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ORIGINAL RESEARCH

Predicting Sensory Block Level in Caudal Anesthesia Based on Sacral Canal Anatomical Parameters and Height: Development of an Ordinal Logistic Regression Model and Nomogram

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Background: Caudal block in clinical practice relies on empirical drug administration without reliable prediction of anesthetic level, thereby limiting its application. This study aimed to develop a predictive model for sensory block level based on sacral canal anatomical factors and patient characteristics.

Methods: A total of 132 patients undergoing elective anal surgery with caudal block were included. Ultrasound measured anatomical parameters (the width of the base of the sacrum (BSW), the anterior-posterior diameter of the sacral hiatus at its apex (SHAP), the anterior-posterior diameter of the sacral hiatus at the first segment inferior to the apex (SHFSIA-AP), the length of the sacral hiatus in the sagittal plane (SHLS) and demographic data (age, gender, height, weight) were collected. Sensory block level was categorized into five ordinal grades. Multivariable ordinal logistic regression identified independent predictors, with variance inflation factor (VIF) assessing multicollinearity and Brant test verifying proportional odds assumption. Model performance was evaluated via concordance index (C-index) and Lipsitz test, with internal validation performed using bootstrapping with 1000 resamples, and a nomogram was constructed.

Results: Univariable analysis showed SHAP, SHLS, SHFSIA-AP, height, age, gender, and weight correlated with sensory block level ($P<0.05$). Final independent predictors were SHAP, SHLS, and height. No multicollinearity (VIF<5) and valid proportional odds assumption (Brant test $P=0.36$) were confirmed. The model had good predictive performance (C-index=0.881, 95% CI [0.809–0.953]) and fit (Lipsitz test $P=0.49$), with the nomogram visualizing probabilities of each block level category.

Conclusion: This study identified SHAP, SHLS, and height as predictors for caudal block sensory level. The nomogram enables individualized, precise drug administration, shifting the technique from experience-based to precision prediction.

Plain Language Summary:

Why was this study done?

Caudal anesthesia is a common technique used to provide pain relief during certain surgeries. However, doctors currently lack a reliable way to predict how high up the spine the numbness will reach. This can make it difficult to give the right drug dose.

What did the researchers do and find?

This study tested whether combining a person's height with ultrasound measurements of their sacral canal (a space at the base of the spine) could predict the level of numbness. The researchers studied 132 patients and developed a statistical model using three simple factors: the front-to-back distance of the sacral canal (SHAP), the side-to-side distance (SHLS), and the patient's height. The model proved very accurate in predicting the numbness level.

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What do these results mean?
Doctors can now use this model—presented as an easy-to-use chart (nomogram)—to predict the block level before giving the injection. This helps them choose the exact drug dose needed for each patient, making the procedure safer, more effective, and less dependent on guesswork.

Keywords: caudal anesthesia, ultrasound-guided, sensory block level, prediction model

Introduction

Caudal block is a type of epidural anesthesia technique that involves puncturing through the sacral hiatus and injecting local anesthetics into the sacral canal to block the sacral nerves.[1] It can provide effective anesthesia and analgesia for anorectal and perineal surgeries.[2,3] With the advancement of Enhanced Recovery After Surgery (ERAS) protocols and the increasing emphasis on perioperative comfort, the precision and individualization of anesthetic techniques have become a major clinical focus.[4,5]

However, there is currently no reliable or validated method for predicting the anesthetic level achieved by caudal blockade, leading to the continued widespread reliance on empirical drug administration in clinical practice. This approach carries significant uncertainty: an excessive local anesthetic volume may result in prolonged muscle weakness and urinary retention post-operatively, which can delay postoperative recovery and reduce patient satisfaction. In contrast, an insufficient volume is prone to inadequate block or block failure, necessitating changes to the anesthetic regimen during surgery. These uncertainties collectively hinder the precise application and broader clinical adoption of caudal blockade.

Although some clinicians attempt to adjust drug dosage based on individual patient characteristics such as age and height, existing studies demonstrate no significant correlation between age and the spread of local anesthetics within the epidural space.[6,7] Though height does correlate with the spread of epidural local anesthetics, its quantitative relationship with the resulting block level remains unclear.[8] In addition to age and height, considerable interindividual variation exists in sacral canal anatomy, which may substantially affect the spread of caudal anesthesia.[9,10] Nevertheless, the extent and pattern of this influence have not been systematically investigated.

In recent years, the introduction of ultrasound guidance has significantly improved the success rate of caudal puncture, while also enabling accurate quantitative assessment of the sacral canal anatomy.[11,12] Building on these advances, the present study aims to systematically analyze the influence of sacral anatomical parameters and patient demographics on the sensory block level in caudal anesthesia by establishing an ordinal logistic regression model, thereby providing a quantitative foundation for individualized and precise blockade.

Methods

Study Population

This study enrolled patients who received caudal anesthesia at Shenshan Medical Center, Sun Yat-Sen Memorial Hospital between August 2022 and March 2023. The study protocol was approved by the Institutional Review Board (IRB) of Shenshan medical center, Sun Yat-sen Memorial Hospital of Sun Yat-sen University (ethics committee number, 2025-SSKY-122-01; approval date, 20 May 2025). Informed consent was waived due to the retrospective nature of the study. In accordance with the institutional guidelines, patient data confidentiality was strictly maintained, and the study adhered to the ethical standards set forth in the Declaration of Helsinki. The study was conducted in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines. The inclusion criteria were as follows: (1) elective anal surgery under caudal anesthesia; (2) American Society of Anesthesiologists (ASA) physical status I–III; (3) age ≥18 years. Exclusion criteria included: (1) ultrasonographic evidence of sacral stenosis or occlusion; (2) pregnancy or lactation; (3) psychiatric disorders or poor compliance; (4) allergy to amide-type local anesthetics; (5) contraindications to caudal anesthesia, such as coagulopathy, severe hepatic or renal insufficiency, history of sacrococcygeal infection or surgery, pre-existing neuralgia, or significant spinal disease.

Study Protocol

Patients meeting the inclusion and exclusion criteria were enrolled in the study, and demographic data including age, gender, height, and weight were collected. All ultrasound measurements and block level assessments were performed according to a standardized protocol established by our department, ensuring uniformity in patient management and data recording.

Prior to surgery, patients fasted for 8 hours and abstained from clear fluids for 4 hours. Upon entering the operating room, standard monitoring was established, including electrocardiogram, non-invasive blood pressure, and pulse oximetry. Oxygen was administered via nasal cannula at a flow rate of 4 L/min. After prehydration with 500 mL of Lactated Ringer's solution, all patients were positioned prone.

A standardized caudal blockade was performed under real-time ultrasound guidance by an experienced anesthesiologist using a Mindray Vetus 7 pro ultrasound system (Mindray, Shenzhen, China). The probe was placed transversely over the sacrum superior to the gluteal cleft to identify the sacral cornua, sacrococcygeal ligament (SCL), and base of the sacrum. These anatomical structures are illustrated in the transverse view of the sacral hiatus (SH) in Figure 1A. BSW was measured in this view. For the longitudinal view of SH (Figure 1B), the ultrasound probe was rotated 90 degrees to identify the apex of the sacral hiatus and SCL. The following measurements were taken in this longitudinal plane: SHAP, SHFSIA-AP, and SHLS.

Under aseptic conditions, a 16-gauge epidural needle was inserted through SCL into the sacral canal under ultrasound guidance, with correct placement in the caudal epidural space confirmed using the loss-of-resistance technique. Needle advancement was visualized in real-time during puncture, with the tip advancement beyond SH limited to 5 mm to avoid dural puncture. After negative aspiration for blood or cerebrospinal fluid, a 2 mL test dose of 0.5% ropivacaine was administered. Following confirmation of no intravascular injection or allergic reaction, 20 mL of 0.5% ropivacaine was injected at a rate of 0.5 mL/s.

Sensory and motor block levels were assessed every 5 minutes for a total duration of 20 minutes. A blunt 23G needle was used for pinprick sensory testing and graded on a three-point scale: 0 = no block; 1 = incomplete block (loss of sensation to sharp prick but preserved sensation to touch or pressure); 2 = complete block (no pinprick sensation). The sensory block level was defined as the highest dermatome with a complete block. Motor block was assessed using a modified Bromage scale (0 = able to move hips, knees, ankles, and toes; 1 = unable to move hips, able to move knees, ankles, and toes; 2 = unable to move hips and knees, able to move ankles and toes; 3 = unable to move hips, knees, and ankles, able to move toes; 4 = unable to move hips, knees, ankles, and toes). After the completion of surgery, a final assessment of sensory and motor block was conducted before the patient left the operating room.

A caudal block was considered successful if all of the following criteria were met: within 20 minutes after local anesthetic injection, complete sensory block in the S3–S5 dermatomal regions and relaxation of the anal sphincter were achieved; no rescue block (including supplemental opioids, general anesthesia, or local infiltration by the surgeon) was required throughout the surgery; and the patient reported no pain before leaving the operating room.

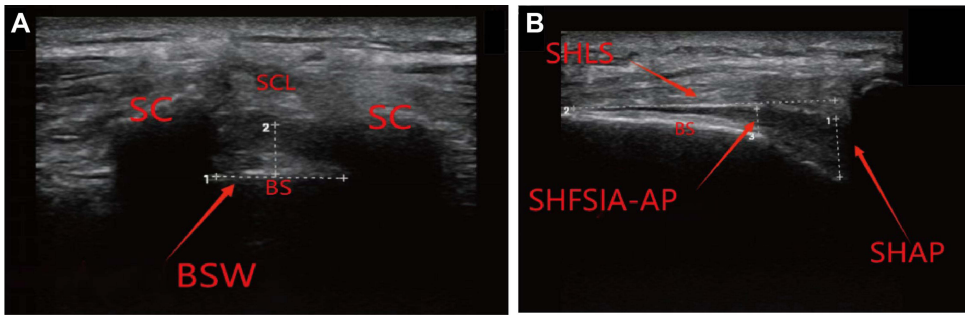

Figure 1 Representative images of ultrasound measurements of the anatomical dimensions of the sacral canal. (**A**) Ultrasound image of the sacral hiatus in the transverse plane. (**B**) Ultrasound image of the sacral hiatus in the longitudinal plane.

Abbreviations: SC, acral cornua; SCL, sacrococcygeal ligament; BS, base of sacrum; BSW, width of the base of the sacrum; SHLS, sacral hiatus length in the sagittal plane; SHFSIA-AP, anterior-posterior diameter of the sacral hiatus at the first segment inferior to the apex; SHAP, anterior-posterior diameter of sacral hiatus at its apex.

Vital signs were monitored during caudal anesthesia. If the mean arterial pressure (MAP) decreased by more than 30% from the baseline value or the MAP was ≤ 65 mmHg, 3 mg of ephedrine was administered intravenously. If the heart rate decreased to less than 45 beats per minute, 0.5 mg of atropine was administered intravenously for treatment.

Prediction Model Construction and Evaluation

Model construction and evaluation were performed using R software (version 4.5.1). Due to the relatively small number of patients with sensory block levels at S5, L5, L4, L3, L2, L1, and T12, patients with block levels at S5 and S4 were combined into Grade 1, those with a block level at S3 were classified as Grade 2, those with a block level at S2 as Grade 3, those with a block level at S1 as Grade 4, and those with block levels at L5, L4, L3, L2, L1, and T12 were merged into Grade 5. Thus, the study endpoint was categorized into 5 ordinal grades.

Each covariate was individually entered into a univariable ordinal logistic regression model to assess its effect on the sensory block level. Covariates that showed statistical significance in the univariable analysis or were considered clinically relevant to the sensory block level were subsequently included in the multivariable model.[13] Variable selection for the multivariable model employed a stepwise selection method, where the inclusion of a covariate was based on its ability to lower the model's Akaike Information Criterion (AIC).

The Variance Inflation Factor (VIF) was used to assess multicollinearity among the covariates.[14] The Brant test was applied to verify the parallel lines assumption.[15] The likelihood ratio test, the Lipsitz test, and the concordance index (C-index) were used to evaluate the model's goodness-of-fit, and a calibration curve was plotted.[16] A C-index of 0.5 or lower indicates poor predictive accuracy, between 0.5 and 0.7 indicates average accuracy, between 0.7 and 0.9 indicates good accuracy, and greater than 0.9 indicates excellent accuracy.[17] Internal validation was performed using bootstrapping with 1,000 resamples to assess model stability and optimism. The optimism-corrected C-index was calculated to provide a more reliable estimate of the model's discriminative performance, thereby accounting for potential overfitting.

Based on the final ordinal logistic regression model, a corresponding nomogram was developed to provide an intuitive and clinically applicable prediction tool.

Results

Patient Characteristics

A total of 174 patients were initially identified from the electronic medical record and anesthesia information systems as potentially eligible for inclusion. After applying the inclusion and exclusion criteria, 132 patients were ultimately included in the final analysis. The patient selection process is illustrated in Figure 2. Table 1 presents the demographic characteristics, ultrasonographically measured anatomical parameters of the sacral canal, and key anesthesia-related data.

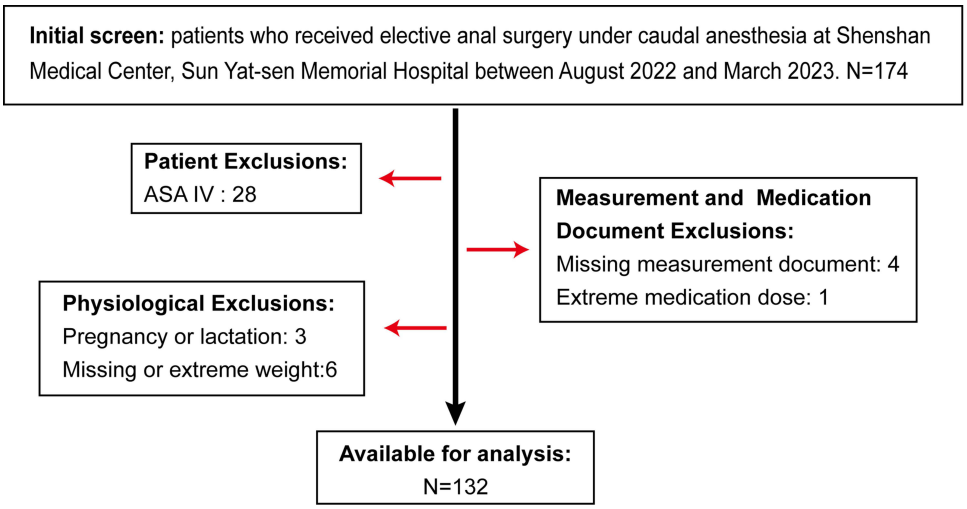

Figure 2 Flow diagram of patient selection.

Table 1 Characteristics of Patients and Anesthetic Data

Variable	Mean ± SD/Median (Range)/n (%)
Age, mean (SD), year	40.31 (4.910)
Sex (male), No. (%)	94 (71.212)
Height, mean (SD), cm	166.10 (8.452)
Weight, mean (SD), kg	65.938 (13.048)
BSW, mean (SD), cm	1.033 (0.196)
SHAP, mean (SD), cm	0.553 (0.125)
SHFSIA-AP, mean (SD), cm	0.306 (0.122)
SHLS, mean (SD), cm	2.795 (0.593)
Variables of sensory block	
Peak sensory block level, median (range)	S3 (S5-T12)
S4, No. (%)	19 (14.394)
S3, No. (%)	59 (44.697)
S2, No. (%)	23 (17.424)
S1, No. (%)	12 (9.091)
Others, No. (%)	19 (14.394)
Variables of motor block	
Maximum degree of motor block*, median (range)	0 (0–4)
0, No. (%)	105 (79.545)
1, No. (%)	17 (12.879)
2, No. (%)	4 (3.03)
3, No. (%)	1 (0.758)
4, No. (%)	5 (3.788)

Notes: *Motor block was assessed using a modified Bromage scale (0 = able to move hips, knees, ankles, and toes; 1 = unable to move hips, able to move knees, ankles, and toes; 2 = unable to move hips and knees, able to move ankles and toes; 3 = unable to move hips, knees, and ankles, able to move toes; 4 = unable to move hips, knees, ankles, and toes).
Abbreviations: BSW, base of sacrum; SHAP, anterior-posterior diameter of sacral hiatus at its apex; SHFSIA-AP, anterior-posterior diameter of the sacral hiatus at the first segment inferior to the apex; SHLS, sacral hiatus length in the sagittal plane; SD, standard deviation.

Among these patients, 114 86.4%) achieved adequate sensory block with no discomfort throughout the surgery, requiring no rescue block or intravenous analgesics. Thirteen (9.8%) patients reported mild discomfort at the surgical site, which was relieved by a single dose of 5 μg sufentanil or 30 mg ketorolac tromethamine. Five (3.8%) patients experienced moderate to severe discomfort at the surgical site and required sedation with 5 μg sufentanil plus ciprofol to proceed with the surgery. No patients needed intravenous ephedrine due to a MAP decrease of more than 30% from baseline, and no patients required urinary catheterization for urinary retention.

Model Construction

The results of the univariable ordinal logistic regression analyses are presented in Table 2. Statistically significant covariates included SHAP, SHFSIA-AP, SHLS, age, gender, height, and weight.

The covariates selected for inclusion in the model through the stepwise procedure are listed in Table 3. Although SHFSIA-AP, age, gender, and weight also showed significant effects, they were not retained in the final model as their inclusion reduced the model's goodness-of-fit. The final model retained SHAP, SHLS, and height, all of which demonstrated significant effects in the univariable ordinal logistic regression model. The VIF values for the selected three variables were less than 5, indicating low multicollinearity among the predictors. In addition, Figure 3 illustrates the influence of each variable on the distribution of block levels.

The full ordinal logistic regression model can be expressed by the following linear predictor (LP):

$LP = -0.254 \times \text{Height (cm)} - 8.92 \times \text{SHAP (cm)} - 0.600 \times \text{SHLS (cm)}$

The cumulative probabilities for each sensory block level are calculated as:

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Table 2 Parameter Estimates of the Univariate Ordered Logistic Regression Model for Sensory Block Level

Variable	BSW (cm)	SHAP (cm)	SHFSIA-AP (cm)	SHLS (cm)	Age (year)	Sex (Male versus Female)	Height (cm)	Weight (kg)
α_1	−2.145	−4.615	−2.608	5.976	−0.329	−3.447	−37.905	−6.096
α_2	−0.072	−2.357	−0.467	−3.6	1.814	−1.018	−34.822	−3.718
α_3	0.777	−1.441	0.411	−2.61	2.707	0.071	−33.493	−2.754
α_4	1.447	−0.737	1.092	−1.863	3.416	0.84	−32.453	−2.029
β	−0.508	−5.21	−3.09	−1.48	0.034	−2.18	−0.214	−0.064
SE	0.796	1.36	1.32	0.291	0.011	0.392	0.027	0.014
p value	0.516	<0.001	0.02	<0.001	0.003	<0.001	<0.001	<0.001
OR (95% CI)	0.596 (0.125, 2.84)	0.006 (0, 0.078)	0.046 (0.003, 0.61)	0.227 (0.128, 0.401)	1.03 (1.01, 1.06)	0.113 (0.052, 0.244)	0.808 (0.766, 0.852)	0.938 (0.913, 0.963)

Abbreviations: BSW, base of sacrum; SHAP, anterior-posterior diameter of sacral hiatus at its apex; SHFSIA-AP, anterior-posterior diameter of the sacral hiatus at the first segment inferior to the apex; SHLS, sacral hiatus length in the sagittal plane; SE, standard error; OR, odds ratio; CI, confidence interval.

Table 3 Parameter Estimates of the Final Ordinal Logistic Regression Model for Sensory Block Level

Variable	β	SE	*P* value	OR (95% CI)	VIF
SHAP	−8.92	1.7	< 0.001	0.0001 (0, 0.0037)	1.059
SHLS	−0.6	0.331	0.07	0.549 (0.287, 1.05)	1.236
Height	−0.254	0.033	< 0.001	0.776 (0.728, 0.828)	1.195
Intercept (Grade ≥ 2)	−51.7	6.11	< 0.001	–	–
Intercept (Grade ≥ 3)	−47.9	5.81	< 0.001	–	–
Intercept (Grade ≥ 4)	−46.2	5.7	< 0.001	–	–
Intercept (Grade ≥ 5)	−45.0	5.63	< 0.001	–	–

Abbreviations: SE, standard error; OR, odds ratio; CI, confidence interval; VIF, variance inflation factor; SHAP, anterior-posterior diameter of sacral hiatus at its apex; SHLS, sacral hiatus length in the sagittal plane.

P (block level ≥ 2) = 1 / [1 + exp (-(−51.7 - LP))]

P (block level ≥ 3) = 1 / [1 + exp (-(−47.9 - LP))]

P (block level ≥ 4) = 1 / [1 + exp (-(−46.2 - LP))]

P (block level ≥ 5) = 1 / [1 + exp (-(−45.0 - LP))]

The probability of achieving a specific block level can be derived by subtracting adjacent cumulative probabilities. For example, P (block level = 3) = P (≥ 3) – P (≥ 4).

Assessment of Model Goodness-of-Fit

The *P*-value from the Brant test was 0.36, indicating that the parallel regression assumption was met. The *P*-value from the likelihood ratio test was <0.001, demonstrating that our constructed model provided a statistically significant improvement in fit over the "intercept-only" model. This confirms that the included covariates significantly explain the ordinal classification of the dependent variable. The *P*-value from the Lipsitz test was 0.49, indicating good agreement between the predicted and observed probabilities. The model demonstrated good discriminative performance with a C-index of 0.881 (95% CI [0.809–0.953]). Internal validation using bootstrapping with 1,000 resamples yielded an optimism-corrected C-index of 0.877, confirming the model's stability and generalizability.

For the four cumulative probability outcomes of the caudal blockade level prediction model (ie., sensory block level ≥ Grade 2, ≥ Grade 3, ≥ Grade 4, and ≥ Grade 5), corresponding calibration curves were generated to assess the agreement between the model's predicted and observed outcomes (Figure 4). The calibration curves for the outcomes of sensory block level ≥ Grade 3 and ≥ Grade 4 (Figure 4B and C) show that the predicted probabilities from the model (Final model), and those obtained via 1000 bootstrap resampling iterations (Bootstrap-based), are similar to the observed values. Both curves closely align with the ideal line (Ideal). Although the alignment with the ideal line is slightly less

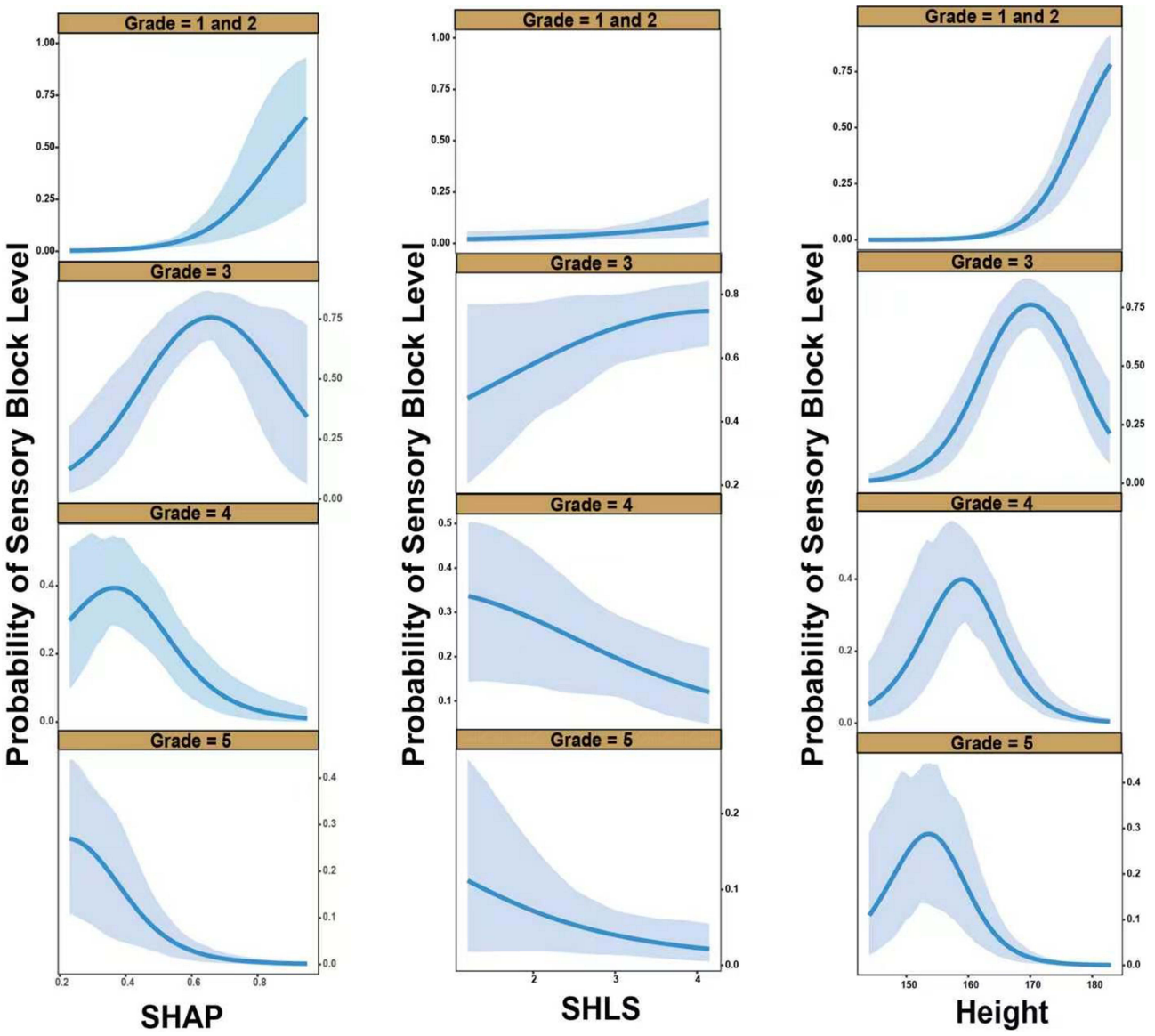

Figure 3 Dependencies of sensory block level on the variables of the final ordinal logistic regression model. The lines and shadowed areas represent the predicted line and 95% confidence interval, respectively.
Abbreviations: SHAP, anterior-posterior diameter of sacral hiatus at its apex; SHLS, sacral hiatus length in the sagittal plane.

tight for the outcomes of sensory block level ≥ Grade 2 and ≥ Grade 5 (Figure 4A and D), the Mean Absolute Error (MAE) for these two outcome categories remains low, at 0.032 and 0.038, respectively, quantitatively confirming the small deviation between the predicted and observed values.

Based on the final ordinal logistic regression model, a nomogram was developed, as shown in Figure 5. For each variable, a specific value is selected, and a vertical line is drawn to the "Points" axis to determine the corresponding score. For example, if a patient's height is 162.5 cm, the "Height" variable is assigned the value "162.5", corresponding to 50 points. The points for each variable are summed to obtain the "Total Points". A vertical line is then drawn from the Total Points to the axes for "Grade ≥ 2", "Grade ≥ 3", "Grade ≥ 4", and "Grade ≥ 5" to determine the probability of the patient experiencing a block level of Grade 2 or higher, Grade 3 or higher, Grade 4 or higher, and Grade 5 or higher, respectively. The grade with the highest probability represents the final predicted sensory block level for the patient.

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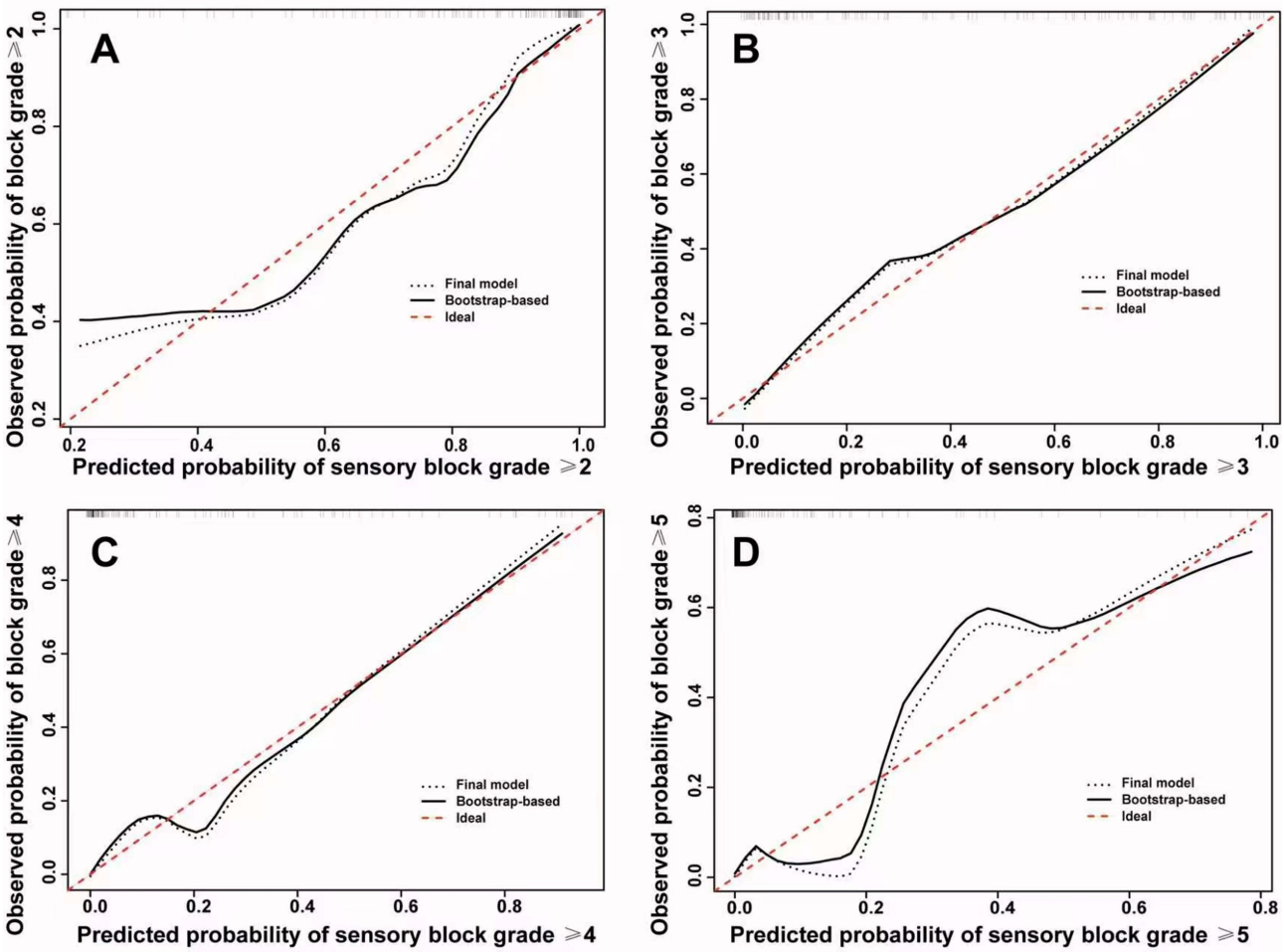

Figure 4 Calibration curves of the ordinal logistic regression model for sensory block level. (**A**) Calibration curve for the probability of sensory block grade ≥ 2. (**B**) Calibration curve for the probability of sensory block grade ≥ 3. (**C**) Calibration curve for the probability of sensory block grade ≥ 4. (**D**) Calibration curve for the probability of sensory block grade ≥ 5. The diagonal red dashed line represents the ideal prediction. The black dashed line represents the comparison between the predicted values of the final model and the actual observed values. The black solid line represents the comparison between the predicted values derived from 1000 Bootstrap resampling iterations and observed values.

Discussion

Accurately predicting the block level is crucial for optimizing anesthetic safety and efficacy, as an excessively high block level during caudal anesthesia can cause extensive sensory and motor blockade, while an insufficient level necessitates rescue blocks. Both scenarios increase patient risk and healthcare costs.[18] This study integrated four sacral anatomical parameters (BSW, SHAP, SHFSIA-AP, and SHLS) and four demographic characteristics (age, gender, height, and weight), identified independent predictors through ordinal logistic regression, and constructed a well-performing nomogram. These results represent the quantitative prediction of the sensory block level in caudal anesthesia by combining ultrasound-quantified anatomical parameters with individual characteristics, promoting a paradigm shift in caudal anesthesia from experience-based practice toward precision prediction.

Currently, most scholars believe that during epidural nerve blockade, local anesthetics exert their effects through multiple pathways. The primary mechanisms include paravertebral blockade, blockade of spinal nerve roots via radicular arachnoid villi and delayed spinal anesthesia resulting from local anesthetics diffusing through the dura mater into the subarachnoid space.[19–21] Given that local anesthetics undergo extensive diffusion and distribution at multiple sites within the epidural space, volume is a critical factor determining the extent of epidural nerve blockade.[22,23] In current clinical practice for caudal blockade in adult anorectal surgery, the typical local anesthetic volume ranges from 15 to 25 mL.

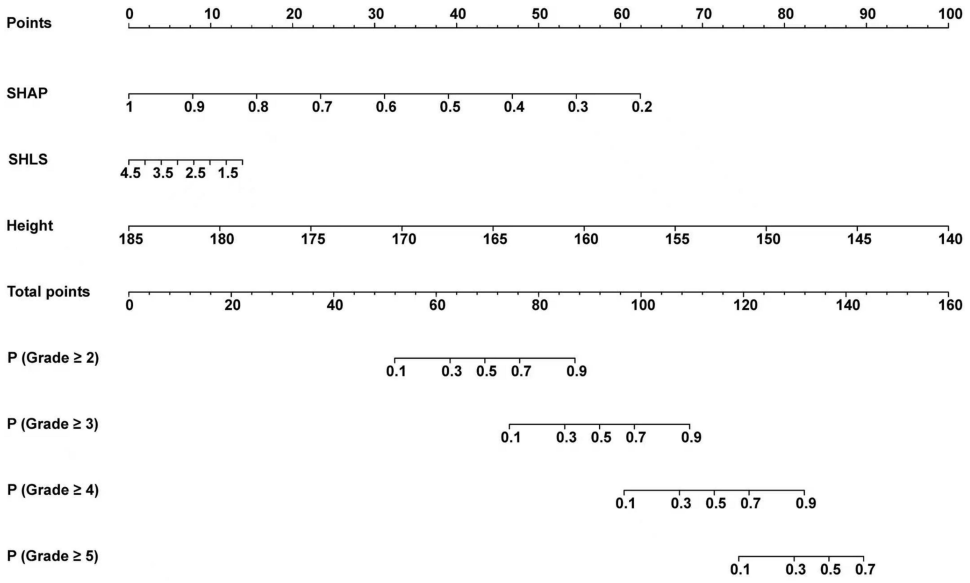

Figure 5 Nomogram of the ordinal logistic regression model for sensory block level.
Abbreviations: SHAP, anterior-posterior diameter of sacral hiatus at its apex; SHLS, sacral hiatus length in the sagittal plane.

Therefore, this study employed a fixed volume of 20 mL to investigate factors other than local anesthetic volume that may influence the level of caudal blockade.

Although the diffusion mechanism of local anesthetics in the epidural space is not fully understood, multiple studies by Hogan et al have demonstrated that solutions injected into the epidural space typically diffuse freely within it, covering the dural sac.[24,25] If the sacral epidural space is considered a fluid reservoir, then with a fixed volume of liquid, the height of the liquid level within the reservoir is determined by the reservoir's volume.[26] Therefore, this study incorporated multiple anatomy-related indicators to assess the volume of the sacral canal. In this study, the anatomical parameters SHAP and SHLS were retained as independent negative predictors after multivariate screening (Table 3). Both had VIF values below 5, eliminating concerns about multicollinearity and indicating their independent and crucial impact on the block level. Specifically, SHAP reflects the anterior-posterior diameter at the apex of the sacral hiatus. A larger SHAP implies a more spacious epidural cavity at the hiatus entrance, allowing the local anesthetic to diffuse more readily in multiple directions (rather than predominantly ascending), thereby reducing upward spread toward higher vertebral levels and consequently limiting the rise of the block level. SHLS represents the longitudinal extension length of the sacral hiatus in the sagittal plane. A longer SHLS suggests that upon injection, the local anesthetic may distribute more toward the caudal direction along the hiatus, rather than cephalad, resulting in a lower block level.

In the univariable analysis of this study, age, gender, and body weight all showed associations with the block level (Table 2). However, after multivariable screening, height remained the only retained demographic predictor (Table 3), with a coefficient of −0.254 ($P < 0.001$). This indicates a significant negative correlation between height and the sensory block level, meaning that for every 1 cm increase in height, the probability of achieving a higher block level significantly decreases. From an anatomical perspective, this finding can be explained by the relationship between height and the volume of the caudal space. A study utilizing MRI to assess spinal canal and caudal space volumes confirmed a significant positive correlation between height and the total volume of the caudal epidural space ($r = 0.68$, $P < 0.001$). Taller patients exhibit a larger epidural space volume within the sacral canal (particularly in the S1-S3 segments), making it more difficult for the local anesthetic to reach higher vertebral levels, thus resulting in a relatively lower block level.[27]

This study employed the ordinal logistic regression model to analyze the factors influencing the sensory block level, as the core rationale lies in the "ordered categorical" nature of the dependent variable. Although the sensory block level is represented numerically from 1 to 5, the relationship between these grades reflects a progressive increase in the extent of

blockade. This attribute aligns well with the methodological assumptions of ordinal logistic regression.[28,29] Furthermore, the ordinal logistic regression model can simultaneously output multiple predicted probabilities of "≥ a certain level", providing a complete risk spectrum for clinical practice.[30] The retrospective design of this study was adopted because our department has established a standardized operating procedure (SOP) for caudal anesthesia, which ensures consistency of anesthesia protocols and completeness of data recording. All data were collected prospectively according to this SOP, which mitigates the risk of selection bias typically associated with retrospective studies. Regarding sample size, based on the events-per-variable (EPV) principle with a recommended threshold of ≥20 events per predictor variable in the final model, and considering that the final ordinal logistic regression model retained three independent predictors (height, SHAP, and SHLS), a minimum sample size of 60 patients would be required. Our study included 132 patients, which substantially exceeds this requirement. This indicates adequate model stability and a low risk of overfitting.

The established nomogram offers a practical and readily applicable tool for clinicians to preoperatively estimate the sensory block level in adult patients undergoing caudal anesthesia for anorectal surgery. Clinicians can obtain an individualized probability of achieving a given block level based on four readily available demographic and anatomical parameters. This individualized probability assessment of sensory block level enables anesthesiologists to tailor local anesthetic volume based on predicted block level, thereby potentially reducing the incidence of both inadequate anesthesia and excessive blockade.

This study has several limitations. Firstly, as a retrospective study, it is inevitably subject to selection bias. Secondly, factors such as vascular distribution and adipose tissue content within the sacral canal were not included, which may affect the diffusion of local anesthetics by altering the actual volume of the epidural space.[31] Thirdly, the accuracy of the proposed nomogram is highly dependent on precise ultrasound measurements of SHAP and SHLS. Inter-observer variability and operator experience may influence measurement reliability. In situations where ultrasound image quality is suboptimal, such as in obese patients or individuals with difficult sacral anatomy, measurement inaccuracy could compromise predictive performance. Lastly, the study did not cover special populations such as children and pregnant women, and the applicability of the model in these populations still needs verification. Moreover, although internal validation using bootstrapping demonstrated good model stability, external validation in independent populations across diverse clinical settings is essential before widespread implementation. Validation in different patient cohorts and institutions will be necessary to confirm the model's generalizability, transportability, and clinical utility.

Despite these limitations, most existing research on caudal anesthesia focuses on success rates and complications, with limited exploration of predictors for the block level. As a study to construct a prediction model by integrating sacral anatomical parameters and demographic characteristics, it comprehensively reveals the complex relationships between various factors and the block level, thus providing valuable clinical insights. In future studies, we will focus on integrating the proposed nomogram into digital calculators, mobile applications, or ultrasound software platforms to facilitate its bedside application and enhance its translational value in routine anesthetic practice.

Data Sharing Statement

The datasets generated and/or analyzed during the current study are not publicly available due to privacy or ethical restrictions but are available from the corresponding author upon reasonable request.

Disclosure

Dr Zhengying Li reports patents related to epidural or nerve block catheter/ needle designs issued including 1 invention patent under review. They are broadly relevant to regional anesthesia but were not used in this study and generate no financial benefits. The authors report no other conflicts of interest in this work.

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