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Development and Validation of Diagnostic Models for Cervical Nerve Root Involvement Based on Items From the Patient Interview and Clinical Examination

■ **OBJECTIVE:** To develop and internally validate diagnostic models for cervical nerve root involvement based on patient interview and clinical examination items.

■ **DESIGN:** Diagnostic predictive modeling study.

■ **METHODS:** People with a suspicion of cervical nerve root involvement (ie, radicular pain and/or radiculopathy) (N = 134) were included. Three diagnostic models (ie, patient interview items alone, clinical examination alone, and combined patient interview plus clinical examination) were developed using multivariable logistic regression analyses. For internal validation, we performed bootstrapping techniques (250 repetitions). The diagnostic accuracy (area under the curve [AUC]) and explained variance (Nagelkerke's R^2) of the models were assessed. An AUC of 0.7 or higher was considered adequate.

■ **RESULTS:** The patient interview model consisted of 2 items and showed an explained variance of 0.23 and an AUC of 0.74 (95% CI: 0.66, 0.81) after bootstrapping. The clinical examination model consisted of 2 items and had an explained variance of 0.29, and an AUC of 0.77 (95% CI: 0.69, 0.85) after internal validation. The combined model had an explained variance of 0.38 and an AUC of 0.82 (95% CI: 0.75, 0.89) after bootstrapping and consisted of the Spurling test (odds ratio [OR], 8.0; 95% CI: 3.1, 20.4), "Arm pain worse than neck pain" (OR, 4.8; 95% CI: 1.9, 11.8) and the patient-reported "Presence of paraesthesia and/or numbness" (OR, 2.8; 95% CI: 1.0, 7.8).

■ **CONCLUSIONS:** The combined model showed the best diagnostic accuracy to determine the likelihood of cervical nerve root involvement. External validation is required before implementing any diagnostic model. *JOSPT Open 2025;3(2):107-113. Epub 26 November 2024. doi:10.2519/josptopen.2024.0082*

■ **KEY WORDS:** *differential diagnosis/primary care, musculoskeletal health care, neck, orthopedics, peripheral nerve injuries, rehabilitation*

Compression or inflammation of a cervical nerve root may lead to various symptoms, such as arm pain, sensory changes, and/or muscle weakness.[10,18] Several terms are used to reflect the symptomatology that results from cervical nerve root involvement, including radicular pain and/or radiculopathy.[28,32] While radicular pain refers to the pain that occurs as a result of nerve root involvement, radiculopathy pertains to neurological deficits, such as sensory changes, muscle weakness, or altered reflexes, associated with nerve root compression.[3,11,17,28,32] When radicular pain and radiculopathy coincide, this is referred to as painful cervical radiculopathy.[17,28] Incongruously, the term cervical radiculopathy also has a broader use, referring to radicular pain, neurological deficits, or a combination thereof.[11,13,17,32] The inconsistent use of terms complicates interpreting, applying and comparing results.[11,13,25,28]

Musculoskeletal health care providers regularly encounter patients with symptoms that suggest cervical nerve root involvement. Therefore, determining the likelihood of cervical nerve root involvement is important for diagnosis. This can be challenging, however, because symptom presentation varies. Common signs and symptoms, such as neck and arm pain, scapular pain, or sensory changes, are not unique to cervical nerve root involvement, making differential diagnosis difficult.[10,19,23] In clinical practice, clinicians combine information from the patient interview and clinical examination to determine the likelihood of cervical nerve root involvement.[10,12,31] Individual items from the patient interview[20] and clinical examination[31] have too little diagnostic value, and it is recommended that future research focuses on determining the most useful combination of items from either the patient interview,

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the clinical examination or a combination thereof. In addition, it would be informative to know to what extent the diagnosis can be based solely on information from the patient interview, and to get more insight into the added diagnostic benefit of the clinical tests for making the diagnosis. Therefore, we aimed to develop and internally validate 3 multivariable diagnostic models to diagnose cervical nerve root involvement, based on items from (1) the patient interview, (2) clinical examination, and (3) both the patient interview and clinical examination.

METHODS

The models were derived from data of a prospective diagnostic study.[29] The study was approved by the Medical Ethics Committee of the Elisabeth Hospital in Tilburg, The Netherlands (METC-2013-02). All participants signed an informed consent form before participating. More details on the procedures have been reported previously.[29] The methods and results are reported according to recommendations made in the Transparent Reporting of a multivariable prediction model for Individual Prognosis or Diagnosis (TRIPOD) statement.[6,21]

Participants

We included consecutive participants with a suspicion of cervical nerve root involvement who were referred to a multidisciplinary clinic by their general practitioner or medical specialist. To be eligible to participate, patients had to be at least 18 years of age, and have sufficient knowledge of the Dutch language to complete the questionnaires. Participants with self-reported serious cervical pathology, multiple sclerosis, diabetes mellitus, chronic regional pain syndrome, polyneuropathy, or a history of spinal surgery were excluded.[29]

Predictors

Patient Interview Patients completed a list of interview items, such as the location and duration of symptoms, as well as provocative and reductive movements and postures. Out of 15 patient interview items, we selected all items that showed a sensitivity and/or specificity ≥0.80 as reported previously.[29] The patient interview items "Arm pain worse than neck pain," "Provocation of symptoms by ironing," "Reduction of symptoms by walking with hand in pocket," and patient-reported "Presence of paraesthesia" and "Presence of paraesthesia and/or numbness" were included in the analyses.

Clinical Examination A musculoskeletal physical therapist with >10 years of experience in diagnosing and treating patients with neck pain performed the clinical examination. The clinical tests were selected based on scientific literature.[14,31] Additionally, the tests had to be feasible and reflect a solid theoretical rationale. The Spurling test, Upper Limb Neurodynamic Test 1 (ULNT1) for the median nerve, the Cervical distraction test, and neurological tests (ie, sensation, reflexes and muscle tests) were included in the analyses.

Combined Model The patient interview items and clinical tests that were retained in their respective models, were included in the analyses for the combined model. Because of the sample size calculation, the number of predictors was limited to 6.

Reference Standard

The reference standard consisted of 2 criteria: (1) a neurosurgeon had to reach a clinical diagnosis of cervical nerve root involvement (ie, presence of radicular pain and/or numbness, muscle weakness or altered reflexes) independently from the patient interview and the clinical examination performed by the physical therapist and (2) the magnetic resonance imaging (MRI) scan had to show nerve root compression or irritation that concurred with the clinical diagnosis (ie, the same or adjacent level).[29]

Blinding

As the patient interview and clinical tests were performed before the reference standard, these were blinded for the reference test results. The MRI was conducted within 2 hours of the patient interview and clinical examination. The diagnosis by the medical specialist was obtained within 1.5 weeks after the patient interview, clinical examination, and MRI. The medical specialist and radiologist were blinded to the patient interview checklist and results of the clinical examination. The radiologist knew that the patients were suspected of having cervical nerve root involvement.[29] Participants did not receive treatment between the patient interview, the clinical examination, and the reference tests.[29]

Statistical Analyses

Missing Values Given that the amount of missing data was below 5% for all predictors, multiple imputation techniques were not required.[8,27]

Sample Size The required sample size was calculated to include a maximum of 6 predictors in each multivariable model using the 4 steps described by Riley et al.[26] We have determined what sample size would produce a precise estimate of the overall outcome risk (step 1), with a small mean error in the estimated outcome probabilities (step 2), a small amount of shrinkage (step 3) and a small optimism in the model fit (step 4). We assumed a prevalence of 30%, a shrinkage factor of 0.90, an estimated Cox-Schnell R-squared of 0.35 and an absolute margin of error of 0.1 around the overall outcome risk. As recommended for binary outcomes,[26] we used the online tool provided by van Smeden etal (https://mvansmeden.shinyapps.io/BeyondEPV) for step 2, with a root mean square percentage of 1.1. According to these criteria,

the largest required sample size was N = 135.

Diagnostic Models For each model, we performed a backward Wald selection procedure, in which the factor with the highest significance level was removed until all variables in the model were significantly related to the outcome ($P<.05$). The explained variance of the models was described in terms of the Nagelkerke R^2. The diagnostic accuracy was determined by the area under the curve (AUC). An AUC of 0.9 or higher was considered outstanding, 0.8 to 0.9 was excellent, 0.7 to 0.8 was acceptable, 0.5 to 0.7 was considered poor, and an AUC of 0.5 reflected no discriminatory value.[16]

The internal validity of the models was assessed through bootstrapping techniques with 250 repetitions. The regression coefficients were adjusted according to the shrinkage factor retrieved from the bootstrapping procedures. The models were internally validated in terms of the explained variance and the accuracy. The statistical analyses were performed in IBM SPSS (Version 28; IBM Corp, Armonk, NY, USA) and the bootstrap techniques in RStudio (Version 1.2.5042).

RESULTS

A total of 134 patients participated in the study, of whom 49% was diagnosed with cervical nerve root involvement (ie, radicular pain, radiculopathy, or both) according to the reference standard. The median duration of symptoms was 26 weeks (IQR: 13-104), the mean (standard deviation) age was 49.9 (10.7) years, and 51.5% was male.[29] **TABLE 1** describes the patient characteristics.

Missing Value Analyses

There were missing data for symptom duration in 1 participant (N = 1; 0.7%). Two predictors had missing data: Spurling test (N = 1; 0.7%) and ULNT1 (N = 4; 3.0%). Participants with missing data on predictors were excluded from analyses for the respective model(s).

Multivariable Logistic Regression Analyses

A description of the patient interview items and clinical tests that were retained in the models is provided in **TABLE 2.**

Patient Interview The final patient interview model contained the predictors "Arm pain worse than neck pain" (odds ratio [OR], 4.9; 95% CI: 2.2, 10.9) and patient-reported 'Presence of paraesthesia and/or numbness' (OR, 3.2; 95% CI: 1.2, 8.2), indicating that the presence of these 2 signs increased the likelihood of cervical nerve root involvement. The initial explained variance of this model was 0.25 and the AUC 0.74 (95% CI: 0.65, 0.82). After internal validation, the explained variance decreased slightly to 0.23, and the AUC remained 0.74 (95% CI: 0.66, 0.81) (see **TABLE 3**).

Clinical Tests The final clinical test model contained 2 tests: Spurling test (OR, 6.8; 95% CI: 2.8, 16.8) and the ULNT1 (OR, 2.3; 95% CI: 1.0, 5.3) indicating that a positive Spurling test and ULNT1 substantially increased the likelihood of cervical nerve root involvement. The initial explained variance of the clinical test model was 0.31 and the AUC 0.77 (95% CI: 0.69, 0.85). After bootstrapping procedures, the explained variance decreased slightly to 0.29, and the AUC remained 0.77 (95% CI: 0.69, 0.85) (see **TABLE 4**).

Combined Model The combined model contained 3 predictors: the Spurling test (OR, 8.0; 95% CI: 3.1, 20.4), "Arm pain worse than neck pain" (OR, 4.8; 95% CI: 1.9, 11.8), and patient-reported "Presence of paraesthesia and/or numbness" (OR, 2.8; 95% CI: 1.0, 7.8). The model initially showed an explained variance of 0.43, and an AUC of 0.82 (95% CI: 0.75, 0.90). After bootstrapping procedures, the explained variance decreased to 0.38 and the AUC remained 0.82 (95% CI: 0.75, 0.89) (see **TABLE 5**).

TABLE 1
Baseline Characteristics of Participants

	All Participants (N = 134)	Cervical Nerve Root Involvement (N = 66)	No Cervical Nerve Root Involvement (N = 68)
Number of males (%)	69 (51.5)	30 (45.5)	39 (57.4)
Age in years[a]	49.9 (10.7)	49.2 (8.9)	50.5 (12.2)
Duration of symptoms in weeks	26 (13-104)[b]	22 (9-92)	44 (13-106)[b]
Patient-reported symptoms (N (%))			
Paraesthesia	95 (70.9)	55 (83.3)	40 (58.8)
Numbness	73 (54.5)	42 (63.6)	31 (45.6)
Muscle weakness	78 (58.2)	41 (62.1)	37 (54.4)
Arm pain intensity (NPRS: 0-10)	6 (3-7)	7 (5-7.25)	6 (0.25-7)
Neck pain intensity (NPRS: 0-10)	6 (4-7)	5 (1-7)	7 (5-8)
Disability (NRS: 0-10)	5.5 (3-7)	5 (3-7)	6 (4-7)

Values are presented as median and interquartile range (IQR) for continuous data and as percentages for categorical data unless stated otherwise.
Abbreviations: NPRS, numeric pain-rating scale; NRS, numeric rating scale.
[a]*Data presented as mean (standard deviation).*
[b]*Value missing for N = 1.*

DISCUSSION

We aimed to determine the diagnostic value of 3 diagnostic models to diagnose nerve root involvement. The patient interview model and the clinical test model both showed adequate explained variance and diagnostic accuracy after internal validation. The diagnostic

TABLE 2
Description of Patient Interview Items and Clinical Tests That Were Retained in the Models

Patient Interview Item	Description
Arm pain worse than neck pain	Participants rated the intensity of their neck pain and arm pain over the last 24 hours on 2 separate Numeric Pain Rating Scales (0-10). If the arm pain intensity was higher than the neck pain intensity, this patient interview item was rated as positive.[29]
Patient-reported "Paraesthesia and/or numbness"	Participants reported the presence of tingling in their arm or hand (yes/no) and numbness in their arm or hand (yes/no) via 2 separate questions. If the participant indicated the presence of paraesthesia, numbness or both, this patient interview item was rated as positive.[29]
Clinical Test	**Description**
Spurling test	The participant was in a seated position. The examiner performed a passive, combined movement of the neck, consisting of extension, ipsilateral lateral flexion, and ipsilateral rotation toward the painful side. Overpressure was applied if no symptom provocation occurred with this movement. The test was rated as positive in case of symptom reproduction.[29,34]
Upper Limb Neurodynamic Test 1	The participant was in a supine lying position. The examiner consecutively (1) fixated the shoulder girdle in a neutral position to prevent shoulder girdle elevation, (2) placed the shoulder in 90-degree abduction, (3) placed the forearm in a supinated position, (4) extended the wrist and fingers, (5) externally rotated the shoulder, (6) extended the elbow, and (7) instructed the participant to perform contralateral and ipsilateral lateral flexion of the neck. The test was rated as positive if 2 conditions were met: (1) at least partial reproduction of symptoms and (2) changes in symptoms with structural differentiation (ie, increase of symptoms with cervical contralateral lateral flexion or decrease with ipsilateral lateral flexion).[22,29]

TABLE 3
Patient Interview Model (N = 134)

Predictor	OR (95% CI)	Sig	Beta Initial[a]	Beta Bootstrap[b,c]
Arm pain worse than neck pain	4.9 (2.2-10.9)	<0.001	1.590	1.542
Patient-reported "Paraesthesia and/or numbness"	3.2 (1.2-8.2)	0.016	1.159	1.124
Constant	0.22	0.001	−1.511	
Performance Measures	**Nagelkerke R^2**		**Area Under the Curve (95% CI)**	
Initial[a]	0.25		0.74 (0.65-0.82)	
Bootstrap[b]	0.23		0.74 (0.66-0.81)	

Abbreviations: CI, confidence interval; OR, odds ratio.
[a]Acquired from the initial analyses.
[b]Acquired from the bootstrapping procedure.
[c]Regression coefficients multiplied by the shrinkage factor of 0.97 (retrieved from the bootstrapping procedure).

accuracy of the clinical test model was slightly higher than that of the patient interview model. The combined model showed that a combination of the Spurling test and 2 patient interview items is the most useful to identify cervical nerve root involvement in participants suspected of having cervical radicular pain and/or radiculopathy. When including patient interview items and clinical tests in a combined model, the explained variance and diagnostic accuracy increased substantially, indicating the additional benefit of clinical tests to patient interview information in patients suspected of having cervical nerve root involvement. The diagnostic models reported in our study have been validated internally using bootstrapping procedures, to adjust for optimism in the models. The internal validation of the models showed a small shrinkage, indicating that the performance of the derived models adequately reflects the models' diagnostic value.

It is noteworthy that the performance and interpretation of the Spurling test and the ULNT1 vary considerably in the scientific literature and clinical practice.[1,33] Multiple versions of the Spurling test exist, in which varying combinations of neck movements are combined with compression.[1] In our study, the version that combines neck extension, ipsilateral lateral flexion, and ipsilateral rotation was used.[34] The ULNT1 also differs in literature, both in movement sequence and in positive test criteria.[33] A standardized test execution and interpretation of neurodynamic tests has long been advocated[4] and was recently reiterated following a systematic review.[33] In our study, reproduction of symptoms that can be altered with structural differentiation (ie, increase of symptoms with cervical contralateral lateral flexion or decrease with ipsilateral lateral flexion) was required for a positive test result.[22]

When developing a model, it is important to consider the intended use of the model.[21] For a diagnostic model, this means that the diagnostic accuracy should be determined in the individuals for whom the tests are intended, and participants in the study should therefore sufficiently resemble the patients these tests are used for in everyday clinical practice.[21] Participants in our study were recruited from a single multidisciplinary clinic that provides both specialist medical care and physical therapy treatment. This setting may have resulted in a somewhat higher

TABLE 4
Clinical Test Model (N = 129)

Predictor	OR (95% CI)	Sig	Beta Initial[a]	Beta Bootstrap[b,c]
Spurling test	6.8 (2.8-16.8)	<0.001	1.918	1.899
Upper Limb Neurodynamic Test 1	2.3 (1.0-5.3)	0.042	0.847	0.839
Constant	0.33	<0.001	−1.110	
Performance Measures	**Nagelkerke R^2**		**Area Under the Curve (95% CI)**	
Initial[a]	0.31		0.77 (0.69-0.85)	
Bootstrap[b]	0.29		0.77 (0.69-0.85)	

Participants with missing data on final predictors in model (N = 5) were excluded from the analyses.
Abbreviations: CI, confidence interval; OR, odds ratio.
[a]Acquired from the initial analyses.
[b]Acquired from the bootstrapping procedure.
[c]Regression coefficients multiplied by the shrinkage factor of 0.99 (retrieved from the bootstrapping procedure).

TABLE 5
Combined Model (N = 129)

Predictor	OR (95% CI)	Sig	Beta Initial[a]	Beta Bootstrap[b,c]
Spurling test	8.0 (3.1-20.4)	<0.001	2.073	1.886
Arm pain worse than neck pain	4.8 (1.9-11.8)	0.001	1.563	1.422
Patient-reported "Paraesthesia and/or numbness"	2.8 (1.0-7.8)	0.045	1.040	0.946
Constant	0.13	<0.001	−2.083	
Performance Measures	**Nagelkerke R^2**		**Area Under the Curve (95% CI)**	
Initial[a]	0.43		0.82 (0.75-0.90)	
Bootstrap[b]	0.38		0.82 (0.75-0.89)	

Participants with missing data on final predictors in model (N = 5) were excluded from the analyses.
Abbreviations: CI, confidence interval; OR, odds ratio.
[a]Acquired from the initial analyses.
[b]Acquired from the bootstrapping procedure.
[c]Regression coefficients multiplied by the shrinkage factor of 0.91 (retrieved from the bootstrapping procedure).

prevalence of cervical nerve root involvement compared to other primary care settings. However, we believe that the included patients are comparable to patients in other primary care settings, because of the selection criteria in our study. Regardless, external validation is needed to verify the results and support the clinical use of the models.

What reference standard to use is an important consideration in studies that aim to determine the diagnostic accuracy of patient interview items and/or clinical tests. Various reference standards and diagnostic criteria are used for the diagnosis of cervical nerve root involvement.[10,18,25] Common reference standards include (a combination of) medical imaging, needle electromyography, or clinical signs and symptoms.[10,30] Our reference standard was based on the presence of radicular pain, radiculopathy (ie, neurological deficits) or a combination thereof, if consistent with nerve root compression or irritation on MRI. As a result, cervical nerve root involvement was also considered to be present if a participant experienced radicular pain only, without neurological deficits, as long as the radicular pain concurred with MRI findings. As neurological deficits were not a requirement for a positive reference standard, these models were not specifically developed to diagnose radiculopathy in the sense of neurological deficits. This can explain why the neurological tests were not retained in the diagnostic models, as a neurological examination is aimed at assessing radiculopathy and not all participants experienced neurological deficits. Our results do not reflect the diagnostic abilities of neurological tests to assess cervical nerve root-related neurological deficits. These models are best suited to improve decision making on whether or not symptoms, be it radicular pain, radiculopathy or a combination, are likely due to cervical nerve root involvement. Further testing may then be required to differentiate radiculopathy from radicular pain.

While conservative management is initially indicated for most people with cervical nerve root involvement, reasons for early surgical treatment include severe pain, worsening neurological deficits, or signs of myelopathy, whereas delayed surgery is mainly considered in the case of continued pain or neurological deficits or when initial nonsurgical management is not successful.[2,5,7,9,15,24,35] Clinicians should therefore assess initial pain intensity levels and identify neurological deficits in people with cervical nerve root involvement, and monitor these symptoms in the course of musculoskeletal care.

CONCLUSION

We present 3 models to determine the likelihood of cervical nerve root involvement in clinical practice based on the patient interview and clinical examination. The diagnostic models all showed adequate diagnostic accuracy and explained variance to be useful to identify cervical nerve root involvement. A combination of 2 interview items and 1 clinical test showed a diagnostic value above 80% to determine the likelihood of cervical nerve root involvement. External validation of the models is indicated to verify the clinical usefulness before implementation. ■

KEY POINTS

FINDINGS: We developed and internally validated 3 diagnostic models for cervical nerve root involvement. The combined model contains the Spurling test and the interview items "Arm pain worse than neck pain" and patient-reported "Presence of paraesthesia and/or numbness," and has a diagnostic accuracy of 82% and an explained variance of 38%.

IMPLICATIONS: The diagnostic models can support physical therapists, general practitioners, and medical specialists in determining the likelihood of cervical nerve root involvement based on information from the patient interview and clinical examination.

CAUTION: External validation is needed to verify the clinical usefulness of the models.

STUDY DETAILS

AUTHOR CONTRIBUTIONS: M.S.K., M.C. and G.S.P. were responsible for the idea, conception and design of the study; R.E., S.R. and G.S.P. provided subjects, equipment and facilities; R.E. and S.R. acquired the data; M.S.K., M.C., M.H., and G.S.P. were involved in the analysis and interpretation of data; All authors were involved in the writing and reviewing of the manuscript; All authors approved the final version of the manuscript. No funds were acquired for this study.

DATA SHARING: The data analyzed during the current study are available from the corresponding author on reasonable request (g.g.m.scholten-peeters@vu.nl).

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