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Nomogram for predicting the success rate of sedation with intranasal dexmedetomidine in paediatric nonpainful diagnostic procedures: a retrospective study

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Intranasal dexmedetomidine (IN DEX) is being increasingly used for sedation in children undergoing nonpainful diagnostic procedures. Successful procedural sedation facilitates rapid and accurate clinical diagnosis and treatment, thereby improving clinical management efficiency. As the success rate of sedation is influenced by multiple factors, enhancing sedation success, reducing procedure-related risks, and minimizing adverse events are critical clinical priorities. In this study, children aged 12–72 months (1–6 years) who underwent outpatient examinations requiring sedation with IN DEX were included. Data were extracted from the electronic medical records system of the outpatient sedation suite. The training dataset was analysed using least absolute shrinkage and selection operator (LASSO) and multivariable logistic regression to develop a nomogram-based clinical predictive model. Model performance was evaluated via receiver operating characteristic (ROC) curves, calibration curves, and decision curve analysis (DCA), with validation performed using a separate validation dataset. The developed nomogram, which incorporates napping before sedation, respiratory diseases, snotty before sedation, neurological diseases, sedation history, sedation duration, and sedation method, exhibited moderate predictive value (AUC = 0.833), favourable calibration, and enhanced clinical benefit. This study establishes a clinical prediction nomogram that can assist anaesthesiologists in the outpatient sedation suite to customize and optimize sedation plans, thereby improving the sedation success rate of IN DEX, enhancing the efficiency of nonpainful diagnostic procedures, and providing substantial clinical benefits.

Procedural sedation is essential for nonpainful diagnostic examinations in paediatric patients, who have unique demographics because of their young age, incomplete physical and mental development, limited tolerance to unfamiliar environments, and poor emotional regulation. Exposure to unfamiliar health care providers, examination equipment, noise, and dim and confined examination rooms often induces panic, crying, and restlessness, leading to non-cooperation during procedures requiring prolonged immobility[1]. These behaviours compromise examination efficiency and quality while increasing the risks of adverse reactions, such as catecholamine-mediated tachycardia, increased respiratory secretions, and dyspnoea. Parental separation during procedures further exacerbates challenges[1]. Thus, moderate-to-deep sedation or anaesthesia is often required to optimize examination outcomes and reduce adverse events in infants and preschoolers[2,3].

Intranasal dexmedetomidine (IN DEX), a highly selective α_2-adrenergic receptor agonist with minimal respiratory depression, has gained popularity in paediatric sedation[4]. Its noninvasive administration is well tolerated by children, yielding sedation comparable to intravenous routes and mimicking natural sleep[1]. A number of sedation studies for nonpainful procedures have reported the efficacy and dosing of dexmedetomidine in a wide range of paediatric age groups[4–6]. While IN DEX has improved sedation success rates in our outpatient

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suite, sedation failure remains problematic because of multifactorial influences (e.g., patient characteristics, sedation protocols, and environmental factors). Identifying predictors of sedation success is critical for optimizing clinical practice.

Although logistic regression analysis can identify factors affecting the success rate of sedation, relatively few studies have investigated the degree of influence of these factors and how to use them to predict the success rate. A nomogram is a graphical representation of complex mathematical formulas[7]. We innovatively use clinical variables that affect the success rate, such as patient age and disease name, to construct a statistical prediction model in a graphical manner, thereby generating an individual-specific prediction of the probability of successful sedation. This can help predict the success rate for patients in need of sedation, and targeted optimization of sedation protocols can be carried out accordingly, with the expectation of improving the actual success rate of sedation[8].

Materials and methods
Study design and population
This single-centre retrospective study included 12,095 paediatric patients (12–72 months) who underwent nonpainful diagnostic procedures at Shenzhen Children's Hospital between January 2022 and June 2023. This study was approved by the Institutional Review Board (IRB no. 202409502) and adhered to the Good Clinical Practice guidelines and the Declaration of Helsinki. Data were extracted from the outpatient sedation suite's electronic medical records system. The inclusion criteria were as follows: (1) age 12–72 months; (2) ASA I–III; (3) parental consent for intranasal sedation; and (4) complete clinical data. The exclusion criteria were as follows: (1) age < 12 or > 72 months; (2) alternative sedation methods (e.g., chloral hydrate or oral midazolam); (3) incomplete/incorrect records; and (4) changes in the mid-procedure sedation method. A study flowchart is shown in Fig. 1.

Clinical practice
The children were accompanied by their parents or legal guardians to outpatient clinics, during which the attending physician prescribed orders for nonpainful diagnostic examinations on the basis of the child's condition. These examinations may have included chest X-rays, computed tomography (CT), magnetic resonance imaging (MRI), pulmonary function tests (PFT), auditory brainstem response (ABR) tests, and transthoracic echocardiograms (TTE). Parents or guardians then took the child and the examination orders to the registration desk in the radiology or imaging department to complete the necessary registration procedures.

After reviewing the registration details and inquiring about the child's fasting status, if the staff in the radiology or imaging department determined that procedural sedation was needed, they recommended that the child fast for more than 1 h, although prolonged fasting was not strictly mandated[9–11]. This information, including the scheduled time for sedation and the examination timeline, was documented on the sedation request form.

Patients were expected to arrive at the sedation room in advance of the scheduled sedation time to undergo an assessment by the anaesthesiologist, during which the patient's baseline characteristics, such as sex, age, medical condition, and medical history, were evaluated. On the basis of the sedation request form, the estimated duration of the examination, and the level of sedation required during the procedure, the anaesthesiologist performed a comprehensive evaluation to develop a sedation plan tailored to the patient's needs. The patient's relevant information was subsequently recorded in the outpatient sedation suite's electronic medical records system.

After reviewing the relevant Literature and research experience and incorporating practical operational summaries, our outpatient sedation protocol at the sedation suite was refined through repeated adjustments. The sedation protocol involved the administration of IN DEX at a dosage of 2.5–3 mcg/kg via an atomizer or drops or a combination of IN DEX at a dosage of 2.5 mcg/kg plus oral midazolam at a dosage of 0.2–0.3 mg/kg for paediatric patients undergoing nonpainful diagnostic procedures[5,11–13]. Adjustments were made as needed, including the use of intravenous or inhalation sedation when necessary[1,14,15]. Anaesthesiologists at the sedation suite developed individualized sedation plans tailored to the specific needs of each patient. A dedicated sedation nurse, trained in a structured program to ensure competency in performing sedation according to the sedation protocol, closely monitored and documented the patient's vital signs (heart rate [HR], respiratory rate [RR], oxygen saturation [SpO_2], ECG, and blood pressure [BP]) and level of sedation. Adverse events were also recorded, and the nurse promptly reported any special cases to the anaesthesiologist. Vital signs and sedation levels were recorded at baseline and every 5 min after medication administration[16]. Sedation levels were assessed using a modified Ramsay score[17]. A modified Ramsay sedation scale is described in Fig. 2. Patients were considered sedated when they achieved modified Ramsay levels 2–3 (moderate or deep sedation)[13,18,19].

Once the patient reached the required sedation level, in conjunction with the child's baseline vital signs and the anaesthesiologist's assessment, the sedation nurse transferred the patient to the examination department at the scheduled time to await the diagnostic procedure. If a patient was not adequately sedated after 30 min, an additional 1 mcg/kg adjunct dose of IN DEX was administered, or intravenous or inhalation sedation was utilized. Successful sedation was defined as the ability to complete all examinations after the onset of sedation without any additional sedatives or dose[18,20]. After completing the examination, patients were transferred to the recovery room for continuous monitoring. Patients were deemed to have recovered once they returned to modified Ramsay level 5 and were only permitted to leave the sedation suite after being evaluated by the anaesthesiologist[18].

Data collection and definitions
Fifteen variables were collected: demographics (gender, age, weight), primary diagnosis (neurological/cardiovascular/respiratory diseases), ASA status, sedation duration (> 30 vs. < 30 min), snotty before sedation (crying or respiratory infections can lead to increased nasal secretions and oral secretions, which can affect
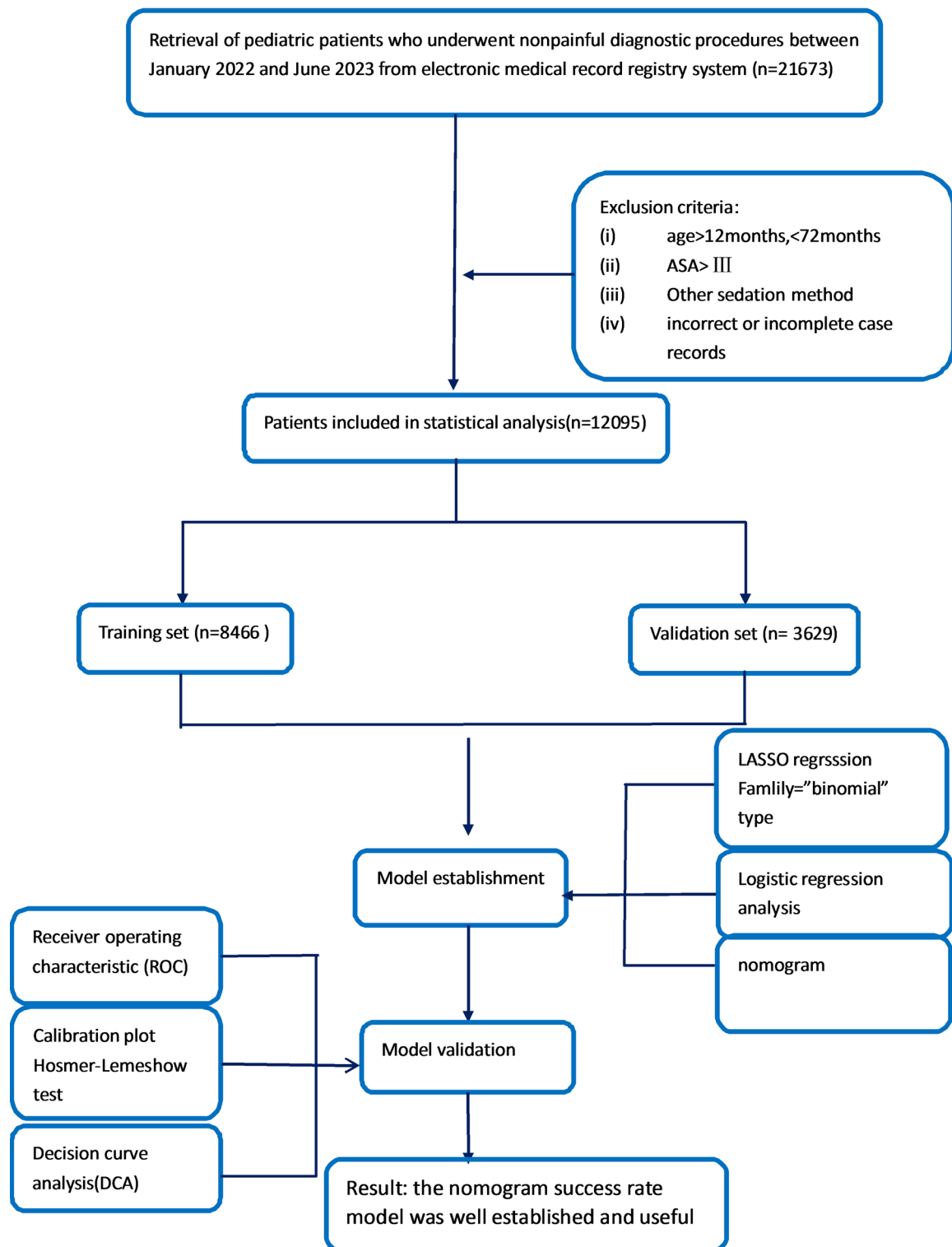
Retrieval of pediatric patients who underwent nonpainful diagnostic procedures between January 2022 and June 2023 from electronic medical record registry system (n=21673)

Exclusion criteria:
(i)   age>12months,<72months
(ii)   ASA> III
(iii)   Other sedation method
(iv)   incorrect or incomplete case records

Patients included in statistical analysis(n=12095)

Training set (n=8466)

Validation set (n= 3629)

LASSO regrsssion Famlily="binomial" type

Logistic regression analysis

nomogram

Model establishment

Receiver operating characteristic (ROC)

Calibration plot Hosmer-Lemeshow test

Decision curve analysis(DCA)

Model validation

Result: the nomogram success rate model was well established and useful

Fig. 1. Flow chart of the study design. *LASSO* least absolute shrinkage and selection operator, *ROC* receiver operating characteristic, *DCA* decision curve analysis.

the effectiveness of intranasal sedation), napping before sedation (adequate sleep or sleep deprivation before sedation can also affect the effectiveness of intranasal sedation), fever, baseline vital signs (Pulse/SpO$_2$ before sedation), sedation history and sedation method (IN DEX alone or with oral midazolam). High-risk patients (ASA≥III) required intravenous access and rescue equipment.

		Minimal Sedation	Moderate Sedation	Deep Sedation		
6	5	4	3	2	1	0
Agitated, anxious, or in pain above baseline	Spontaneously awake without stimulus	Drowsy but easily arouses to consciousness to light tactile or verbal/tactile stimulus	Arouses to consciousness with moderate tactile or loud verbal stimulus	Arouses slowly to consciousness with sustained painful tactile stimulus	Arouses, but not consciousness, with painful stimulus	Unresponsive to painful stimulus

Fig. 2. Modified Ramsay scale.

Statistical analyses

The statistical analyses were conducted using R software (version 4.3.0; The R Foundation for Statistical Computing, Vienna, Austria). The R caret package was employed to randomly partition the data into a training set and a validation set at a theoretical ratio of 7:3. Descriptive statistics were performed to summarize the baseline characteristics, with continuous variables presented as medians and interquartile ranges (IQR), and categorical variables expressed as frequencies with percentages (%). For comparisons of continuous data, the Mann-Whitney U test was applied. Categorical variables were analysed using the chi-square (χ^2) test or Fisher's exact test, depending on the distribution of the data.

For predictor selection and regularization, least absolute shrinkage and selection operator (LASSO) regression analysis was performed[21]. Lambda_1se (the lambda value corresponding to the most regularized model with the lowest prediction error) was used to identify the optimal model with the fewest independent variables. The features selected by LASSO regression were incorporated into a multivariable logistic regression model to develop a predictive model for sedation success. A nomogram was constructed on the basis of the logistic regression model to facilitate visualization and interpretation of the predictive probabilities[22]. The characteristics of the predictors are presented as odds ratios (OR) with corresponding 95% confidence intervals (CI). The performance of the nomogram was evaluated in both the training and validation sets using calibration and discrimination analyses[23]. Calibration curves were constructed to assess the agreement between the predicted and observed probabilities, while Harrell's concordance index (C-index) and the area under the receiver operating characteristic (ROC) curve (AUC) were calculated to evaluate the discriminative ability of the model[24]. Additionally, decision curve analysis (DCA) was performed to assess the clinical utility and net benefit of the predictive model[25]. Statistical significance was defined as a two-sided p value < 0.05.

Results

Patient baseline data

Among the 12,095 patients (7398 males and 4697 females), 8466 were allocated to the training set, and 3629 were allocated to the validation set, with no significant baseline differences (Table 1).

Screening for predictive factors in the training set

With LASSO regression, seven variables were selected: napping before sedation, respiratory diseases, snotty before sedation, neurological diseases, sedation history, sedation duration, and sedation method (Fig. 3A, B).

Predictive model construction

Multivariate logistic regression revealed that all seven variables were significant predictors (Table 2). A nomogram was developed, with risk factors including napping before sedation (OR = 0.584), respiratory/neurological diseases (OR = 0.470/0.333), snotty before sedation (OR = 0.573), sedation history (OR = 0.158), and sedation time (> 30 min) (OR = 0.208), while IN DEX + oral midazolam was protective (OR = 7.259) (Fig. 4A,B).

Predictive model validation (Predictive Performance)

The sensitivity and specificity of the predictive model were measured using the ROC curve. The prediction model had an AUC for the nomogram pooled over the training set of 0.833 (95% CI, 0.815–0.851), a cut-off value of 0.926, precision of 0.845, sensitivity of 0.858, and specificity of 0.654 (Fig. 5A), whereas for the validation set the AUC was 0.853 (95% CI, 0.825–0.881), and the cut-off value was 0.926, with a precision of 0.866, a sensitivity of 0.876, and a specificity of 0.707 (Fig. 5B), indicating fair to good performance.

The predictive model was calibrated with the use of a calibration curve and Hosmer-Lemeshow test. The calibration curves exhibited a high level of alignment for both the predictive model and the validation set. Hosmer-Lemeshow analysis demonstrated excellent agreement between the calculated and observed probabilities (Fig. 6A,B).

The DCA nomogram similarly suggested that the prediction model (red) showed greater net benefit than "Intervene All" (thin) or "Intervene None" (thick) management did, indicating that our nomogram has potential for use in clinical decision-making (Fig. 7A,B).

Discussion

This single-centre study conducted a retrospective analysis by extracting raw data from the sedation suite between January 2022 and June 2023. Our data analysis revealed that age significantly influenced the success rate of sedation with IN DEX. Previous studies have also confirmed that age is a critical factor in sedation failure,

	Train	Validation	
	N = 8466	N = 3629	P overall
Status (success %)			0.723
No	534 (6.31%)	222 (6.12%)	
Yes	7932 (93.7%)	3407 (93.9%)	
Nap before sedation			0.760
Yes	5541 (65.5%)	2364 (65.1%)	
No	2925 (34.5%)	1265 (34.9%)	
Gender			0.251
Female	3259 (38.5%)	1438 (39.6%)	
Male	5207 (61.5%)	2191 (60.4%)	
Weight (kg)	13.9 (3.73)	14.0 (3.77)	0.530
Age (months)	34.8 (16.4)	35.2 (16.7)	0.261
Fever			0.187
No	7811 (92.3%)	3374 (93.0%)	
Yes	655 (7.74%)	255 (7.03%)	
Respiratory diseases:			0.388
No	6646 (78.5%)	2875 (79.2%)	
Yes	1820 (21.5%)	754 (20.8%)	
Cardiovascular diseases:			1.000
No	7777 (91.9%)	3333 (91.8%)	
Yes	689 (8.14%)	296 (8.16%)	
Neurological diseases:			0.983
No	6274 (74.1%)	2688 (74.1%)	
Yes	2192 (25.9%)	941 (25.9%)	
Sedation time			0.331
<30 min	4046 (47.8%)	1770 (48.8%)	
> 30 min	4420 (52.2%)	1859 (51.2%)	
ASA			0.576
I	4914 (58.0%)	2107 (58.1%)	
II	3544 (41.9%)	1516 (41.8%)	
III	8 (0.09%)	6 (0.17%)	
Sedation history			0.260
No	6469 (76.4%)	2808 (77.4%)	
Yes	1997 (23.6%)	821 (22.6%)	
Snotty before sedation			0.317
No	7998 (94.5%)	3411 (94.0%)	
Yes	468 (5.53%)	218 (6.01%)	
Sedation method			0.583
Intranasal	1850 (21.9%)	776 (21.4%)	
Intranasal + oral	6616 (78.1%)	2853 (78.6%)	
S_pO_2 before sedation	98.4 (1.33%)	98.4 (1.45%)	0.777
Pulse before sedation (bpm)	120 (19.0)	120 (18.5)	0.169

Table 1. Baseline characteristics of the training and validation sets.

with particular attention given to younger and older age groups[10,19,26,27]. Specifically, Zhou X et al.[28]. reported that age (0–1 year and >6 years) was a risk factor for sedation failure, with success rates of 90.2% for the 0–1 year group, 93.1% for the 1–3 year group, 92.7% for the 3–6 year group, and 78.4% for the >6 years group. These findings underscore that age groups (0–1 year and >6 years) may not be suitable for establishing a predictive model.

Children younger than 6 years are at elevated risk of adverse events[29]particularly because of the heightened vulnerability of their respiratory systems to sedating medications. This age group is especially susceptible to the effects of sedation on respiratory drive, airway patency, and protective airway reflexes[16]. In our sedation suite, children aged 1–6 years constituted more than 70% of the patient population, with a comparable success rate for IN DEX sedation within this range. Therefore, improving sedation success rates and reducing complications in this specific age group are significant advantages. This rationale informed our decision to analyse and develop a predictive model utilizing data from children aged 1–6 years.
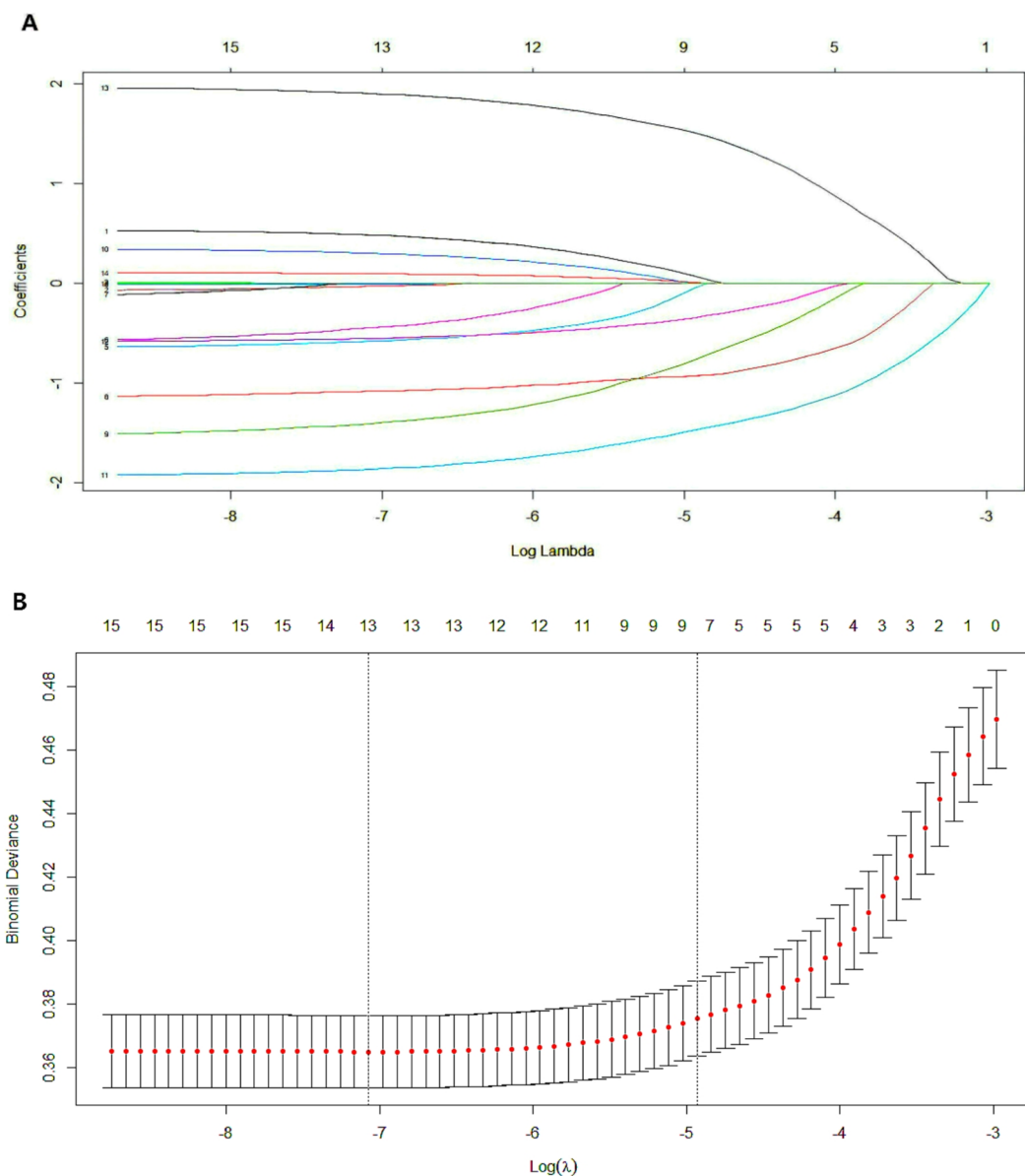
Fig. 3. Variable selection by logistic LASSO regression. **A** LASSO coefficient profiles for variables significant in univariate analysis; each coefficient profile plot was produced against the log(lambda) sequence. **B** seven variables with nonzero coefficients were selected by optimal lambda. By verifying the optimal parameter (lambda) in the LASSO model, the partial likelihood deviance (binomial deviance) curve was plotted versus log(lambda), and dotted vertical lines were set using the minimum criteria and the one standard error of the minimum criteria. LASSO indicates least absolute shrinkage and selection operator.

Variable	β	Std. Error	z value	OR	Reference category	95% CI	P_value
Nap before sedation (yes)	−0.538	0.189	−3.583	0.584	Nap before sedation (no)	0.435–0.784	< 0.001
Respiratory diseases(yes)	−0.755	0.157	−4.80	0.470	Respiratory diseases(no)	0.345–0.64	< 0.001
Snotty before sedation (yes)	−0.557	0.152	−3.652	0.573	Snotty before sedation (no)	0.425–0.773	< 0.001
Neurological diseases (yes)	−1.100	0.128	−8.587	0.333	Neurological diseases (no)	0.259–0.428	< 0.001
Sedation history (yes)	−1.847	0.110	−16.754	0.158	Sedation history (no)	0.127–0.196	< 0.001
Sedation time(> 30 min)	−1.568	0.136	−11.502	0.208	Sedation time(< 30 min)	0.160–0.272	< 0.001
Sedation method (intranasal + oral)	1.982	0.118	16.814	7.259	Sedation method (intranasal)	5.761–9.146	< 0.001

Table 2. Multivariable logistic regression analyses in the train Cohort. *CI* confidence interval, *OR* odds ratio.
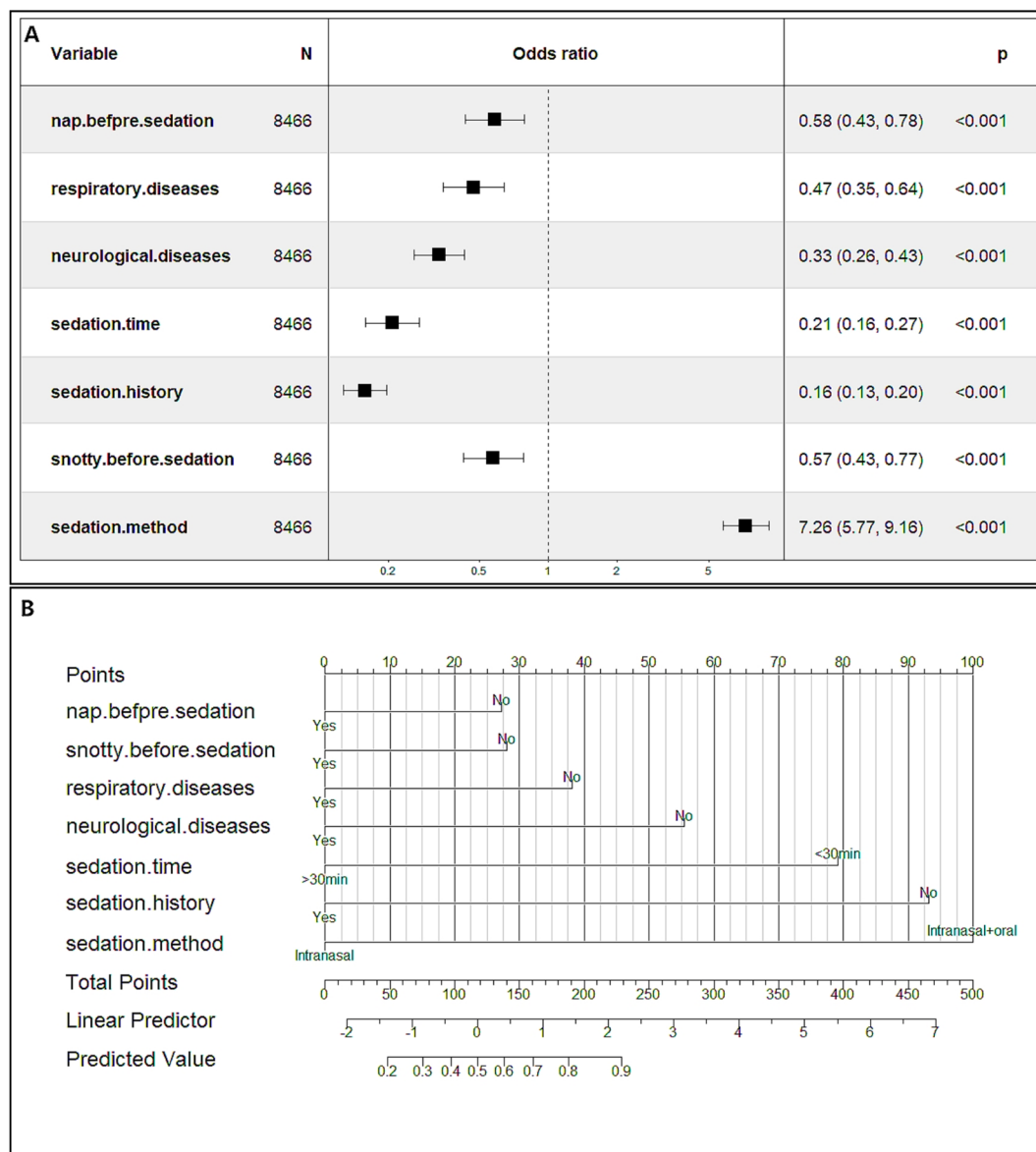
Fig. 4. A predictive model was developed using multivariate logistic regression. (**A**) Multivariate logistic regression analysis of risk predictors. The ORs, CIs, and p values are displayed, and $p < 0.05$ indicated a statistically significant difference. (**B**) Nomogram for predicting the success rate of sedation with IN DEX in children who underwent nonpainful diagnostic procedures.

We analysed data from 12,095 paediatric patients who met the inclusion criteria and employed LASSO and logistic regression to analyse and select from the 15 recorded variables. Our analysis identified seven statistically significant variables, which were used to construct forest plots and a nomogram. Among these, six variables were categorized as risk factors with ORs < 1: napping before sedation (yes), respiratory diseases (yes), nasal congestion before sedation (yes), neurological diseases (yes), sedation time (>30 min), and sedation history (yes). Additionally, the use of intranasal and oral sedation was identified as a protective factor, with an OR > 1. These variables are presented in Table 2.

When appropriate, daytime nap durations were considered biologically normal for individuals under the age of 6 years[30,31]. Missing one nap by preschoolers resulted in more negative emotional responses[32] and the provision of naps improved toddlers' performance on a generalization task[33] and improved their cognitive performance[34]. For physiological and health reasons, paediatric patients tend to nap during medical appointments. In the sedation process, children who nap before sedation may have more difficulty falling asleep, potentially affecting the success rate of sedation. In our study, "nap before sedation" had a β value of −0.538 and an OR of 0.584.

Among the various influencing factors, the primary diseases of paediatric patients are crucial[19,28]. We concluded that "respiratory diseases" had a β value of −0.755 and an OR of 0.470, whereas "neurological diseases" had a β value of −1.100 and an OR of 0.333, highlighting their significant negative influencing factors.
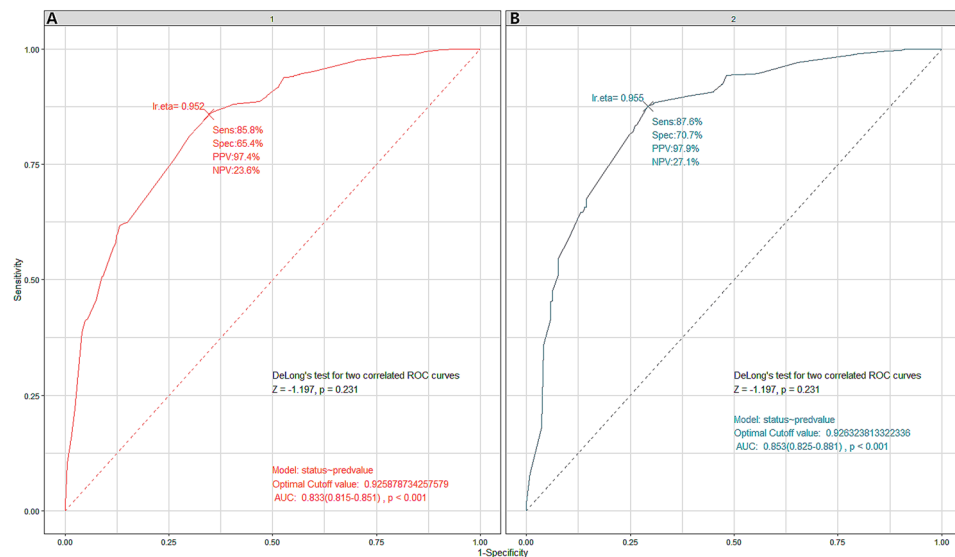
Fig. 5. Validation of the success rate prediction nomogram using a receiver operating characteristic (ROC) curve. The y-axis indicates the true positive rate of the success rate prediction, whereas the x-axis indicates the false-positive rate. The solid line depicts the performance of the nomogram in the training set (**A**) and validation set (**B**).

In outpatient examinations, upper respiratory tract infections (URTI) and pneumonia in children constitute the majority of respiratory diseases. Grunwell et al.[35] reported that URTI was a significant risk factor for failed sedation. Children aged 1–6 years were at high risk for URTI, with the pathogens invading mainly the child's upper respiratory tract, including the nose and throat[36]. Clinical manifestations typically include symptoms such as nasal congestion, runny nose, cough, or fever[37]. Changes in nasal mucosa conditions could affect the sedative effect of IN DEX[27] and further investigation is needed to determine whether the administration of antiviral or antibiotic medications for treating respiratory system diseases in children influences the efficacy of IN DEX.

In addition to increased nasal secretions caused by underlying diseases, young age and facing unfamiliar hospital environments and health care workers can lead to fear and resistance among paediatric patients during the IN DEX process. This resistance may manifest as a refusal to cooperate and crying. In such cases, even in patients without respiratory diseases, crying can also result in a rapid increase in nasal secretions and even significant discharge. Dexmedetomidine is absorbed through the nasal mucosa, crosses the blood-brain barrier, and affects the central nervous system. Therefore, any condition that leads to increased nasal mucosa secretions can affect the absorption of dexmedetomidine through the nasal mucosa, impacting the success rate and effectiveness of sedation[28]. In this study, "snotty before sedation" had a β value of −0.557 and an OR of 0.573.

Another primary disease factor was neurological disease, with a β value of −1.100 and an OR of 0.333. Children with intellectual disabilities or developmental delays in psychomotor development have incomplete neurological development, leading to a low arousal threshold, poor self-control, and self-awareness, which enhance their psychological defence mechanisms. As a result, they may exhibit refusal and avoidance during examinations, making sedation more challenging for these children than for typical children[38]. Longer procedures that require immobility involving children younger than 6 years or those with developmental delay often require an increased depth of sedation to gain control of their behaviour[16]. Psychostimulants may increase the dosage requirement of sedatives during anaesthesia[39]. Long-term use of antiepileptic drugs in children with epilepsy can induce the expression of liver microsomal enzyme P-450, altering the liver metabolism and capacity to clear anaesthetics. This can lead to an increased demand for nondepolarizing muscle relaxants, sedatives, and analgesics in paediatric patients during surgery[40,41]. Autism spectrum disorders (ASD) are also common neurological disorders in children. When children with autism undergo outpatient examinations, the challenges they face are related to communication, sensory issues, the hospital environment, and health care providers[42]. Some scholars believe that patients with ASD have reduced sensitivity to pain, whereas others argue that pain sensitivity in patients with ASD is either increased or not abnormal[43,44]. Medications commonly used by patients with ASD, such as aripiprazole or risperidone, have certain side effects that may include changes in sleep patterns, extrapyramidal symptoms, weight gain, abdominal pain, irritability, headaches, and other effects, additionally inducing hypotension during general anaesthesia and potentially triggering arrhythmias[45]. Therefore, when paediatric patients with neurological diseases are receiving IN DEX sedation, it is important to consider both the impact of the disease and treatment medications on the sedative effect and to pay attention to the prevention and management of complications.

A history of sedation or sedation failure is a risk factor that influences the success rate of sedation. In this study, the β-value for "sedation history" was − 1.847, with an OR of 0.158. Several studies[26,27,35] analysing risk factors for failed sedation in children have shown that a history of sedation failure increased the likelihood of sedation failure. Li et al.[46] identified a history of sedation failure as the sole risk factor for sedation failure.
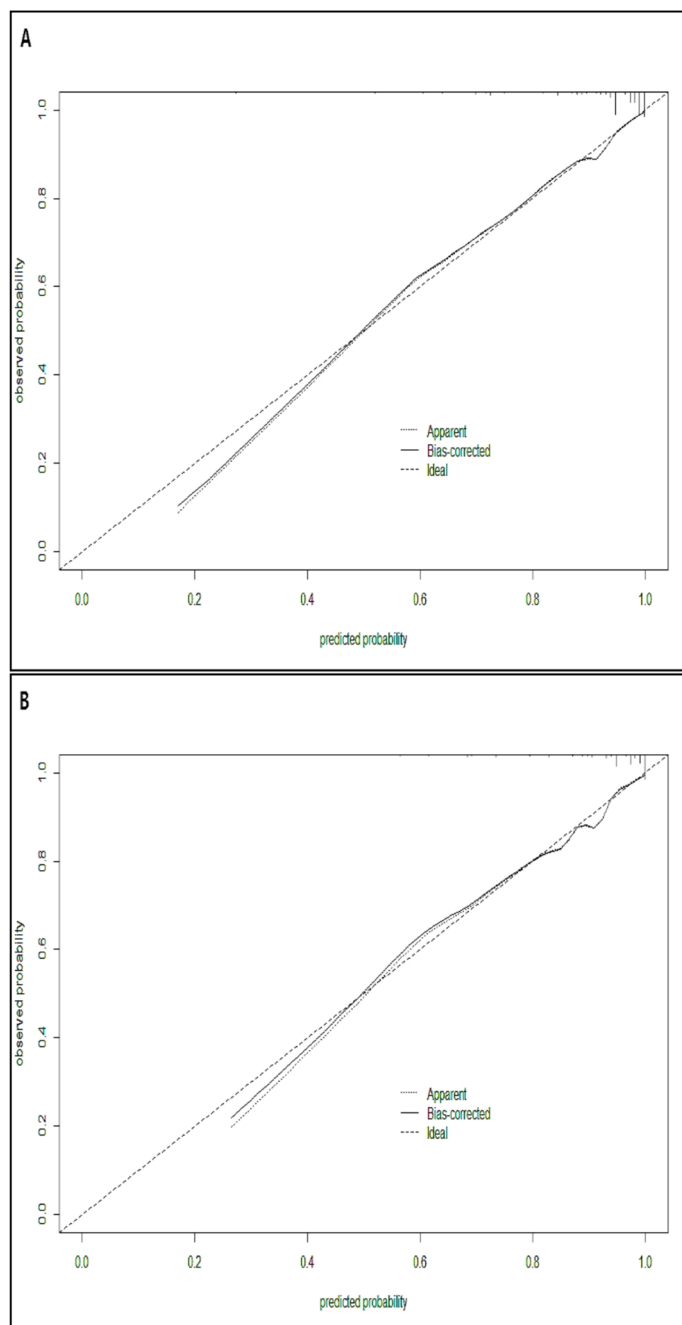
Fig. 6. The calibration curves of the prediction model in the training (**A**) and validation (**B**) sets. Calibration curves were used to evaluate how a classifier was calibrated and how the probabilities of predicting each class label differ. The x-axis represents the average predicted probability. The y-axis is the ratio of positives. The ideal calibrated model generates a calibration curve that presents a straight line from (0, 0) and moves linearly.

Sedation time is another influencing factor and one of the most challenging factors to assess during the sedation process. It is crucial to estimate the sedation time needed for the patient during the examination process before IN DEX. This determines the sedation method and dosage of sedative medication. Estimating the sedation time required for the examination needs to be considered from multiple perspectives and tailored to the individual circumstances. The sedation time is the total duration from the onset of intranasal sedation to the successful completion of nonpainful diagnostic procedures[1]. This timeframe encompasses waiting times, preexamination preparation times, and, if multiple examinations were involved, the integration of the time required for each procedure, along with the time spent transporting the patient between procedures.

On the basis of the operational experience of the sedation suite, single examinations such as X-rays, CT scans, and transthoracic echocardiography can generally be successfully completed within 30 min under smooth conditions at each stage. However, complex procedures such as MRI scans, auditory monitoring, pulmonary
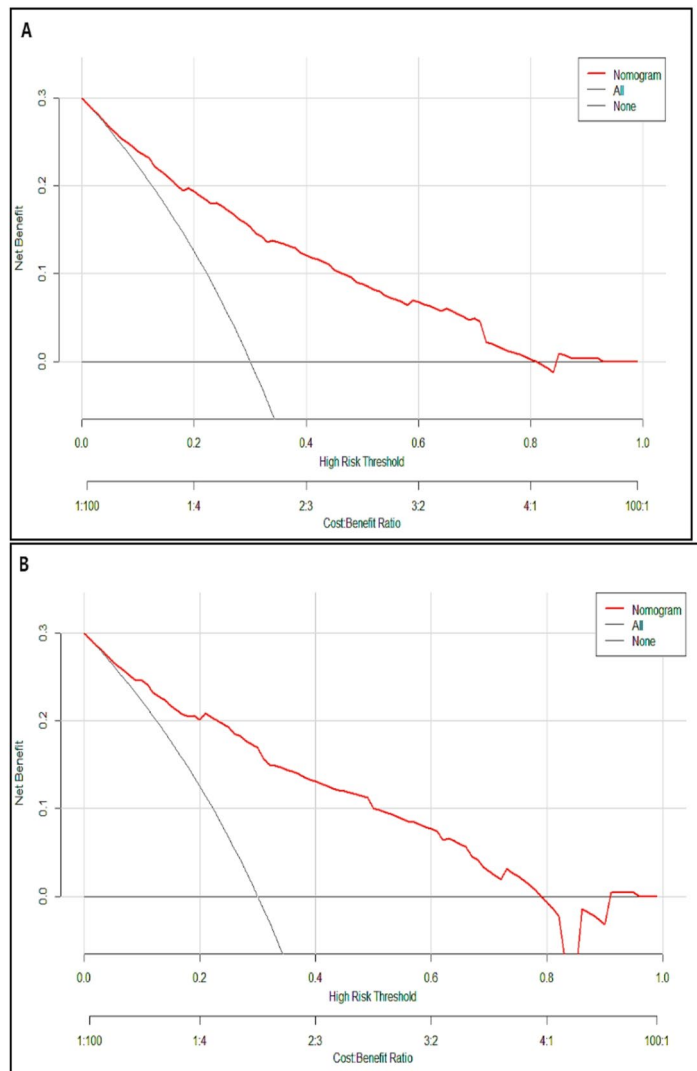
Fig. 7. Decision curve analysis for the success rate prediction nomogram from the training set (**A**) and from the validation set (**B**). The y-axis represents the net benefit. The thick solid line indicates the assumption that all patients received no intervention. The thin solid line represents the assumption that all patients have intervention, and the red line represents the success rate prediction nomogram. Additionally, the area under the decision curve was used to assess the clinical utility of the prediction model. The net benefit of the prediction model (red) was greater than that of "Intervene All" (thin) or "Intervene None" (thick) management, indicating that our nomogram has potential for use in clinical decision-making.

function tests, and multi-item combined examinations require more time and have high quality requirements, usually necessitating sedation times exceeding 30 min. Therefore, we categorized sedation time into > 30 min and < 30 min. Examinations requiring < 30 min have a high success rate, whereas those requiring > 30 min have higher sedation requirements, involving complex examination processes and a higher incidence of unexpected situations, resulting in relatively lower success rates. The β value for the influencing factor of sedation time was − 1.568, with an OR of 0.208.

The decision to administer IN DEX alone or in combination with oral midazolam, as well as to determine the specific dosage, should be based on a comprehensive consideration of various factors, such as the nature of the examination, quality requirements, and the estimated sedation time. Some examinations, such as X-rays, CT scans, and transthoracic echocardiography, are of short duration and are conducted in a relatively quiet environment with minimal external stimuli. For such examinations, IN DEX alone to achieve a moderate sedation depth of modified Ramsay level 3 will be sufficient[10]. On the other hand, for longer procedures such as MRI scans where the MRI equipment generates considerable noise, for examinations that require the patient to remain still, or in cases of multiple combined procedures, IN DEX alone may not be adequate. In such instances, a combination of IN DEX and oral midazolam is often needed to achieve a sedation depth ranging from moderate to deep, corresponding to modified Ramsay levels 3− 2 [1]. Therefore, the sedation method and dosage play crucial roles in determining the probability of sedation success. However, it is not advisable to opt solely for a high-dose combination of IN DEX and oral midazolam sedation, uniformly applying deep sedation,

as this may lead to excessive and unnecessary complications, resulting in oversedation in medical practice. The optimal sedation target should be achieved by selecting the lowest effective dose of medication with the highest therapeutic index for the procedure[1,2].

We analysed the data retrieved from the electronic medical records registry system of the sedation suite, segregating the eligible data into training and validation sets. In the training set, we employed LASSO regression analysis and multivariable logistic regression analysis for variable selection, identifying 7 statistically significant variables from the initial pool of 15. A predictive model was subsequently developed on the basis of these findings, and a ROC curve was generated. The predictive model was subsequently evaluated using the ROC curve. The prediction model had an AUC for the nomogram pooled over the training set of 0.833 (95% CI, 0.815–0.851) (Fig. 3A) and was calibrated with the use of a calibration curve and the Hosmer-Lemeshow test. The calibration curves demonstrated a very good degree of fit for both the predictive model and the validation set. Hosmer-Lemeshow analysis demonstrated excellent agreement between the calculated and observed probabilities (Fig. 4A). The DCA of the nomogram similarly suggested that our nomogram has potential for use in clinical decision-making (Fig. 5A). We also successfully validated the model using a validation set (Figs. 3B, 4B and 5B), which demonstrated that the predictive model could effectively predict the success rate of sedation with IN DEX, offering valuable guidance for clinical practice and making it worthy of emulation in clinical settings.

Conclusions

In conclusion, we constructed a predictive model that incorporates seven variables to develop a nomogram that demonstrates good clinical utility. This nomogram can assist anaesthesiologists in the sedation suite in identifying and screening potential risk factors leading to sedation failure, guiding the formulation of more individualized sedation plans, increasing the success rate of sedation, and ultimately facilitating the smooth completion of outpatient examinations, thereby enhancing the clinical efficiency of care for paediatric patients.

Limitations

(1) Clinical data of paediatric patients were manually entered into the electronic medical records system by anaesthesiologists or sedation nurses rather than being automatically collected and stored. Although incomplete data were excluded, some data may not have accurately reflected the original information. (2) Some influencing factors were difficult to assess accurately, such as "sedation time", and some factors were challenging to classify, perhaps requiring more reasonable classification methods. In practical work, many clinical manifestations of paediatric patients lack specific quantifiable indicators, such as "nap before sedation" or "snotty before sedation", yet these factors affect the success rate of sedation. (3) The nomogram was well developed with sufficient internal validation but lacked external validation. External validation, ideally across multiple and diverse datasets, is the gold standard and should be performed when feasible. Unfortunately, most nomograms (including those from our institution) typically report only internal validation. While these methods prevent overinterpretation of data, they fail to eliminate all bias from potential overfitting inherent in variable and threshold selection, nor do they assess accuracy across diverse patient populations[23]. (4) Numerous factors influenced the success rate of procedural sedation, and some influencing factors might not have been included in the statistical analysis and discussion, which could have affected the model's establishment, such as medication use (e.g., antiepileptics, antipsychotics) and recent upper respiratory tract infections or premedication.

Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request. E-mail address: bestxyt@126.com.

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

Ethics declarations

This study was reviewed and approved by the Clinical Trial and Biomedical Ethics Committee of Shenzhen Children's Hospital, Guangdong, China, with the approval number IRB no. 202409502. All patients (or their proxies/legal guardians) agreed to intranasal sedation and signed informed consent. Because this study analysed only anonymized data without involving privacy leakage or harm and because the potential risks to patients' rights and welfare were no greater than those associated with routine medical care or minimal risk, the ethics committee waived the requirement for informed consent for this retrospective design.

Additional information

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