Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Current perception threshold for symptomatic nerve root identification in multilevel lumbar degenerative disease: diagnostic performance and development of a clinical prediction model

Cheng Chi
Beijing Tongren Hospital
Jianwei Zhou
Beijing Tongren Hospital
Jiandang Zhang
Beijing Chao-Yang Hospital
Jiaguang Tang
tangjiaguang2013@163.com

Beijing Tongren Hospital

Research Article

Keywords: Current perception threshold, Multilevel lumbar degenerative disease, Symptomatic nerve root, Selective nerve root block, Nomogram

Posted Date: May 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9375205/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

Objective

To evaluate the diagnostic performance of current perception threshold (CPT) testing for identifying the symptomatic nerve root in patients with multilevel lumbar degenerative disease (MLDD), and to develop a clinically applicable prediction model integrating functional, anatomical, and symptom-based variables.

Methods

This prospective diagnostic accuracy study consecutively enrolled 126 patients with MLDD who were candidates for surgical treatment between January 2022 and December 2024. Root-level analysis was performed on 182 clinically suspicious nerve roots. A composite reference standard based on selective nerve root block (SNRB) and comprehensive clinical judgment was used for symptomatic nerve root identification; when SNRB results were equivocal or inconsistent with the clinical picture, final root classification was determined by consensus of two senior spine surgeons following a pre-specified protocol. CPT testing was performed at the L4, L5, and S1 dermatomes using 2000, 250, and 5 Hz stimuli. A dermatome was considered CPT-positive when at least two of the three frequencies exceeded the upper limit of age- and sex-specific reference ranges established in a separate healthy control cohort. Diagnostic performance was assessed using receiver operating characteristic (ROC) analysis. Independent predictors were identified using multivariable logistic regression, and a nomogram was constructed and internally validated using bootstrap resampling.

Results

Of the 182 clinically suspicious nerve roots, 62 were classified as symptomatic and 120 as non-symptomatic. CPT positivity was significantly more frequent in symptomatic than in non-symptomatic roots (66.1% vs. 13.3%, $P < 0.001$). CPT testing yielded an accuracy of 79.7%, with a sensitivity of 66.1%, specificity of 86.7%, and an area under the ROC curve (AUC) of 0.764 for symptomatic nerve root identification. Multivariable analysis showed that CPT abnormality (OR = 14.85, 95% CI 6.56–33.62, $P < 0.001$), severe MRI stenosis (Schizas grade C/D; OR = 2.80, 95% CI 1.28–6.13, $P = 0.010$), and a higher visual analogue scale (VAS) score (OR = 1.41, 95% CI 1.08–1.85, $P = 0.012$) were independent predictors of symptomatic nerve roots. A nomogram incorporating these variables demonstrated good discrimination, with an AUC of 0.836 (95% CI 0.769–0.902), satisfactory calibration, and favorable clinical utility on decision curve analysis.

Conclusions

CPT testing demonstrates clinically useful specificity for identifying symptomatic nerve roots in MLDD under a strict root-level matching strategy. A prediction model integrating CPT abnormality, MRI stenosis severity, and pain intensity improves preoperative discriminative performance compared with CPT alone and may serve as a quantitative adjunct for surgical planning. External validation in multicenter cohorts is required before routine clinical adoption.

Introduction

Multilevel lumbar degenerative disease (MLDD) is a common cause of low back pain, radicular pain, and functional impairment in middle-aged and older adults [1, 2]. With population aging, the prevalence of multilevel degenerative changes has increased substantially, and a growing proportion of surgical candidates present with structural abnormalities at more than one lumbar level. In these patients, magnetic resonance imaging (MRI) often reveals disc herniation, lateral recess stenosis, or central canal stenosis at multiple levels. However, radiological abnormalities do not always correspond to the patient's dominant symptoms [3, 4]. This clinical-radiological mismatch makes it difficult to determine which compressed nerve root is actually responsible for the current radicular symptoms, and may lead to either insufficient decompression or unnecessarily extensive surgery.

Accurate identification of the symptomatic nerve root is therefore central to treatment planning in MLDD, particularly in the era of targeted and minimally invasive spine surgery. In routine practice, symptom distribution, neurological examination, and MRI findings are usually considered together, but each has important limitations. Dermatomal pain patterns are often variable, physical signs may be non-specific, and MRI primarily reflects structural compression under static, supine conditions rather than the dynamic neural stress experienced during standing or walking [3, 4]. Selective nerve root block (SNRB) is widely regarded as an important adjunctive method for symptomatic level identification because it links temporary pain relief to blockade of a specific nerve root [5, 6, 7]. Nevertheless, SNRB is invasive, requires fluoroscopic guidance, and still depends partly on subjective symptom reporting, which limits its routine use as a broad screening tool in patients with multiple suspicious levels [8, 9].

Current perception threshold (CPT) testing is a noninvasive quantitative sensory method based on frequency-selective electrical stimulation. By applying stimuli at 2000, 250, and 5 Hz, CPT testing evaluates the functional status of Abeta, Adelta, and C fibers, respectively, and provides objective information regarding sensory nerve function that is not captured by anatomical imaging. CPT has been applied in the evaluation of lumbar radiculopathy, carpal tunnel syndrome, and diabetic peripheral neuropathy, where it has demonstrated acceptable diagnostic utility and good reproducibility [10, 11, 12, 13]. However, its diagnostic performance in the specific context of MLDD - where multiple structurally abnormal roots must be functionally differentiated - has not been systematically evaluated. In our study framework, CPT abnormalities were interpreted using age- and sex-specific reference ranges, and root-level diagnostic analysis was performed using strict one-to-one matching between the tested dermatome and the anatomically corresponding target nerve root, a strategy designed to improve spatial specificity and better reflect the value of CPT in symptomatic root identification.

In recent years, multivariable prediction models have been increasingly used to support individualized clinical decision-making [14, 15, 16, 17]. For a complex condition such as MLDD, integrating anatomical findings, functional neural assessment, and symptom severity is more informative than relying on any single modality alone. We therefore conducted a prospective diagnostic accuracy study to evaluate the performance of CPT testing for identifying symptomatic nerve roots in MLDD using a composite reference standard based on SNRB and comprehensive clinical judgment. In addition, we sought to develop and internally validate a clinically applicable prediction model that combines CPT findings with MRI stenosis severity and pain intensity to support preoperative symptomatic nerve root assessment.

Methods

Study design and patients

This was a prospective diagnostic accuracy study conducted at a single tertiary referral center. Consecutive patients with MLDD who were scheduled for surgical treatment between January 2022 and December 2024 were screened for eligibility. The study protocol was approved by the institutional ethics committee, and written informed consent was obtained from all participants before enrollment.

Patients were eligible for inclusion if they met all of the following criteria: (1) age between 18 and 80 years; (2) presence of unilateral or bilateral radicular leg pain consistent with lumbar nerve root compression; (3) lumbar MRI showing degenerative abnormalities involving at least two levels, including disc herniation, lateral recess stenosis, or central canal stenosis; (4) imaging findings suggestive of multilevel nerve root compression, but with clinical symptoms, pain distribution, sensory disturbance, or physical examination findings insufficient to identify a single symptomatic nerve root with confidence; (5) failure of at least 3 months of conservative treatment, including medication, physical therapy, or nerve block; (6) willingness to undergo preoperative SNRB, with an interval of no more than 1 week between SNRB and CPT testing; (7) completion of preoperative CPT testing at the L4, L5, and S1 dermatomes; and (8) availability of complete clinical data.

Patients were excluded if they had: (1) a history of previous lumbar surgery; (2) spinal tumor, infection, or severe spinal deformity; (3) concomitant peripheral nervous system disorders, such as diabetic peripheral neuropathy, postherpetic neuralgia, or alcoholic neuropathy; (4) severe lower-extremity vascular disease; (5) serious cognitive impairment or psychiatric illness precluding reliable cooperation with testing; or (6) substantial missing clinical data.

A total of 126 patients met the eligibility criteria and were included in the study. Because MLDD commonly involves more than one radiologically suspicious level, the primary analysis was performed at the nerve root level rather than the patient level. In total, 182 clinically suspicious nerve roots entered the root-level diagnostic analysis. These roots were selected on the basis of symptom laterality, dermatomal distribution, and preoperative clinical assessment, rather than including all radiologically abnormal levels indiscriminately, and were subsequently evaluated by both SNRB and CPT testing.

Reference standard for symptomatic nerve root identification

Symptomatic nerve root identification was based on a composite reference standard consisting of SNRB findings and comprehensive clinical judgment. All SNRB procedures were performed by the same spine surgeon with more than 10 years of clinical experience under fluoroscopic guidance. After the needle tip had been positioned at the target nerve root in the extraforaminal region and correct placement confirmed with contrast medium, 1.5 mL of 1% lidocaine was slowly injected.

Leg pain intensity was assessed using the visual analogue scale (VAS) immediately before and 30 minutes after the procedure [18]. Pain relief was calculated as: Pain relief (%) = (pre-block VAS - post-block VAS) / pre-block VAS x 100%. Consistent with previous literature and our institutional practice [6], a pain relief rate of at least 70% was considered a positive SNRB result, indicating that the blocked nerve root was likely symptomatic.

Because no single test can serve as an absolute gold standard for symptomatic nerve root identification in MLDD, SNRB results were interpreted alongside the overall clinical picture, including symptom distribution, imaging findings, and follow-up information. When SNRB results were equivocal (pain relief 50–69%) or inconsistent with the dominant clinical presentation, final root classification was determined by consensus between two senior spine surgeons (each with > 10 years of experience) following a pre-specified decision protocol that incorporated dermatomal symptom mapping, neurological examination findings, and MRI-based compression severity. This consensus process was documented prospectively and was independent of CPT findings. Nerve roots fulfilling the composite criteria were classified as symptomatic; the remaining suspicious roots were classified as non-symptomatic.

To reduce assessment bias, the physician performing and evaluating SNRB was blinded to the CPT findings. Likewise, personnel responsible for CPT testing were blinded to the SNRB results and final symptomatic root classification.

CPT reference ranges

Age- and sex-specific CPT reference ranges used in this study were established in a separate healthy control cohort of 120 volunteers (60 men and 60 women; age range 20–79 years, stratified into six decade-based groups) recruited at our institution prior to the study period. Individuals with any neurological, metabolic, or vascular condition known to affect peripheral nerve function were excluded. CPT measurements were obtained at the L4, L5, and S1 dermatomes using the same Neurometer device and protocol as in the patient cohort. The upper limit of the normal reference range for each frequency, dermatome, age group, and sex was defined as the 95th percentile of the control distribution. These reference values were applied consistently throughout the study period.

Clinical variables, MRI assessment, and CPT testing

Demographic and clinical data were collected before surgery, including age, sex, body mass index (BMI), symptom duration, preoperative VAS score for radicular leg pain [18], and Oswestry Disability Index (ODI) [20]. Because the primary diagnostic analysis was performed at the nerve root level, patient-level variables were linked to each clinically suspicious root contributed by the same patient.

Preoperative lumbar MRI was independently reviewed by two spine surgeons blinded to the patients' clinical symptoms and CPT findings. The severity of spinal canal stenosis was graded using the Schizas classification [19]. Discrepancies between the two reviewers were resolved by consensus. For regression analysis and model construction, Schizas grades C and D were classified as severe stenosis. Interobserver agreement was evaluated using the kappa statistic.

CPT testing was performed using the Neurometer device at the L4, L5, and S1 dermatomes on the symptomatic side. In patients with bilateral symptoms, both sides were tested and recorded separately. Stimuli were delivered at 2000, 250, and 5 Hz, which primarily assess Abeta, Adelta, and C fiber function, respectively [10, 11]. CPT results were interpreted according to the age- and sex-specific reference ranges described above. A single frequency exceeding the upper limit of the corresponding reference range was defined as abnormal at that frequency. To improve diagnostic specificity and reduce the influence of physiological fluctuation or measurement variability, a dermatome was defined as CPT-positive when at least two of the three tested frequencies were abnormal. In the diagnostic accuracy analysis, CPT findings were matched to target nerve roots using a strict one-to-one ipsilateral segmental correspondence principle.

Statistical analysis

Statistical analyses were performed using SPSS version 26.0 and R version 4.2.1. Missing data were handled using multiple imputation. Continuous variables were tested for normality using the Shapiro-Wilk test. Normally distributed variables are presented as mean +/- standard deviation and were compared using the independent-samples t test; non-normally distributed variables are presented as median (interquartile range) and were compared using the Mann-Whitney U test. Categorical variables are presented as counts and percentages and were compared using the chi-square test or Fisher's exact test, as appropriate.

Because the primary unit of analysis was the nerve root, and individual patients could contribute more than one suspicious root, within-patient correlation was accounted for by using cluster-robust standard errors at the patient level in comparative analyses and regression models. Diagnostic performance of CPT testing was evaluated using ROC analysis, with calculation of sensitivity, specificity, accuracy, and AUC.

Univariable logistic regression was first performed to explore variables associated with symptomatic nerve root status. Variables with $P < 0.05$ were entered into the multivariable model. Multicollinearity was assessed using the variance inflation factor (VIF). Because ODI and VAS reflect overlapping aspects of symptom burden, their potential collinearity and relative clinical relevance were considered during model

development. A nomogram was developed using the rms package in R [15, 16, 17] and internally validated using bootstrap resampling with 1000 repetitions. Model discrimination was assessed using the C-index and ROC analysis. Calibration was evaluated using the Hosmer-Lemeshow goodness-of-fit test and calibration plots. Clinical utility was assessed by decision curve analysis (DCA). All statistical tests were two-sided, and $P < 0.05$ was considered statistically significant.

Results

Study population and baseline characteristics

A total of 126 consecutive patients with MLDD met the eligibility criteria and were included. The cohort comprised 75 men (59.5%) and 51 women (40.5%), with a mean age of 57.1 +/- 11.2 years and a mean BMI of 23.4 +/- 3.2 kg/m2. All patients completed preoperative CPT testing and SNRB evaluation.

In total, 182 clinically suspicious nerve roots were included in the diagnostic analysis. According to the composite reference standard, 62 nerve roots were classified as symptomatic and 120 as non-symptomatic. The number of symptomatic roots was lower than the number of enrolled patients because the reference classification was assigned strictly at the individual root level, and not all suspicious roots met the predefined criteria for symptomatic status after targeted evaluation.

There were no significant differences between symptomatic and non-symptomatic roots with respect to age, sex, or BMI (all $P > 0.05$). Symptom duration was significantly longer in the symptomatic group (14.8 +/- 6.3 vs. 12.6 +/- 5.9 months, $P = 0.022$). VAS score (7.6 +/- 1.2 vs. 5.8 +/- 1.4, $P < 0.001$) and ODI score (52.3 +/- 11.5% vs. 41.6 +/- 10.9%, $P < 0.001$) were both significantly higher in symptomatic roots. Severe MRI stenosis (Schizas grade C/D) was more frequent in symptomatic than in non-symptomatic roots (61.3% vs. 39.2%, $P = 0.005$). CPT positivity was markedly more common in symptomatic roots (66.1% [41/62] vs. 13.3% [16/120], $P < 0.001$). Detailed baseline characteristics are presented in Table 1.

Diagnostic performance of CPT for symptomatic nerve root identification

Among the 182 clinically suspicious nerve roots, CPT testing yielded 41 true-positive, 104 true-negative, 16 false-positive, and 21 false-negative results. CPT testing achieved an overall accuracy of 79.7% for symptomatic nerve root identification, with a sensitivity of 66.1% and a specificity of 86.7%. These findings indicate that CPT testing had relatively high specificity for ruling out non-symptomatic roots, whereas its sensitivity was moderate, suggesting that some symptomatic roots - particularly those in earlier or less severe stages of compression - may not yet exhibit sufficiently pronounced functional abnormalities to meet the predefined CPT-positive threshold. Detailed diagnostic performance data are shown in Table 2.

ROC analysis demonstrated an AUC of 0.764 for CPT testing in identifying symptomatic nerve roots (Figure 1), corresponding to the observed sensitivity of 66.1% and specificity of 86.7% under the predefined binary criterion.

Univariable and multivariable logistic regression analyses

Age, sex, and BMI were not significantly associated with symptomatic root identification (all $P > 0.05$). Longer symptom duration, higher ODI score, higher VAS score, severe MRI stenosis (Schizas grade C/D), and CPT abnormality were all significantly associated with symptomatic nerve roots in univariable analysis (all $P < 0.05$; Table 3).

After multivariable adjustment, CPT abnormality, severe MRI stenosis, and VAS score remained independently associated with symptomatic nerve root status, whereas symptom duration and ODI score were no longer significant. CPT abnormality was the strongest independent predictor (OR = 14.85, 95% CI 6.56-33.62, $P < 0.001$). Severe MRI stenosis was also independently associated with symptomatic nerve roots (OR = 2.80, 95% CI 1.28-6.13, $P = 0.010$), as was higher VAS score (OR = 1.41, 95% CI 1.08-1.85, $P = 0.012$; Table 4).

Development and validation of the nomogram

A nomogram was developed incorporating CPT abnormality, severe MRI stenosis (Schizas grade C/D), and VAS score (Figure 2). The model demonstrated good discriminative performance, with a C-index and AUC of 0.836 (95% CI 0.769-0.902), representing a meaningful improvement over CPT testing alone (AUC = 0.764; Figure 3). The Hosmer-Lemeshow goodness-of-fit test indicated no significant lack of fit ($P > 0.05$), and the bootstrap-corrected calibration curve based on 1000 resamples showed good agreement between predicted and observed probabilities (Figure 4). On decision curve analysis, the nomogram provided a higher net benefit than the treat-all and treat-none strategies across a broad range of threshold probabilities, supporting its value as an adjunctive tool for preoperative symptomatic nerve root assessment (Figure 5).

Discussion

Principal findings

In this prospective diagnostic accuracy study, we evaluated the value of CPT testing for symptomatic nerve root identification in patients with MLDD using a composite reference standard based on SNRB and comprehensive clinical judgment. Three principal findings emerged. First, under a strict root-level matching strategy and a predefined criterion of abnormality in at least two frequencies, CPT testing showed acceptable diagnostic performance, with relatively high specificity (86.7%) and moderate sensitivity (66.1%). Second, CPT abnormality, severe MRI stenosis, and higher pain intensity were

independent predictors of symptomatic nerve root status, with CPT abnormality showing the strongest association (OR = 14.85). Third, a nomogram integrating functional, anatomical, and symptom-based information demonstrated better discrimination than CPT testing alone, with satisfactory calibration and favorable clinical utility on decision curve analysis. Together, these findings suggest that CPT testing serves as a useful adjunctive functional tool for preoperative symptomatic nerve root assessment in MLDD, particularly when interpreted in combination with MRI and clinical symptoms.

Comparison with prior studies and the complementary role of CPT

One of the major challenges in MLDD is the frequent mismatch between radiological abnormalities and clinical symptoms. Previous studies have shown that lumbar MRI abnormalities are common even in asymptomatic individuals [3, 4]. In the present study, 182 clinically suspicious nerve roots were evaluated, but only 62 were ultimately classified as symptomatic, highlighting the limitation of relying solely on anatomical imaging in multilevel disease.

Prior studies applying CPT in lumbar radiculopathy have shown that Abeta and Adelta fiber function is significantly impaired at the level of root compression, and that CPT values correlate with the severity and laterality of sensory disturbance [10, 11]. These observations support the use of CPT as a functional complement to structural imaging and are consistent with the diagnostic performance observed in the present study. Our observed sensitivity of 66.1% and specificity of 86.7% are broadly in line with the performance range reported for CPT in single-level radiculopathy [10, 11] and for other quantitative sensory methods in peripheral nerve evaluation [12, 13]. Compared with single-level disease, however, the clinical challenge in MLDD is greater because multiple structurally abnormal roots must be functionally differentiated. Our strict root-level matching strategy and the two-of-three frequency positivity criterion were specifically designed to address this challenge, and the resulting specificity profile suggests that CPT is particularly useful for confirming rather than screening suspected symptomatic roots in this population.

In this context, CPT provides complementary functional information that MRI alone cannot offer. While MRI characterizes structural compression under static conditions, CPT reflects whether that compression is associated with clinically meaningful sensory fiber dysfunction. The findings therefore support a complementary rather than competitive relationship between the two modalities, in which structural imaging identifies candidate targets and CPT helps refine the probability that a given root is truly symptomatic.

Possible neurophysiological explanation for CPT abnormalities

The diagnostic contribution of CPT in the present study may be interpreted in light of the neurophysiological changes associated with lumbar nerve root compression. Chronic root compression leads to mechanical deformation, local inflammation, and microcirculatory compromise, resulting in

demyelination, axonal dysfunction, and altered sensory excitability [21, 22]. These pathological processes do not necessarily affect all sensory fiber populations simultaneously or to the same degree. In early or milder stages of compression, abnormalities may be limited to one fiber type, whereas more established neural compromise tends to involve multiple frequencies.

This consideration provides a rationale for requiring abnormalities in at least two of three tested frequencies for CPT positivity. This stricter threshold reduces the influence of physiological fluctuation and measurement variability, and increases the likelihood that an observed CPT abnormality reflects clinically meaningful neural dysfunction - a design choice that likely contributed to the relatively high specificity observed in our study. At the same time, the moderate sensitivity is an expected trade-off: symptomatic roots in earlier or less severe stages of compression may not yet exhibit multi-fiber abnormalities and would therefore be missed by this criterion.

A stepwise complementary strategy for clinical decision-making

The present findings support a stepwise complementary strategy for symptomatic nerve root identification in MLDD. In routine practice, MRI is essential for detecting structural abnormalities and narrowing the range of suspicious levels, but its specificity for identifying the truly symptomatic root is limited in the setting of multilevel degeneration. SNRB provides more direct functional confirmation of the suspected pain-generating root [5, 6, 7], yet it is invasive and depends partly on subjective symptom relief after blockade [8, 9]. Repeated use of SNRB across multiple suspicious levels may be impractical in some patients.

In this context, CPT may serve as a useful intermediate assessment tool. Because it is noninvasive, quantitative, and dermatome-specific, CPT can be used to provide additional functional evidence before proceeding to invasive confirmation. A clinically pragmatic pathway may involve initial identification of suspicious levels based on symptoms and MRI, followed by CPT-based functional evaluation to prioritize the most likely symptomatic roots, and then selective use of SNRB when further confirmation is required. Such a strategy may help improve the efficiency and consistency of preoperative assessment, especially in patients with multiple radiologically abnormal levels and equivocal clinical localization. This framework does not imply that CPT can replace established diagnostic approaches; rather, its value lies in improving confidence when integrated with anatomical and clinical information.

Clinical significance of the nomogram

The multivariable nomogram outperformed CPT testing alone in identifying symptomatic nerve roots, with an AUC of 0.836 versus 0.764. By integrating CPT abnormality, severe MRI stenosis, and pain intensity, the model incorporated three complementary dimensions of clinical information: functional impairment, anatomical severity, and symptom burden. This integrated approach reflects the reality that symptomatic nerve root identification in MLDD is rarely determined by a single source of evidence, and is consistent with current principles of individualized clinical prediction [14, 15, 16, 17].

The final composition of the model is clinically meaningful. Although both symptom duration and ODI score were associated with symptomatic root status in univariable analysis, neither retained independent significance after multivariable adjustment. By contrast, VAS score remained significant, suggesting that pain intensity more directly reflects current radicular irritation than broader functional disability measures. Accordingly, the final three-variable model favors variables most directly linked to the pathophysiological identification of the symptomatic root, improving interpretability and clinical utility.

The nomogram is intended as a quantitative adjunct to support preoperative assessment and improve consistency in evaluating complex MLDD cases - particularly for prioritizing suspicious roots, guiding the selective use of SNRB, and informing the extent of decompression when clinical and radiological findings are not fully concordant. It is not designed to replace clinical judgment or serve as a stand-alone decision tool.

Limitations

Several limitations of this study should be acknowledged. First, this was a single-center prospective study, and the nomogram was only internally validated using bootstrap resampling. The generalizability of the model to other institutions, patient populations, and clinical settings therefore remains uncertain, and external validation in independent multicenter cohorts is required before broader clinical implementation.

Second, the composite reference standard incorporated comprehensive clinical judgment alongside SNRB, which introduces a degree of circularity risk, as some clinical variables included in the prediction model may have influenced root classification. Although the consensus classification process was pre-specified and documented prospectively, and CPT personnel were blinded to reference standard results, some degree of misclassification cannot be completely excluded.

Third, CPT testing is a psychophysical test that depends to some extent on patient cooperation, attention, and understanding of the testing procedure. Despite the use of standardized protocols and blinded assessment, short-term fluctuation in patient responses may still have influenced threshold measurements.

Fourth, the present study focused on the L4, L5, and S1 dermatomes, which represent the most commonly involved lumbar nerve roots in clinical practice. The applicability of our findings to higher lumbar roots, such as L2 or L3, remains unclear.

Finally, while the proposed model demonstrated favorable discrimination, calibration, and decision-curve performance in the current cohort, future studies incorporating external validation, longer postoperative outcome assessment, and additional objective functional markers are warranted to further improve the robustness and clinical applicability of this approach.

Conclusion

In conclusion, CPT testing demonstrated useful specificity for symptomatic nerve root identification in patients with MLDD under a strict root-level matching strategy. CPT abnormality, severe MRI stenosis, and pain intensity were independent predictors of symptomatic nerve root status. A nomogram integrating these variables provided improved discriminative ability compared with CPT testing alone and may serve as a quantitative adjunct for preoperative symptomatic nerve root assessment. Given the single-center design and the absence of external validation, these findings should be interpreted with caution, and multicenter studies are warranted before routine clinical adoption.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Beijing Tongren Hospital, Capital Medical University, Beijing, China. Written informed consent was obtained from all participants prior to enrollment. All methods were performed in accordance with the Declaration of Helsinki and relevant guidelines and regulations.

Consent for publication

Not applicable.

Clinical trial number

Not applicable.

Competing interests

The authors declare no competing interests.

Funding

This study received no external funding.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Author contributions

Cheng Chi conceived and designed the study, drafted the manuscript. Jianwei Zhou collected the data, performed the statistical analysis. Jiandang Zhang interpreted the results. Jiaguang Tang revised the manuscript critically for important intellectual content, and approved the final version of the manuscript.

Data Availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Ravindra VM, Senglaub SS, Rattani A, et al. Degenerative lumbar spine disease: estimating global incidence and worldwide volume. Global Spine J. 2018;8(8):784–94.
2. Kalichman L, Hunter DJ. Diagnosis and conservative management of degenerative lumbar spondylosis. Eur Spine J. 2008;17(3):327–35.
3. Boden SD, Davis DO, Dina TS, et al. Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects. A prospective investigation. J Bone Joint Surg Am. 1990;72(3):403–8.
4. Jensen MC, Brant-Zawadzki MN, Obuchowski N, et al. Magnetic resonance imaging of the lumbar spine in people without back pain. N Engl J Med. 1994;331(2):69–73.
5. Sasso RC, Macadaeg K, Nordmann D, et al. Selective nerve root injections can predict surgical outcome for lumbar and cervical radiculopathy: comparison to magnetic resonance imaging. Spine. 2001;26(22):2433–8.
6. Yeom JS, Lee JW, Park KW, et al. Value of diagnostic lumbar selective nerve root block: a prospective controlled study. AJNR Am J Neuroradiol. 2008;29(5):1017–23.
7. North RB, Kidd DH, Zahurak M, et al. Specificity of diagnostic nerve blocks: a prospective, randomized study of sciatica due to lumbosacral spine disease. Pain. 1996;65(2–3):77–85.
8. Lutz GE, Vad VB, Wisneski RJ. Fluoroscopic transforaminal lumbar nerve root blocks: a clinical study. Spine. 1998;23(10):1198–202.
9. Narozny M, Zanetti M, Boos N. Clinical efficacy of fluoroscopically guided nerve root blocks in patients with lumbar stenosis. Spine. 2001;26(24):2699–703.
10. Yamashita T, Kanaya K, Sekine M, Takebayashi T, Kawaguchi S, Katahira G. A quantitative analysis of sensory function in lumbar radiculopathy using current perception threshold testing. Spine. 2002;27(14):1567–70.
11. Imoto K, Takebayashi T, Kanaya K, Kawaguchi S, Yamashita T. Quantitative analysis of sensory functions after lumbar discectomy using current perception threshold testing. Eur Spine J. 2007;16(5):719–23.
12. Masson EA, Veves A, Fernando D, et al. Current perception thresholds: a new, quick, and reproducible method for the assessment of peripheral neuropathy in diabetes mellitus. Diabetologia.

1989;32(10):724–8.
13. Katims JJ, Rouvelas P, Sadler PT, et al. Current perception threshold: reproducibility and comparison with nerve conduction in evaluation of carpal tunnel syndrome. Arch Phys Med Rehabil. 1989;70(3):228–31.
14. Kattan MW, Hess KR, Amin MB, et al. American Joint Committee on Cancer acceptance criteria for inclusion of risk models for individualized prognosis in the practice of precision medicine. CA Cancer J Clin. 2016;66(5):370–4.
15. Iasonos A, Schrag D, Raj GV, et al. How to build and interpret a nomogram for cancer prognosis. J Clin Oncol. 2008;26(8):1364–70.
16. Steyerberg EW. Clinical Prediction Models: A Practical Approach to Development, Validation, and Updating. New York: Springer; 2009.
17. Balachandran VP, Gonen M, Smith JJ, et al. Nomograms in oncology: more than meets the eye. Lancet Oncol. 2015;16(4):e173–80.
18. Hawker GA, Mian S, Kendzerska T, et al. Measures of adult pain: Visual Analog Scale for Pain (VAS Pain), Numeric Rating Scale for Pain (NRS Pain), McGill Pain Questionnaire (MPQ), Short-Form McGill Pain Questionnaire (SF-MPQ), Chronic Pain Grade Scale (CPGS), Short Form-36 Bodily Pain Scale (SF-36 BPS), and Measure of Intermittent and Constant Osteoarthritis Pain (ICOAP). Arthritis Care Res. 2011;63(Suppl 11):S240–52.
19. Schizas C, Theumann N, Burn A, et al. Qualitative grading of severity of lumbar spinal stenosis based on the morphology of the dural sac on magnetic resonance images. Spine. 2010;35(21):1919–24.
20. Fairbank JC, Pynsent PB. The Oswestry Disability Index. Spine. 2000;25(22):2940–52.
21. Garfin SR, Rydevik BL, Brown RA. Compressive neuropathy of spinal nerve roots. A mechanical or biological problem? Spine. 1991;16(2):162–6.
22. Garfin SR, Rydevik BL, Lind B, Massie J. Spinal nerve root compression. Spine. 1995;20(16):1810–20.

Tables

Table 1. Baseline characteristics of symptomatic and non-symptomatic nerve roots in patients with multilevel lumbar degenerative disease

Variable	Symptomatic nerve roots (n = 62)	Non-symptomatic nerve roots (n = 120)	P value
Patient-level variables			
Age (years)	57.8 ± 11.6	56.5 ± 10.8	0.448
Sex (male/female)	37 / 25	71 / 49	0.921
BMI (kg/m²)	23.6 ± 3.1	23.3 ± 3.3	0.561
Symptom duration (months)	14.8 ± 6.3	12.6 ± 5.9	0.022
VAS score	7.6 ± 1.2	5.8 ± 1.4	<0.001
ODI score (%)	52.3 ± 11.5	41.6 ± 10.9	<0.001
Nerve root-level variables			
Severe MRI stenosis (Schizas grade C/D)	38 (61.3%)	47 (39.2%)	0.005
CPT positivity in the corresponding dermatome	41 (66.1%)	16 (13.3%)	<0.001

Note: Data are presented as mean ± standard deviation or n (%), as appropriate. Comparisons were performed at the nerve root level, with cluster-robust standard errors used to account for within-patient correlation because individual patients could contribute more than one suspicious nerve root. Severe MRI stenosis was defined as Schizas grade C or D. CPT positivity was defined as abnormality at ≥2 of the 3 tested frequencies in the dermatome corresponding to the target nerve root.

Table 2. Diagnostic performance of current perception threshold testing for symptomatic nerve root identification in multilevel lumbar degenerative disease

CPT test result	SNRB-positive (symptomatic root)	SNRB-negative (non-symptomatic root)	Total
CPT-positive	41	16	57
CPT-negative	21	104	125
Total	62	120	182

Note: Symptomatic nerve root status was determined using a composite reference standard based on selective nerve root block (SNRB) and comprehensive clinical judgment. CPT positivity was defined as abnormality at ≥2 of the 3 tested frequencies in the corresponding dermatome. TP, true positive; TN, true negative; FP, false positive; FN, false negative. In the present cohort, CPT testing yielded 41 TP, 104 TN, 16 FP, and 21 FN results, corresponding to an accuracy of 79.7%, sensitivity of 66.1%, and specificity of 86.7%.

Table 3. Univariable logistic regression analysis of factors associated with symptomatic nerve root status

Variable	β	SE	OR	95% CI	P value
Age (years)	0.012	0.009	1.012	0.995–1.031	0.173
Sex (male vs female)	0.041	0.287	1.042	0.592–1.833	0.887
BMI (kg/m²)	0.028	0.041	1.028	0.949–1.114	0.491
Symptom duration (months)	0.058	0.021	1.060	1.018–1.105	0.005
ODI score (%)	0.043	0.010	1.044	1.023–1.066	<0.001
VAS score	0.327	0.111	1.387	1.115–1.724	0.003
Severe MRI stenosis (Schizas grade C/D)	0.900	0.321	2.459	1.311–4.612	0.005
CPT abnormality	2.541	0.380	12.69	6.03–26.71	<0.001

Note: OR, odds ratio; CI, confidence interval; BMI, body mass index; VAS, visual analogue scale; ODI, Oswestry Disability Index; CPT, current perception threshold. Severe MRI stenosis was defined as Schizas grade C or D. CPT abnormality was defined as abnormality at ≥2 of the 3 tested frequencies in the dermatome corresponding to the target nerve root. Variables with $P < 0.05$ in univariable analysis were considered candidate predictors for multivariable modeling.

Table 4. Multivariable logistic regression analysis of independent predictors of symptomatic nerve root status

Variable	β	SE	OR	95% CI	P value
Symptom duration (months)	0.025	0.018	1.025	0.989–1.063	0.165
VAS score	0.345	0.137	1.41	1.08–1.85	0.012
ODI score (%)	0.019	0.012	1.019	0.995–1.044	0.118
Severe MRI stenosis (Schizas grade C/D)	1.029	0.400	2.80	1.28–6.13	0.010
CPT abnormality	2.698	0.417	14.85	6.56–33.62	<0.001

Note: OR, odds ratio; CI, confidence interval; VAS, visual analogue scale; ODI, Oswestry Disability Index; CPT, current perception threshold. Severe MRI stenosis was defined as Schizas grade C or D. CPT abnormality was defined as abnormality at ≥2 of the 3 tested frequencies in the dermatome corresponding to the target nerve root. In the adjusted model, CPT abnormality, severe MRI stenosis, and VAS score remained independent predictors of symptomatic nerve root status, whereas symptom duration and ODI score did not retain statistical significance. For nomogram construction, only CPT abnormality, severe MRI stenosis, and VAS score were included to improve model parsimony and clinical interpretability.

Figures

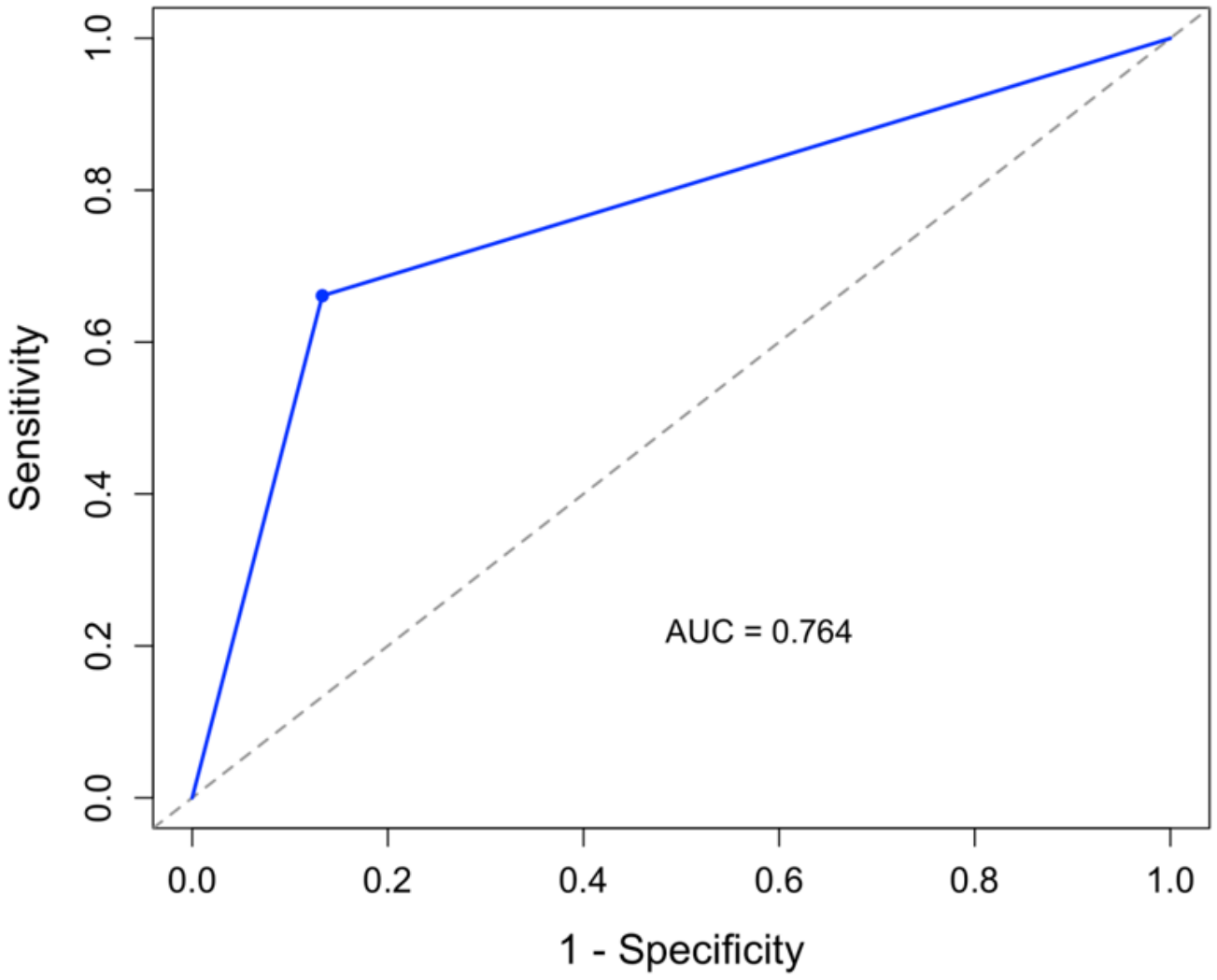


Figure 1

Receiver operating characteristic curve of current perception threshold testing for symptomatic nerve root identification.

The blue solid line represents the receiver operating characteristic (ROC) curve of current perception threshold (CPT) testing using the predefined binary criterion of abnormality at >=2 of the 3 tested frequencies in the corresponding dermatome. The area under the curve (AUC) was 0.764, with a sensitivity of 66.1% and a specificity of 86.7% for symptomatic nerve root identification. The diagonal dashed line indicates the line of no discrimination.

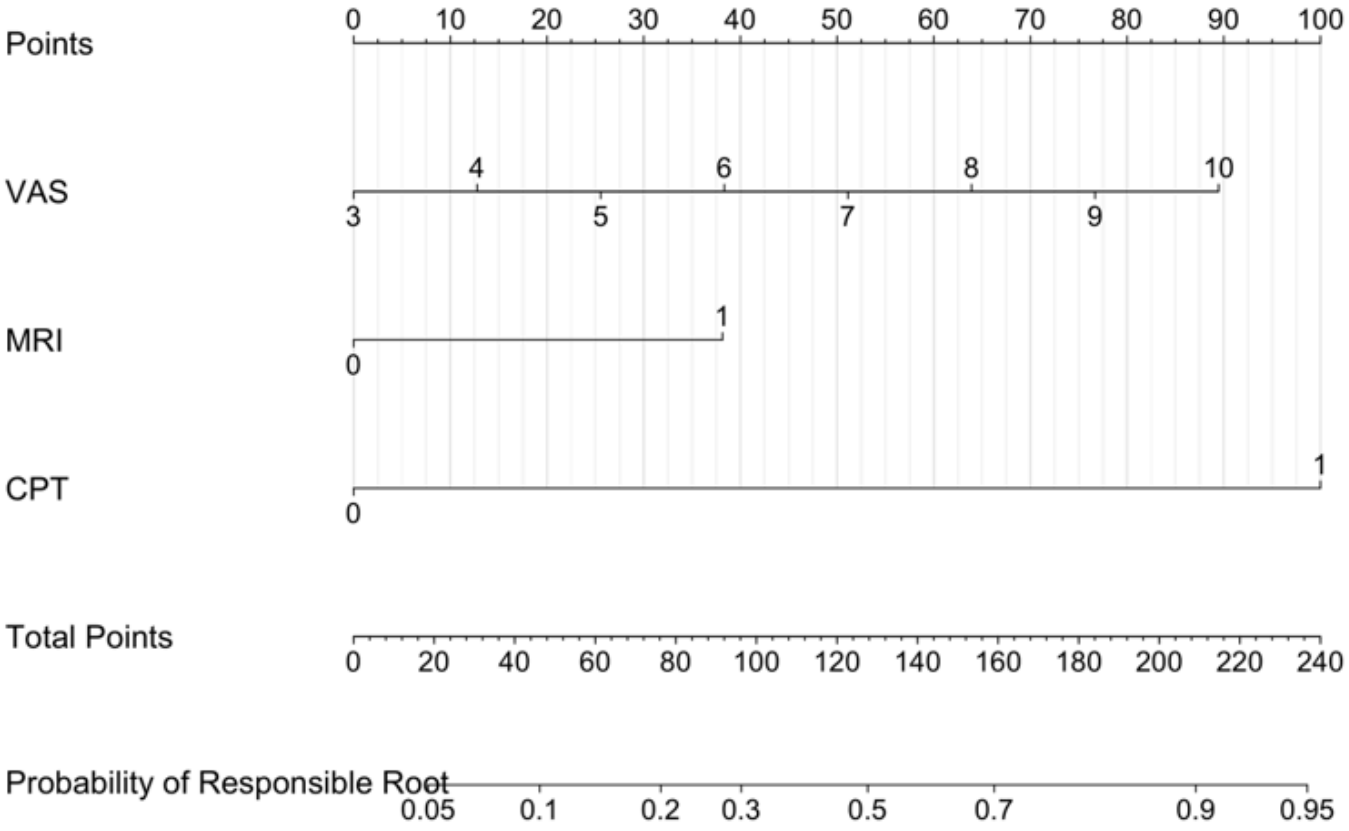


Figure 2

Nomogram for individualized prediction of symptomatic nerve root status in multilevel lumbar degenerative disease.

The nomogram incorporates current perception threshold (CPT) abnormality, severe MRI stenosis (Schizas grade C/D), and visual analogue scale (VAS) score to estimate the probability that a clinically suspicious nerve root is symptomatic. To use the nomogram, locate the value of each predictor on its corresponding axis, draw a vertical line upward to the Points axis to assign a score for each variable, sum the individual scores to obtain the Total Points, and then project the total downward to estimate the predicted probability of a symptomatic nerve root.

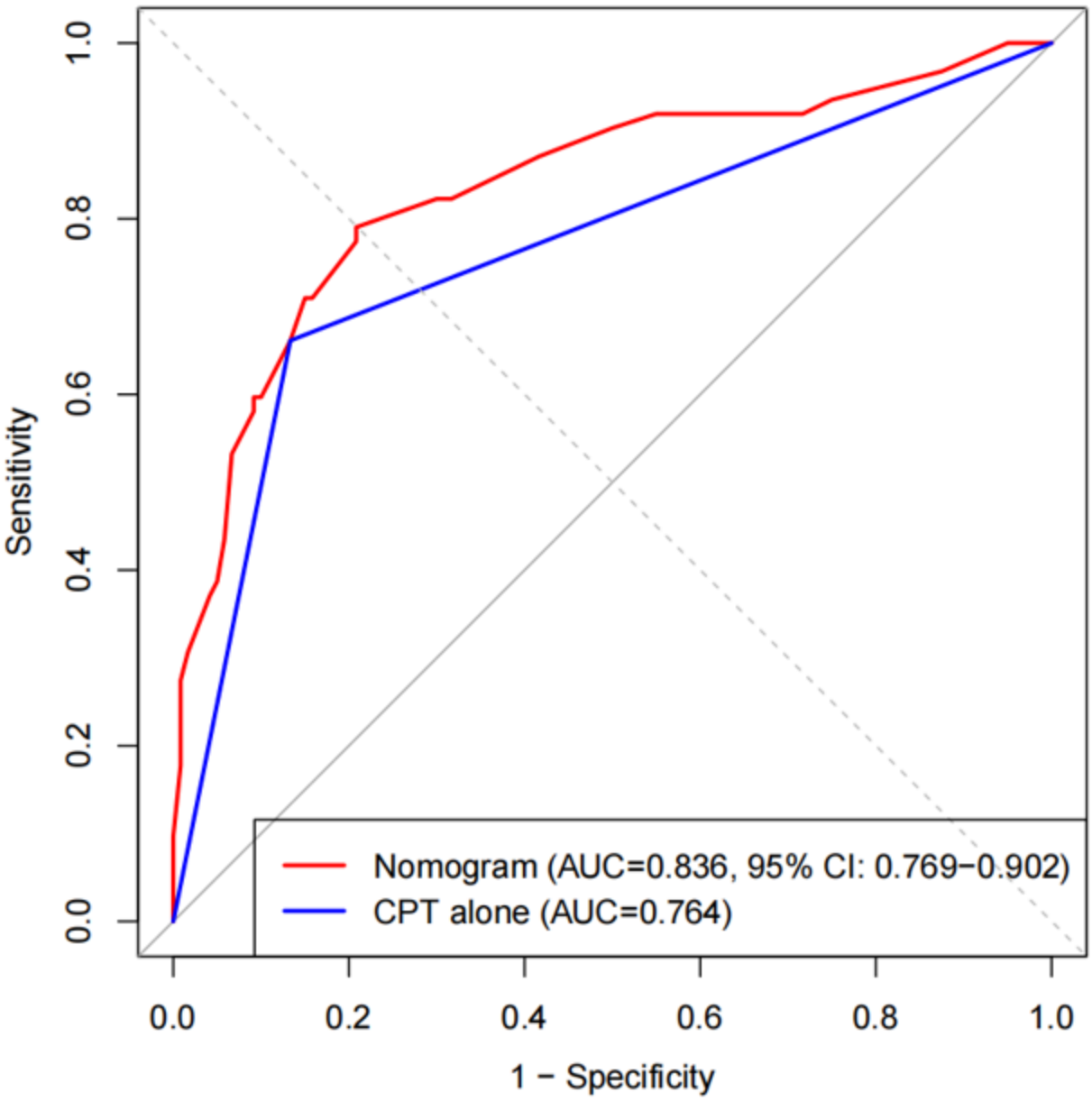


Figure 3

Receiver operating characteristic curves comparing the nomogram and current perception threshold testing alone.

The red solid line represents the ROC curve of the multivariable nomogram incorporating CPT abnormality, severe MRI stenosis, and VAS score. The blue solid line represents the ROC curve of CPT testing alone. The nomogram achieved an AUC of 0.836 (95% CI 0.769-0.902), which was higher than that of CPT testing alone (AUC = 0.764), indicating improved discriminative performance for symptomatic nerve root identification. The diagonal dashed line indicates the reference line.

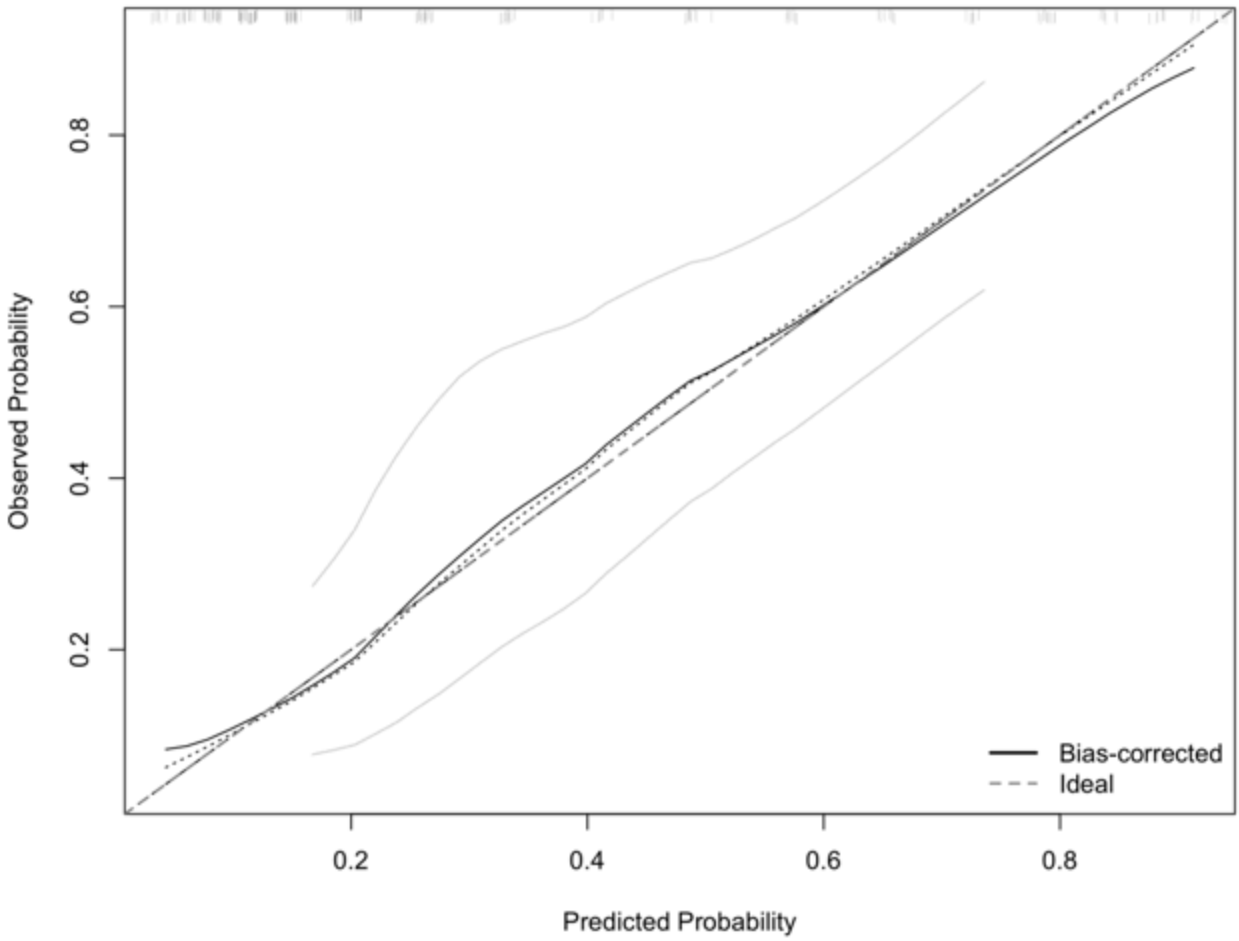


Figure 4

Calibration plot of the nomogram for symptomatic nerve root prediction.

The x-axis shows the predicted probability of symptomatic nerve root status generated by the nomogram, and the y-axis shows the observed probability. The diagonal reference line indicates perfect agreement between predicted and observed outcomes. The bias-corrected curve represents the bootstrap-corrected calibration based on 1000 resamples. Closer agreement between the calibration curve and the diagonal line indicates better calibration.

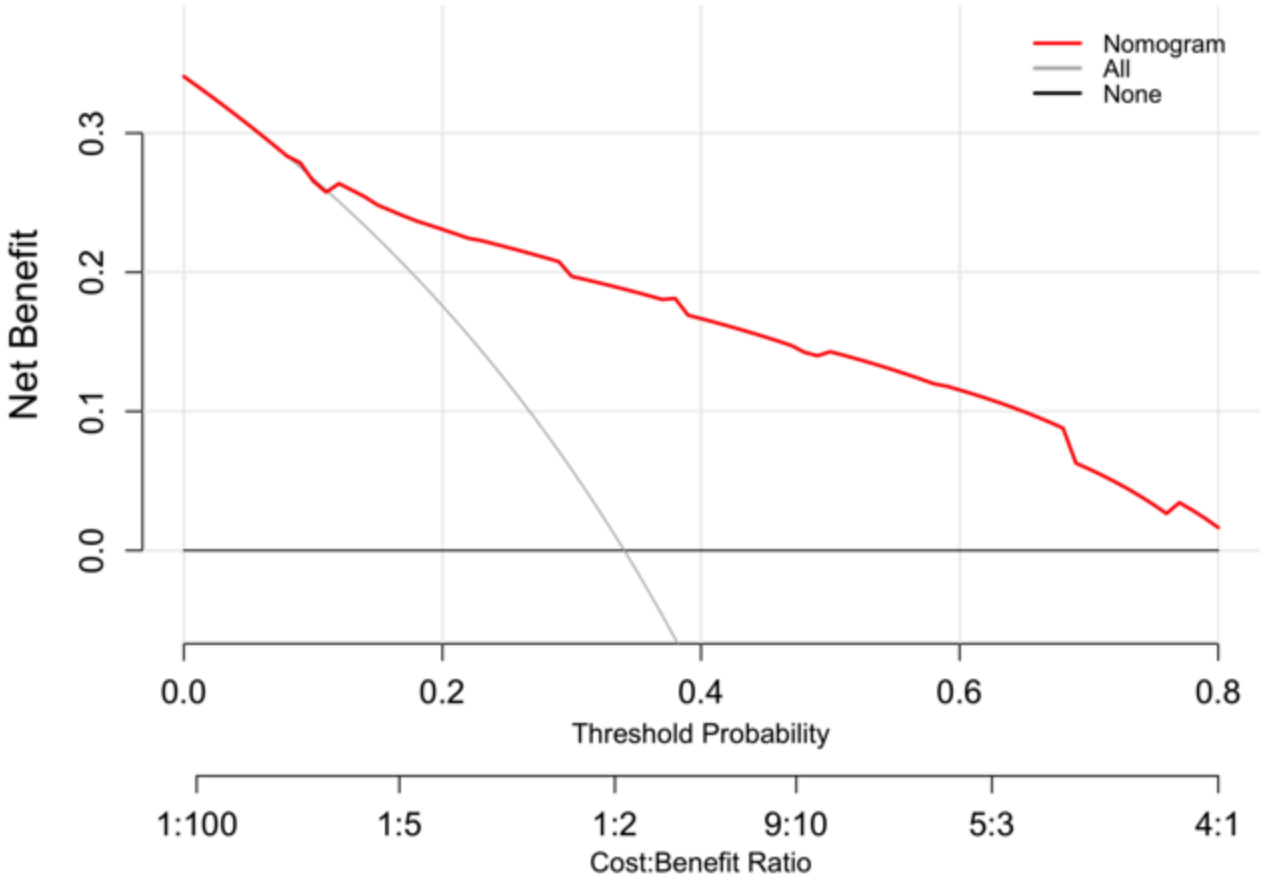


Figure 5

Decision curve analysis of the nomogram for symptomatic nerve root prediction.

The y-axis represents net benefit and the x-axis represents threshold probability. The red line indicates the clinical net benefit of using the nomogram to guide symptomatic nerve root assessment. The gray line represents the treat-all strategy, and the black horizontal line represents the treat-none strategy. Across a broad range of threshold probabilities, the nomogram provided a higher net benefit than either default strategy, supporting its potential clinical usefulness as an adjunctive decision-support tool.