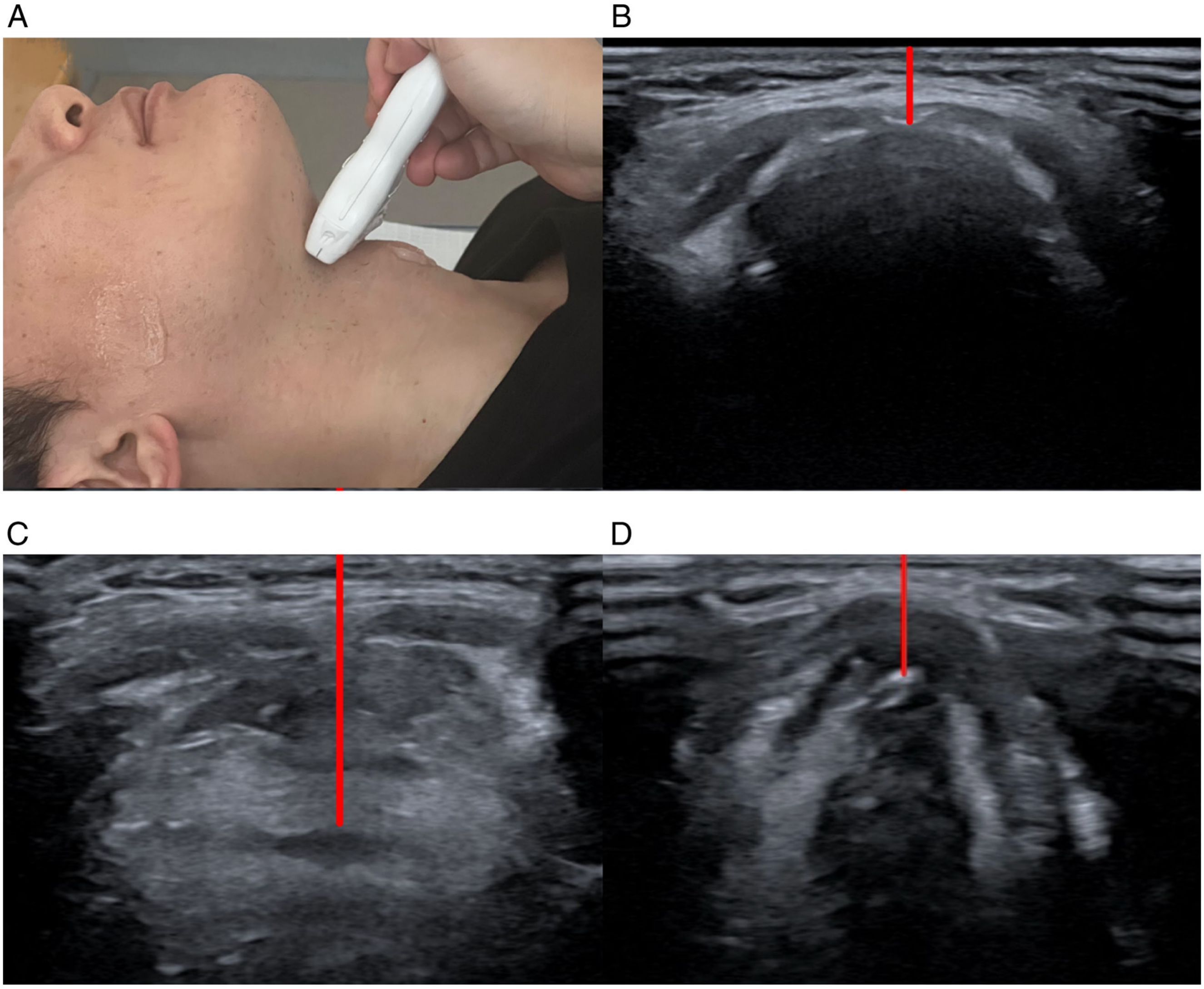

Figure 1. Ultrasound measurement of anterior neck airway parameters using a high-frequency linear array probe. (A) Placement of the high-frequency linear array probe on the anterior neck. (B) the distance from the skin to the hyoid bone (the red line), (C) the distance from the skin to the epiglottis (the red line) and (D) the distance from the skin to the anterior commissure of the vocal cords (the red line).

Where feasible, inter-operator reliability was assessed on a pilot subset, targeting intraclass correlation coefficients ≥0.80 for key parameters (DSH, DSE, DSAC, TT, HMD, ACT). Outcome adjudication (occurrence of hypoxemia) was independently verified by two investigators based on monitor trends and intervention logs.

Statistical analysis. Statistical analyses were performed using SPSS 27.0 software (IBM Corp.). Categorical data are expressed as cases (%), and differences between groups were analyzed using the χ^2 test. Measurement data that did not conform to a normal distribution are expressed as median (lower quartile-upper quartile), and the non-parametric Mann-Whitney U test was used to compare hypoxemia and non-hypoxemia groups. Multiple index joint diagnosis was achieved using binary logistic regression analysis to calculate odds ratios (ORs) and confidence intervals (CIs). A novel combined predictive model was developed, and its predictive value was evaluated using the area under the receiver operating characteristic (ROC) curve (AUC). The combined predictive model equation was established according to the regression coefficients of the independent predictors retained in the multivariate logistic regression analysis. The nomogram was constructed based on this final logistic regression model. The Hosmer-Lemeshow goodness-of-fit test was used to assess the calibration of the model. The efficiency of diagnosing hypoxemia was analyzed using ROC curves. Calibration curves were constructed to assess the consistency between predicted and observed probabilities. Decision curve analysis (DCA) was performed to evaluate the clinical utility of the model. All tests for statistical significance were two-tailed, and $P<0.05$ was considered to indicate a statistically significant difference. The adequacy of the sample size for multivariable modeling was assessed according to the events-per-variable criterion.

Results

Clinical characteristics and laboratory data of patients. A total of 218 patients were included in the present study (Table I). The median age was 45.00 (36.00-57.00) years in

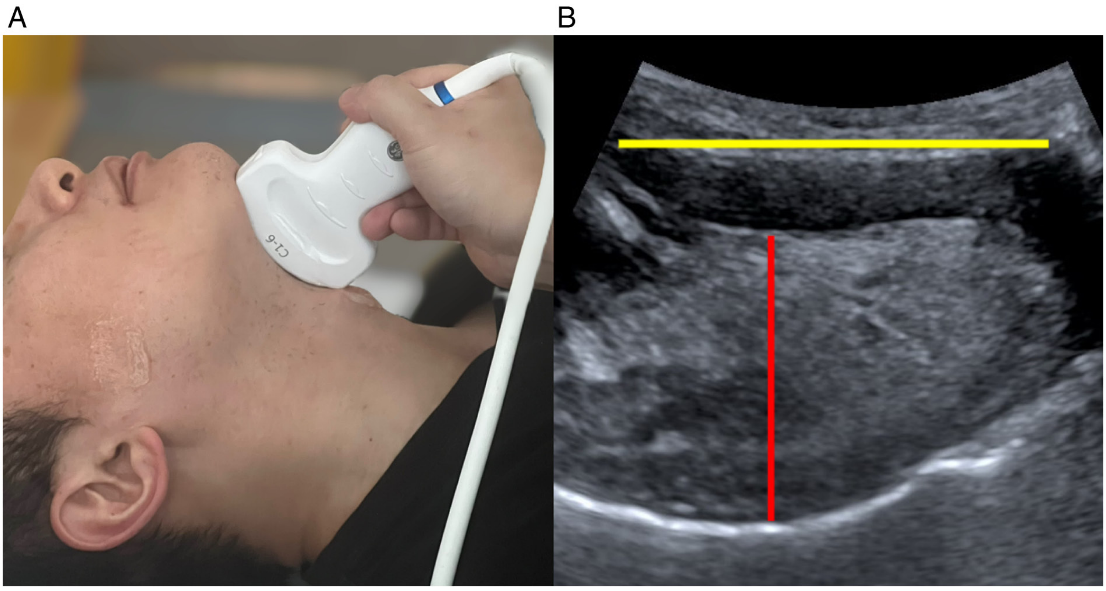

Figure 2. Ultrasound measurement of tongue thickness and hyoid-mental distance using a low-frequency curvilinear array probe. (A) Placement of the low-frequency curvilinear array probe in the submental region. (B) Measurement of tongue thickness (red line) and hyoid-mental distance (yellow line).

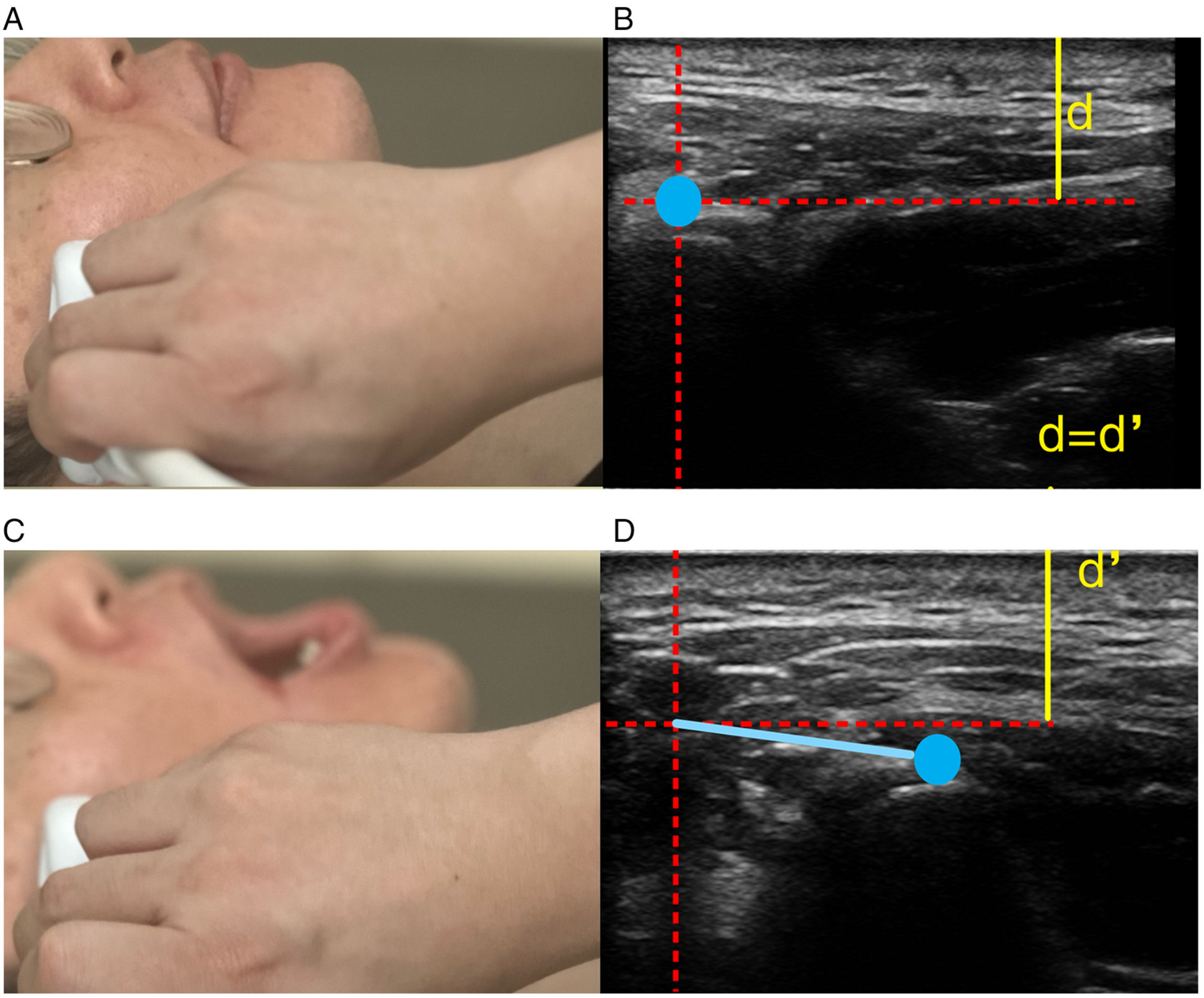

Figure 3. Method of applying high-frequency linear array ultrasonic probe to evaluate condylar mobility of temporomandibular joint. (A) Patient's position in shut mouth and place of ultrasonic probe. (B) The anterior condyle (the blue dot). (C) Image of ultrasound in opened mouth. (D) Anterior condylar translation (the blue line).

Table I. Comparison of clinical characteristics between hypoxemia and non-hypoxemia groups.

Variable	Non-hypoxemia (n=168)	Hypoxemia (n=50)	P-value
Sex (female %)	115 (68.45)	28 (56.00)	0.104
Age, years	45.00 (36.00-57.00)	34.50 (28.00-56.00)	0.055
BMI, $kg \cdot m^{-2}$	23.80 (21.75-25.40)	27.10 (25.40-29.33)	<0.001
Neck circumference, cm	32.00 (30.00-35.00)	35.00 (29.00-37.00)	0.018
SMD, cm	12.00 (12.00-13.00)	13.00 (11.00-13.00)	0.405
DSH, mm	0.85 (0.79-0.94)	1.02 (0.97-1.22)	<0.001
DSE, mm	2.13 (2.01-2.54)	2.78 (2.63-2.82)	<0.001
DSAC, mm	0.79 (0.71-0.85)	0.95 (0.83-1.07)	<0.001
TT, cm	5.09 (4.75-5.19)	6.11 (5.28-6.27)	<0.001
HMD, cm	4.91 (4.69-5.24)	5.24 (4.86-5.28)	0.001
ACT, cm	1.21 (1.15-1.27)	1.00 (0.99-1.12)	<0.001

DSH, distance from the skin to the hyoid bone; DSE, distance from the skin to the epiglottis; DSAC, distance from the skin to the anterior commissure of the vocal cords; TT, tongue thickness; HMD, hyoid-mental distance; ACT, anterior condylar translation.

Table II. Univariate and multivariate logistic regression analysis.

Variable	Univariate OR (95% CI)	P-value	Multivariate OR (95% CI)	P-value	VIF
BMI	2.573 (1.806-3.667)	<0.001	2.867 (1.257-6.539)	0.012	1.165
Neck circumference	1.509 (1.089-2.091)	0.013	1.496 (0.689-3.247)	0.309	1.145
DSH	3.924 (2.512-6.129)	<0.001	5.251 (1.892-14.572)	0.001	1.575
DSE	7.287 (3.919-13.55)	<0.001	3.907 (1.534-9.949)	0.004	1.040
DSAC	4.299 (2.738-6.750)	<0.001	6.289 (2.601-15.205)	<0.001	1.809
TT	3.208 (2.227-4.622)	<0.001	2.929 (1.281-6.696)	0.011	1.234
HMD	1.639 (1.205-2.229)	0.002	2.353(0.954-5.804)	0.063	1.362
ACT	0.218 (0.136-0.349)	<0.001	0.409 (0.184-0.909)	0.028	1.131

DSH, distance from the skin to the hyoid bone; DSE, distance from the skin to the epiglottis; DSAC, distance from the skin to the anterior commissure of the vocal cords; TT, tongue thickness; HMD, hyoid-mental distance; ACT, anterior condylar translation; VIF, variance inflation factor; OR, odds ratio; CI, confidence interval.

the non-hypoxemia group and 34.50 (28.00-56.00) years in the hypoxemia group. In the hypoxemia group, 28 (56.00%) were female, while in the non-hypoxemia group, 115 (68.45%) were female. Compared with the non-hypoxemia group, patients in the hypoxemia group had higher BMI (P<0.001), neck circumference (P=0.018), DSH (P<0.001), DSE (P<0.001), DSAC (P<0.001), TT (P<0.001), and HMD (P=0.001), but lower ACT (P<0.001). No significant differences were observed in sex (P=0.104), age (P=0.055) or SMD (P=0.405).

Univariate and multivariate logistic regression analyses for predicting hypoxemia. Univariate analysis showed that BMI (P<0.001), neck circumference (P=0.013), DSH (P<0.001), DSE (P<0.001), DSAC (P<0.001), TT (P<0.001), HMD (P=0.002) and ACT (P<0.001) were significantly associated with hypoxemia (Table II). Multivariate logistic regression analysis identified BMI (OR=2.867; 95% CI: 1.257-6.539; P=0.012), DSH (OR=5.251; 95% CI: 1.892-14.572; P=0.001), DSE (OR=3.907; 95% CI: 1.534-9.949; P=0.004), DSAC (OR=6.289; 95% CI: 2.601-15.205; P<0.001), TT (OR=2.929; 95% CI: 1.281-6.696; P=0.011) and ACT (OR=0.409; 95% CI: 0.184-0.909; P=0.028) as independent predictors of hypoxemia. By contrast, neck circumference (P=0.309) and HMD (P=0.063) were not significant in the multivariable model.

To assess multicollinearity, variance inflation factors (VIFs) were calculated. All predictors showed low VIF values (1.040-1.809), below the threshold of 5.0, indicating no significant multicollinearity and good stability of the multivariate model.

The combined predictive model equation is: logit(P)=1.053 x BMI + 1.363 x DSH + 1.658 x DSE + 1.839 x DSAC + 1.075 x TT-0.894 x ACT. The nomogram provides a visual tool for estimating this probability based on the individual contributions of these factors (Fig. 4). The calibration curve demonstrates good agreement between the predicted and observed probabilities of hypoxemia (Fig. 5). Finally, the DCA indicates that the combined predictive model has clinical utility, showing a net benefit over assuming all or no patients will experience hypoxemia across a range of risk thresholds (Fig. 6).

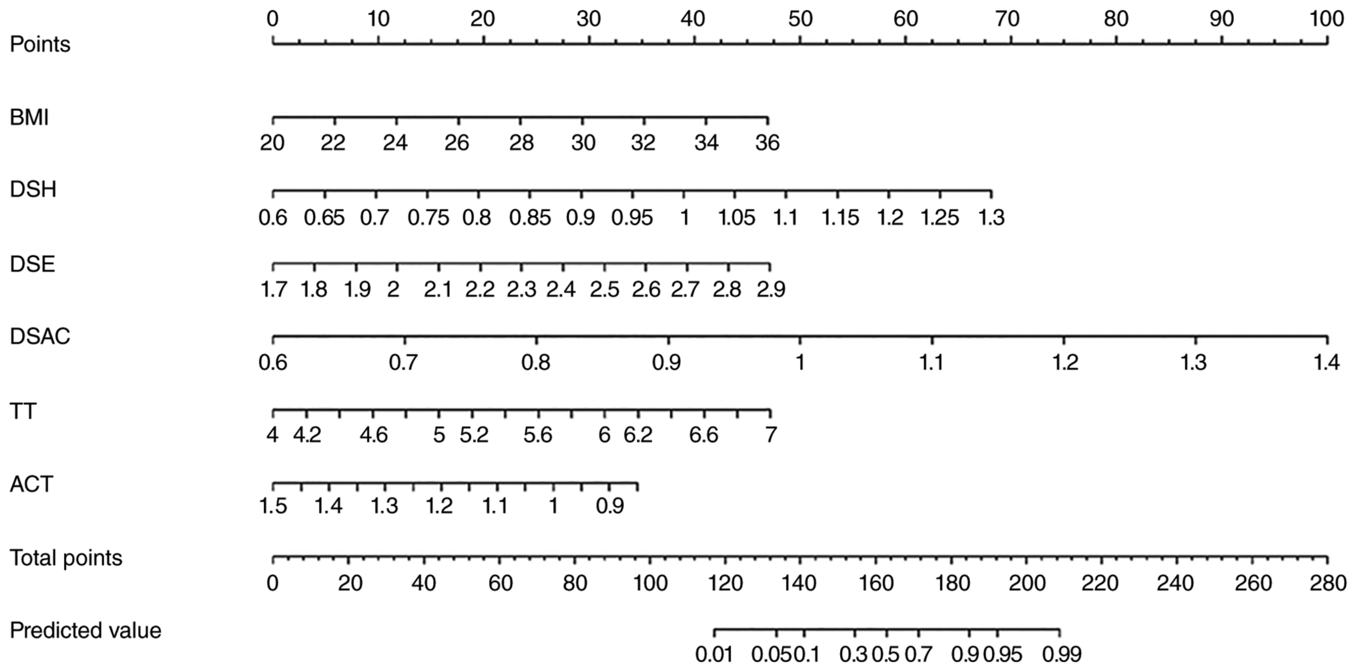

Figure 4. Nomogram for predicting hypoxemia. BMI, body mass index; DSH, distance from the skin to the hyoid bone; DSE, distance from the skin to the epiglottis; DSAC, distance from the skin to the anterior commissure of the vocal cords; TT, tongue thickness; HMD, hyoid-mental distance; ACT, anterior condylar translation.

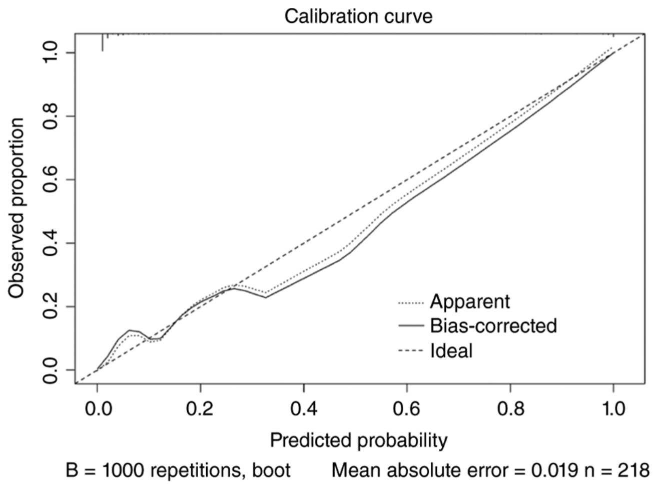

Figure 5. Calibration nomogram. Where the x-axis represents the predicted probability of hypoxemia occurrence by the model, and the y-axis represents the actual observed proportion of hypoxemia occurrence. The dashed line (ideal) is the ideal calibration line, the dotted line (apparent) is the calibration curve of the original data and the solid line (bias-corrected) is the bias-corrected curve calculated using 1,000 bootstraps.

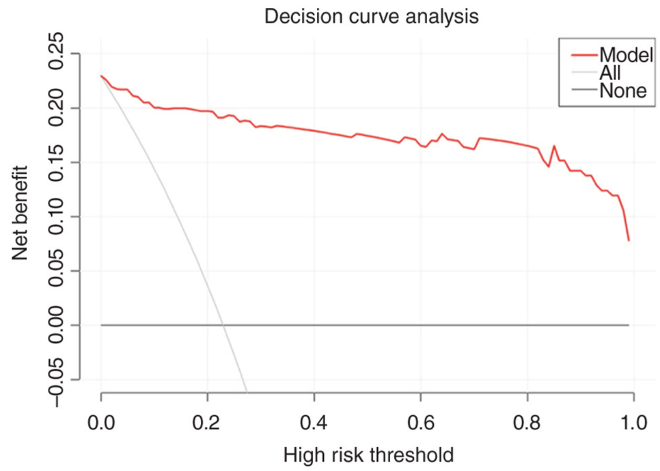

Figure 6. Decision curve analysis. The decision curve analysis demonstrates the clinical utility of the combined predictive model for hypoxemia. The y-axis represents the net benefit, and the x-axis represents the threshold probability for high risk. The red line (model) indicates the net benefit of using the predictive model to guide clinical decisions. The gray line labeled 'All' assumes all patients will experience hypoxemia and the black line labeled 'None' assumes no patients will experience hypoxemia. The model shows a net benefit over the 'All' or 'None' strategies across a range of threshold probabilities.

Predicting hypoxemia status. In the ROC curve analysis, the AUC values for different variables in predicting hypoxemia were all >0.7, indicating good discriminative ability (Table III and Fig. 7). Among them, DSE (AUC=0.879; 95% CI: 0.818-0.940) and ACT (AUC=0.821; 95% CI: 0.740-0.901) performed best in independently predicting hypoxemia. BMI (AUC=0.775; 95% CI: 0.710-0.840), DSH (AUC=0.789; 95% CI: 0.703-0.875), DSAC (AUC=0.791; 95% CI: 0.700-0.883) and TT (AUC=0.800; 95% CI: 0.724-0.876) also demonstrated good predictive efficacy. In terms of sensitivity and specificity, DSE had the highest sensitivity (0.900), meaning this indicator can more effectively identify hypoxemia positive cases, while DSAC had the highest specificity (0.905), indicating its stronger ability to distinguish hypoxemia negative cases. Regarding the best thresholds, the optimal cut-off for BMI is 25.600, for DSH is 0.955, for DSE is 2.525, for DSAC is 0.905, for TT is 5.200 and for ACT is 1.130. The AUC of the combined model reached 0.989 (95% CI: 0.979-0.999), which is significantly higher than individual indicators, indicating that combining multiple variables can further improve the accuracy of

Table III. Receiver operating characteristic curve analysis for predicting hypoxemia.

Variable	AUC (95%CI)	Cut-off value	P-value	Sensitivity	Specificity
BMI	0.775 (0.710-0.840)	25.600	<0.001	0.760	0.756
DSH	0.789 (0.703-0.875)	0.955	<0.001	0.820	0.786
DSE	0.879 (0.818-0.940)	2.525	<0.001	0.900	0.732
DSAC	0.791 (0.700-0.883)	0.905	<0.001	0.720	0.905
TT	0.800 (0.724-0.876)	5.200	<0.001	0.840	0.756
ACT	0.821 (0.740-0.901)	1.130	<0.001	0.800	0.792
Model	0.989 (0.979-0.999)	-	<0.001	0.940	0.970

DSH, distance from the skin to the hyoid bone; DSE, distance from the skin to the epiglottis; DSAC, distance from the skin to the anterior commissure of the vocal cords; TT, tongue thickness; HMD, hyoid-mental distance; ACT, anterior condylar translation; AUC, area under the curve; CI, confidence interval.

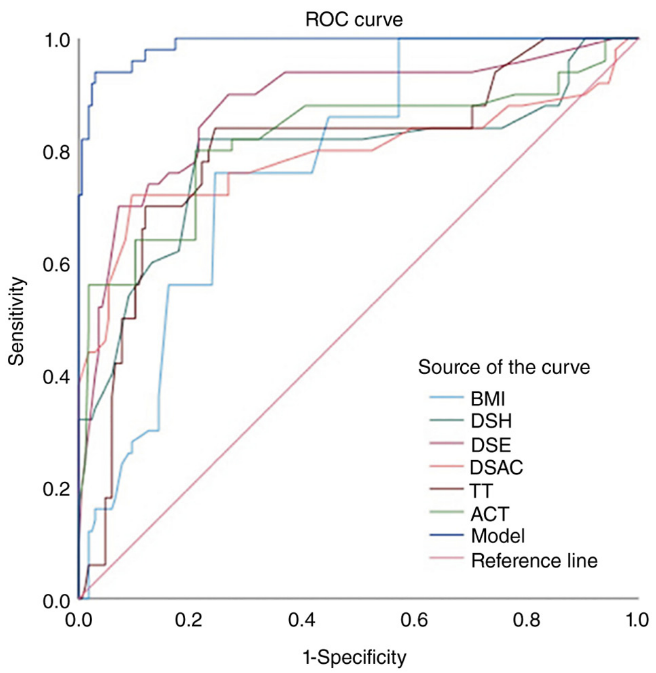

Figure 7. ROC curve. ROC, receiver operating characteristic; DSH, distance from the skin to the hyoid bone; DSE, distance from the skin to the epiglottis; DSAC, distance from the skin to the anterior commissure of the vocal cords; TT, tongue thickness; HMD, hyoid-mental distance; ACT, anterior condylar translation.

hypoxemia prediction. The sensitivity of the combined model is 0.940, and the specificity is 0.970, balancing the stability and reliability of the prediction.

Discussion

The present prospective observational study analyzed clinical and ultrasonographic data from 218 patients undergoing painless gastroscopy. Analysis revealed significant differences in BMI, neck circumference, DSH, DSE, DSAC, TT, HMD and ACT between the hypoxemia and non-hypoxemia groups. The relevance of these upper-airway ultrasonographic parameters in airway assessment has also been reported in previous studies (14-16). Multivariate analysis identified BMI, DSH, DSE, DSAC, TT and ACT as independent predictors of hypoxemia. A novel combined predictive model was constructed based on logistic regression analysis. ROC analysis demonstrated that the combined prediction model had an AUC of 0.989, which was significantly superior compared with individual parameters, indicating that the integration of ultrasonographic parameters can significantly improve the accuracy of preoperative hypoxemia prediction; the evaluation methods used were consistent with previous methodological studies (17-19).

The high incidence of hypoxemia during painless gastroscopy poses a notable clinical challenge (20-22). As gastroscopy is a valuable tool for diagnosing and treating gastrointestinal diseases, the associated hypoxemia can lead to severe adverse events, including myocardial ischemia, arrhythmias, neurological damage and even death (23,24). Systematic pre-procedural assessment of hypoxemia risk in patients undergoing painless gastroscopy may enable early intervention and markedly reduce its incidence (25). This approach allows clinicians to formulate individualized oxygenation-management strategies in advance, thereby enhancing peri-procedural oxygenation stability, improving procedural safety, minimizing adverse events and ultimately optimizing both diagnostic quality and patient outcomes (26-29).

In the present study, the incidence of hypoxemia was 22.9% (50/218). The present findings demonstrated that specific ultrasonographic measurements, such as DSH, DSE, DSAC and TT, are independently associated with hypoxemia during painless gastroscopy, which is consistent with previous studies on airway ultrasound assessment (13-16). Specifically, a higher DSH, DSE and DSAC were associated with increased risk of hypoxemia (30-32). These parameters provide valuable information about the upper airway anatomy and potential airway obstruction, which can contribute to respiratory compromise during sedation (33-35). Notably, ACT, reflecting mandibular mobility, was also identified as an independent predictor of hypoxemia, where a lower ACT was associated with hypoxemia. This suggests that limited mandibular movement may contribute to airway obstruction and increase the risk of hypoxemia during painless gastroscopy, which is supported by previous studies on mandibular movement and airway patency (36-38).

Several studies have demonstrated that ultrasound measurement of upper airway anatomical parameters can accurately assess difficult airways, including parameters such as DSH, DSE, DSAC, TT and ACT. In line with prior studies, the present results highlight the importance of upper airway assessment in predicting hypoxemia (16,34,35). The strength of the present study lies in its prospective design and comprehensive data collection. The prospective nature minimized recall bias and allowed for standardized data acquisition. Comprehensive preoperative assessments were undertaken, and demographic and anthropometric data were recorded including sex, age, BMI and neck circumference. To obtain a series of upper respiratory tract anatomical parameters, ultrasound measurements were performed utilizing the convex and linear probes of the GE ultrasound system (39,40).

The combined predictive model, incorporating BMI, DSH, DSE, DSAC, TT and ACT, demonstrated excellent predictive accuracy (AUC=0.989), surpassing the predictive ability of individual parameters. The novel combined predictive model equation was derived: logit(P)=1.053 x BMI + 1.363 x DSH + 1.658 x DSE + 1.839 x DSAC + 1.075 x TT-0.894 x ACT. This highlights the value of integrating multiple ultrasonographic parameters to create a more robust and reliable risk assessment tool (13-16). The nomogram based on the predictive model offers a user-friendly method for clinicians to estimate the probability of hypoxemia, facilitating individualized management strategies. The calibration curve further validates the reliability of the model. The DCA (19,41) also showed that the combined predictive model has clinical utility, showing a net benefit across a range of risk thresholds (18).

In the present study, the findings were partly consistent with previous studies, but some differences were also observed. Similar to earlier reports, BMI was a notable predictor of hypoxemia. Previous studies mainly focused on conventional clinical variables or limited ultrasound indicators (2,42,43). For example, an earlier artificial neural network (ANN) model included BMI, habitual snoring and neck circumference (42), whereas a recent nomogram study included BMI, propofol dose, Mallampati score and TT (43). Machine-learning studies also showed that integrating more peri-procedural variables could improve predictive performance (2,44). Different from these studies, the present study systematically evaluated multiple upper-airway ultrasound parameters, including DSH, DSE, DSAC, TT, HMD and ACT, and found that DSH, DSE, DSAC, TT and ACT were independent predictors of hypoxemia. These results indicate that hypoxemia during painless gastroscopy may be associated not only with general clinical factors, but also with multidimensional upper-airway anatomical characteristics. This may provide additional information for pre-procedural risk assessment in clinical practice.

Some limitations should be acknowledged. First, this was a single-center study, which may limit the generalizability of the present findings (41). Second, while comprehensive data on upper airway anatomical parameters were collected, other potential contributing factors to hypoxemia (such as sedative dosage and endoscope insertion technique) were not fully evaluated. Specifically, anesthesia was induced and maintained via continuous intravenous infusion of propofol, and prior to the administration of propofol for sedation, all patients received oxygen at 3 l min^{-1} via standard nasal cannula. The dose of sufentanil was predetermined at a concentration of 5 μg (25). Future studies should consider incorporating these variables to refine the predictive model (17,41). Third, although the present study was conducted prospectively, the sample size could be larger to enhance statistical power (41). Despite these limitations, the present study provides valuable insights into the use of ultrasonography for predicting hypoxemia during painless gastroscopy. The identified ultrasonographic parameters and the developed combined predictive model hold promise for improving patient safety and optimizing oxygenation management during these procedures.

Future research should focus on validating the present findings in larger, multi-center studies (41). Furthermore, investigating the impact of targeted interventions based on ultrasonographic risk assessment on hypoxemia incidence and patient outcomes would be beneficial (26). With the increasing use of point-of-care ultrasound, further studies could explore the role of machine learning and artificial intelligence for automated analysis and prediction of hypoxemia risk, improving diagnostic efficiency and accuracy (17).

In conclusion, the present study supports the use of ultrasonography as a valuable tool for predicting hypoxemia during painless gastroscopy and provides a foundation for future research in this area.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

YZ was responsible for the conceptualization and methodology of the study, led the investigation and formal analysis and wrote the original draft; LL contributed to clinical data collection, organization and checking of the dataset, and reviewed and edited the manuscript; JL contributed to statistical analysis, construction and assessment of the prediction model, and preparation of the figures; JX contributed to patient recruitment, data acquisition and interpretation of clinical data; AW contributed to the study design, patient recruitment, data acquisition and interpretation of clinical data; FD led the conceptualization and supervision of the research, was responsible for funding acquisition, project administration and reviewed and edited the entire manuscript and handled all correspondence. DH contributed to the interpretation of clinical data and critical revision of the manuscript. YZ and LL confirm the authenticity of all the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

The present research was carried out after receiving approval from the Ethics Committee of Jiangnan University Medical Center (approval no. 2024Y329). The present study was performed in accordance with The Declaration of Helisinki (2013) and registering on Clinical Trials (ChiCTR2500109627, Chinese Clinical Trial Registry), and all participants gave written informed consent.

Patient consent for publication

Written informed consent for publication of identifiable personal/face images shown in Figs. 1-3 was obtained from the patients.

Competing interests

The authors declare that they have no competing interests.

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