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Neurological examination for cervical radiculopathy: a scoping review

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Abstract

Background To diagnose cervical radiculopathy according to the International Association for the Study of Pain definition, signs of neurological deficits must be examined with the neurological examination. However, the diagnostic accuracy of the standard neurological examination remains unclear, and no clear recommendations exist about standard components. Therefore, the objectives of this review are to map the research about the diagnostic accuracy, components, and performance of the neurological examination for cervical radiculopathy.

Method PubMed, Embase, Scopus, Cinhal, DiTA databases were searched up to February 23rd, 2024. Additional studies were identified through screening reference lists of the included studies. Studies on neurological examination procedures and their diagnostic accuracy for cervical radiculopathy were included.

Results From an initial 12,365 records, 6 articles met the inclusion criteria. All articles were cross-sectional studies and compared the neurological examination with electrodiagnostic tests or magnetic resonance imaging. Reduced tendon reflexes were found to be most specific (81% (95% CI 69–89%) to 99% (95% CI not reported)), while somatosensation testing was least sensitive (25% (95% CI 12–38%; -LR 0.84) to 52% (95% CI 30–74%)). Taking all components into account resulted in higher specificity (98% (95% CI not reported) to 99% (95% CI 95–100%)) but lower sensitivity (7% (95% CI not reported) to 14% (95% CI 5–16%)) compared to electrodiagnostic tests.

Conclusions We found varying operational definitions of radiculopathy, suboptimal reference standards, and great heterogeneity in the neurological examination procedure and its diagnostic accuracy. Future research should address these issues to establish the clinical utility of the neurological examination for cervical radiculopathy.

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Key messages

What is already known about this topic According to the International Association for the Study of Pain, cervical radiculopathy is defined by neurological deficit which can be probed by a bedside neurological examination. Little is known about its diagnostic accuracy and procedure.

What does the study add There is heterogeneity in the neurological examination procedure, the reference standards (e.g., electrophysiology and diagnostic imaging), and its diagnostic accuracy. Components of the neurological examination for cervical radiculopathy have high specificity but low sensitivity.

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Introduction

Cervical radiculopathy (CR) is commonly encountered in clinical practice and poses a diagnostic challenge [1]. CR prevalence ranges from 1.07 to 1.76 per 1,000 for males and 0.63 to 5.8 per 1,000 for females [2]. The variation in prevalence is likely attributable to the differing diagnostic criteria, the geographical population location, and occupational features [2]. The understanding of CR is still limited and based on early studies, reporting a heterogeneity of pathomechanisms and various clinical presentations [3–5]. The definition of CR is not universally accepted among guidelines which commonly define CR by symptoms (e.g., pain or paraesthesia) radiating into the arm [3, 4, 6–8]. According to the International Association for the Study of Pain (IASP) definition, radiculopathies are not defined by pain/symptoms, but by loss of sensory and/or motor function due to action potential conduction slowing or block of a spinal nerve or its roots [9]. In contrast, pain and paraesthesia are indicative of gain of nerve function due to abnormal excitability and ectopic discharges of dorsal roots or dorsal root ganglia. Gain of function is caused by inflammation, ischaemia, or mechanical deformation and may manifest without radiculopathy (i.e., without loss of function) [9]. Therefore, they should not be considered as diagnostic criteria for CR [9, 10].

Despite the clear IASP definition of CR, a review observed that researchers and clinicians provide various definitions of CR and consistently use neck and/or arm pain as diagnostic/selection criteria in randomised controlled trials [5]. Furthermore, a recent review identified several classification systems for CR which varied among studies but have been summarised in nine diagnostic criteria including sensory, motor, and tendon reflex deficits, as well as neural mechanosensitivity testing (e.g., upper limb neurodynamic tests) and provocative neck manoeuvres (e.g., Spurling's test) [11]. Surprisingly, one recent review did not identify any studies using the bedside neurological examination (BNE) for diagnosing CR while other studies found little literature on distinct components of the BNE or mainly refer to provocative manoeuvres [4, 12–14]. Neural mechanosensitivity testing and provocative manoeuvres have no clinical use in identifying loss of nerve function, but are designed to detect predominantly gain of nerve function [1, 4, 15–19]. Among the clinical tests routinely used to identify loss of nerve function as per IASP recommendations [9], the BNE includes the assessment of peripheral sensory (light touch, pinprick, cold/worm) and motor responses (myotomal weakness and reduced tendon reflexes) and should thus represent the core clinical diagnostic criterion of CR [9, 20–27]. This absence of universally accepted diagnostic criteria for CR may lead to an increased risk of misdiagnosis and inappropriate treatment, resulting in delayed recovery and poor health outcomes [28–30]. Numerous researchers advocated the need to establish consensus regarding the diagnosis for this condition [2, 31, 32].

To date, no previous reviews systematically investigated the validity of the BNE for the diagnosis of CR. Therefore, establishing the diagnostic accuracy and the recommendation about standard components and performance of the BNE for CR is a priority for future research and practice [33]. In the absence of a large body of literature, we conducted a scoping review to identify and map the available evidence and analyse knowledge gaps on this concept [34]. We aimed to address the following questions: What is reported in the literature about the components and performance of the BNE for CR? What is the diagnostic accuracy (i.e., sensitivity, specificity, positive or negative likelihood ratio) of the BNE for CR?

Methods

Our scoping review was conducted following the framework of Arksey and O'Malley [35] and the extensions to the original framework recommended by the Joanna Briggs Institute methodology (JBI) for scoping reviews [36]. The PRISMA extension for Scoping Reviews Checklist was used for reporting [37]. A protocol was prospectively registered on medRxiv with the registration number 2023.05.22.23290194.

Eligibility criteria

We followed the framework of Population, Concept and Context (PCC):

- Population: patients with CR.
- Concept: studies reporting the diagnostic accuracy and performance of at least one component of the BNE for CR (i.e., somatosensation, motor, tendon reflex testing, and inspection for atrophies) [33].
- Context: studies conducted in any context.
- Type of evidence sources: cross–sectional studies, case–control studies, and randomized controlled trials (RCT) that aim to study the diagnostic accuracy of the BNE for CR [38]. Also, in line with the characteristics of a scoping review, we have included narrative syntheses, systematic reviews, and scoping reviews. No restrictions regarding time, location, language, or setting were applied [36].

Search strategy

A three-step approach was used.

1. A preliminary search in PubMed was undertaken to identify relevant articles and the shared terminology. We analysed all the terms reported to describe the three domains of PCC of interest. Variations of the terms were refined to create a second search strategy with search phrases and Medical Subject Headings (MeSH) terms. The initial search was used to develop a more comprehensive search strategy (Appendix 1).
2. A final comprehensive search (adapted for each database) was conducted on PubMed, Embase, Scopus, Cinhal, DiTA from inception to January 23rd, 2024.
3. Grey literature (e.g., Google Scholar) and the reference lists of included articles were searched manually through forward and backward citation tracking strategies (Web of Science) to identify any additional relevant studies.

The PRISMA literature search extension was used to report the search strategies [39].

Study selection and data charting process

Titles and abstracts to identify potentially eligible records were screened. Endnote (Clarivate Analytics, PA, USA) was used to remove duplicates. If a full text could not be retrieved, we contacted authors with a maximum of two attempts on a weekly basis. Subsequently, full texts were assessed for eligibility; any reasons for exclusions were recorded. We used the Rayyan platform for the selection process [40].

Data extraction was conducted using an ad-hoc data extraction form which was developed a priori, based on the JBI data extraction tool [41]. Extracted information included author(s), year of publication, study location, study population and size, aims of the study, study design, reference test to diagnose CR, nerve root level, details of the components of the BNE including information on its performance, diagnostic accuracy, and relevant results and considerations. Missing data was gathered by contacting the corresponding author with a maximum of two attempts on a weekly basis. in the absence of a reply, we calculated: sensitivity/specificity based on true/false positives and true/false negatives when reported; likelihood ratios (LR) using sensitivity/specificity values when reported. The entire selection and data extraction processes were performed independently by 2 blinded reviewers. Discrepancies were discussed with another reviewer.

Included studies were reported as frequency and percentage. A descriptive analysis was performed, and the results were presented numerically. Extracted data were summarized in tables. The performance and components of the BNE were reported narratively. Diagnostic accuracy (i.e., sensitivity/specificity, +/- LRs) was descriptively reported by ranges (lowest and highest values among studies) and grouped by reference standard.

Results

A total of 12,365 records were identified in the original searches, with four records added from backward citation searching, and 4,301 duplicates removed. A total of 8,064 records were screened for title and abstract, excluding 8,006 as unsuitable and removing an additional 6 records not retrieved. Of the remaining 52 full texts screened, 6 articles fulfilled the eligibility criteria and were included (Fig. 1). Authors of four studies [42–45] were contacted with two consecutive emails to retrieve diagnostic accuracy data, but no answers were received. Appendix 2 details reasons for exclusion.

Characteristics of the included studies

Table 1 summarizes the characteristics of the included studies. All studies were cross-sectional and written in English.

Examiners and BNE procedures

Participants with CR were included based on: a clinical suspicion (e.g., "neck and upper limb symptoms", "radicular complaints", or "signs and symptoms compatible with CR") in four studies (67%) [46–49]; a diagnosis provided by a consultant according to MRI [50] and EMG in two studies (33%) [12]. The BNE was performed by physicians (specialty not reported) in two studies (33%) [47, 48], neurophysiologists in one study (17%) [46], and by physiotherapists in three (50%) studies [12, 49, 50].

The reporting of the BNE procedure was poor and vague. Three studies (50%) did not detail the exact procedures nor any reference [12, 46–48]. Only one study reported a reference (Butler, 2000) for the BNE [50]. One study reported a reference (Viikari-Juntura, 1987) for one component (sensory) of the BNE [49]. Three studies (50%) provided information on how the three components of BNE were tested [12, 49, 50]. Table 2 summarizes the description of the BNE procedures.

Reference standards

The reference tests to diagnose CR were highly heterogeneous. Four studies (67%) aimed to investigate the diagnostic accuracy of BNE compared to needle EMG and motor and sensory nerve conduction study (NCS) [46–49], while two studies (33%) compared to MRI [12, 50].

Diagnostic accuracy

For one study we could only calculate sensitivity as solely true positive and false negative values were reported [50].

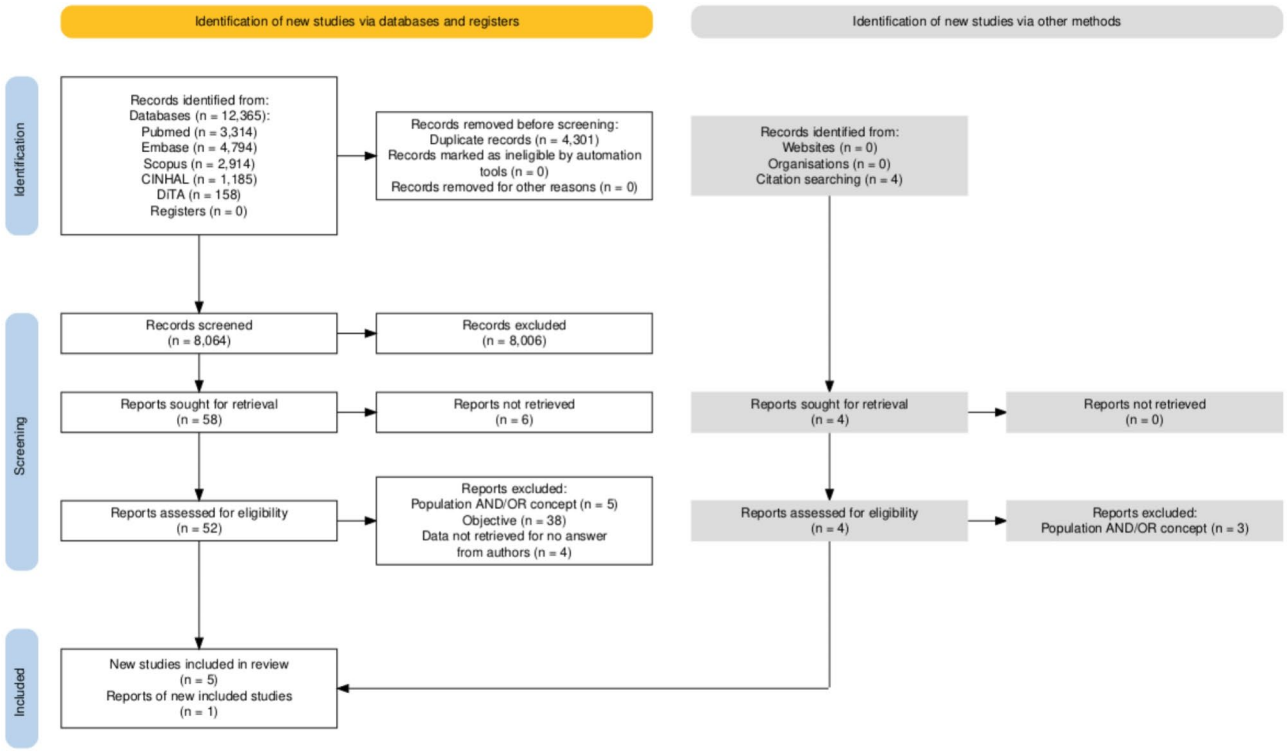

Fig. 1 Preferred reporting items for systematic review and meta-analyses (PRISMA 2020) flow diagram

Reflexes

Compared to EMG and NCS, the specificity of tendon reflex testing was reported to range between 94% (+LR 3.5) and 97% (95% CI 92–99; +LR 7.33). Sensitivity ranged between 21% (-LR 0.84) and 22% (95% CI 11–27%; -LR 0.80) [46, 48]. When compared to the representative root level, all tendon reflex testing was found highly specific: the Biceps Brachii (C5-6) ranges between 90% (95% CI NR; +LR 1.4) and 95% (95% CI 90–100%; +LR 4.9); the Brachioradialis (C5-7) ranges between 94% (95% CI NR; +LR 2.83) and 95% (95% CI 90–100%; +LR 1.2); the Triceps (C7) ranges between 92% (95% CI NR; +LR 1.75) and 95% (95% CI 87–99%; +LR 0.4) [48, 49]. When compared with any root level, specificity increases: 99% (95% CI NR; +LR 10) for the Biceps Brachii; 99% (95% CI NR; +LR 8) for the Brachioradialis; 99% (95% CI NR; +LR 2) for the Triceps [48].

Compared to MRI, the sensitivity was reported to range between 28% (95% CI 18–40%; -LR 0.85) and 67% (95% CI 43–85%) [12, 50], while specificity was reported at 81% (95% CI 69–89%; +LR 1.38) [12].

Overall, tendon reflex testing was found to have low sensitivity but high specificity (Table 3).

Somatosensation

Somatosensation includes thermoreception, mechanoreception, nociception, and proprioception [51]. Five studies (83%) investigated the diagnostic accuracy of somatosensation with heterogenous procedures among studies [12, 46, 48–50]. Somatosensation was mostly assessed within dermatomes using light touch ("soft brush and soft balls" [i.e., cotton wool]) and pinprick.

Compared to EMG and NCS, pinprick sensitivity ranges between 25% (95% CI 12–38%; -LR 0.84) and 38% (95% CI not reported [NR]; -LR 1.35) [46, 48]. Specificity ranges between 46% (95% CI not reported [NR]; +LR 0.7) and 89% (95% CI 0.83–0.95%; +LR 2.27) [46, 48]. C5 root testing was identified to be most sensitive (29%, 95% CI 8–51%: -LR 0.82) and C8 as the least sensitive (12%, 95% CI 0-0.27%; -LR 1.09). C5 root testing was most specific (86%, 95% CI 0.77–0.94%; +LR 2.10) while C6 was least specific (66%, 95% CI 0.54–0.78%; +LR 0.69) [49].

Compared to MRI, sensitivity of light touch testing ranged from 42% (95% CI 30–54%) to 52% (95% CI 30–74%) [12, 50]. When combined with pinprick, sensitivity increased to 67% (95% CI 43–85%) [50]. Specificity was reported at 72% (95% CI 59–82%) for both "soft brush and soft ball" testing, with +LR 1.56 and 1.42, respectively [12].

Overall, sensory testing was found to have low sensitivity but moderate specificity (Table 4).

Muscle function

Compared to EMG and NCS, muscle strength testing sensitivity ranged between 54% (95% CI 38–65%; -LR 0.49) and 73% (95% CI NR; -LR 0.44) [46, 48]. Specificity

Table 1 Characteristics of included studies

Author (year) Country	Sample size (gender, age)	Setting (period of recruitment)	Patient's description	Examiner	Index test (components)	Reference standard	Study design	Objective
Conradie (2006) South Africa	*N* = 21 Female = 11 Male = 10 Mean age = 47.86 (range 33–63)	Private medical practices. (not reported)	Referred by a neurosurgeon after the diagnosis of acute CR confirmed by MRI.	A physiotherapist blinded to the level(s) of nerve root involvement.	Neurological examination (muscle strength, tendon reflexes, sensation).	MRI	Cross-sectional	To determine the level(s) of nerve root involvement suggested by the distribution patterns of the clinical features and MRI and the most common associations between MRI and clinical findings in patients with acute CR.
Hassan (2013) Pakistan	*N* = 77 Female = 39 Male = 38 Mean age = 46.4 ± SD 14.6 (range 16–86)	Academic clinical neurophysiology laboratory. (ten-months period)	Patients with clinical suspicion of cervical o lumbosacral radiculopathy.	Two electromyography fellows.	Neurological examination (muscle strength, tendon reflexes, sensation).	Needle EMG and NCS (motor and sensory)	Cross-sectional	To identify clinical features that would accurately predict presence of radiculopathy on EMG.
Inal (2013) Turkey	*N* = 41 with cervical radiculopathy (total = 92). Female = 33 Male = 8 Mean age = 43.54 ± SD 10.43	Not reported.	Patients with radicular complaints in the upper extremity.	Neurological examination was performed by a blinded physician.	Neurological examination (muscle strength, tendon reflexes, sensation).	Needle EMG and NCS (motor and sensory)	Cross-sectional	To evaluate the relationship between neurological examination and ENMG findings in patients with suspected radiculopathies.
Lauder (2000) U.S.A.	*N* = 183 (96 CR, 45 normal studies, 42 abnormal electrodiagnostic findings other than radiculopathy) Female = 84 Male = 99 Mean age = 46 ± SD 10	Five different medical centers. (May 1996–September 1997)	All subjects with neck and upper-limb symptoms who were referred to the participating EDX laboratories to rule out the presence of CR by electrodiagnosis were asked to participate.	Faculty certified by the American Board of Electrodiagnostic Medicine or their supervised resident physician.	Neurological examination (muscle strength, tendon reflexes, sensation).	Needle EMG and NCS (motor and sensory)	Cross-sectional	To determine the effectiveness of medical history and physical examination in predicting electrodiagnostic outcome in patients with suspected CR.
Sleijser-Koehorst, (2021) Netherlands	*N* = 134 Female = 65 Male = 69 Mean age = 49.9 ± SD 10.7	Multidisciplinary clinic. (not reported)	Patients with a suspicious of CR.	All clinical tests were performed by an experienced musculoskeletal physiotherapist.	Neurological examination (muscle strength, tendon reflexes, sensation).	MRI	Cross-sectional	To determine the diagnostic accuracy of patient interview items and clinical test to diagnose CR.
Wainner (2003) U.S.A.	*N* = 82 Female = 41 Male = 41 Mean age = 45 ± SD 12 (range 18–70)	Four medical facilities. (December 1998–April 2000)	Patients with suspected CR.	Two physiotherapists blinded to the subjects' suspected diagnosis.	Neurological examination (muscle strength, tendon reflexes, sensation).	Needle EMG and NCS (motor and sensory)	Cross-sectional	To assess the reliability and accuracy of individual clinical examination items and self-report instruments (VAS and NDI) for the diagnosis of CR.

CR = cervical radiculopathy; MRI = magnetic resonance imaging; EMG = electromyography; NCS = nerve conduction study; VAS = Visual analogue scale; NDI = neck disability index

varied between 61% (95% CI NR; +LR 1.87) and 93% (95% CI 85–97%; +LR 7.71) [46, 48]. The highest sensitivity (24%, 95% CI 3–44%) was found for the muscle strength testing of the Biceps Brachii (-LR 0.82) and Deltoid muscles (-LR 0.86), while the lowest sensitivity (3%, 95% CI 0–10%) was reported for the first dorsal interossei (-LR 1.05). Higher specificity (94%, 95% CI 88–100%) was reported for the Biceps Brachii (+LR 3.7) and Triceps Brachii (+LR 1.9), while the lowest specificity (84%, 95% CI 75–93%) was reported for the Abductor Pollicis Brevis (+LR 0.37) [49].

Compared to MRI, specificity was found 72% (95% CI 60–82%; +LR 1.05) [12]. Sensitivity ranged between 30% (95% CI 20–43%; -LR 0.94) and 81% (95% CI 58–95%) [12, 50].

Overall, muscle strength testing was found to have low to moderate sensitivity but moderate to high specificity (Table 5).

Atrophy

None of the identified studies reported on atrophies.

Combined testing

Two studies (33%) investigated various combinations of two components of the BNE [46, 48], while four studies (67%) reported the diagnostic accuracy of the full BNE (i.e., all the three components) [46–48, 50]. Compared to EMG and NCS, single components were reported to have a sensitivity of 84% (95% CI NR; -LR 0.52) and a specificity of 31% (95% CI NR; +LR 1.22) [48]. The combination of two components of the BNE was reported to have low sensitivity (ranges between 9% [95% CI NR; -LR 0.94] and 27% [95% CI NR; -LR 0.99]) but high specificity (ranges between 74% [95% CI NR; +LR 1.04] and 99% [95% CI 94–100%; +LR 14–22]) [46, 48]. The higher specificity of 99% was reported with the combination of tendon reflex deficit and sensory loss or muscle weakness (95% CI 94–100%) [46]. These combinations may be used to increase the post-test probability of CR (+LR 14 and 22, respectively) [46]. The specificity of the full BNE (three components) ranges between 28% (95% CI 13–47%; +LR 1.15) and 99% (95% CI 95–100%; +LR 14), while sensitivity ranges between 7% (95% CI NR; -LR 0.95) and 83% (95% CI 52–98%; -LR 0.61) [46–48]. Compared to MRI, the full BNE was reported to have high sensitivity 91% (95% CI 70–99%: -LR NR) [50]. Accuracy of combined components testing is summarized in Table 6.

Discussion

Our scoping review found poor and vague reporting of the BNE procedure for CR. There was a heterogeneous performance of the BNE (e.g., key muscles for muscle strength testing, and representative root level for tendon reflex testing), with only three studies providing information on how the three components of the BNE (sensation, strength, tendon reflexes) were performed [12, 49, 50]. Reference standards for CR used in the included studies were electrodiagnostic tests or MRI, the limitations of which are discussed below. While there was large variation among studies, reduced tendon reflexes were found to be most specific, with sensory testing least specific. All components had low sensitivity. The combination of the BNE components resulted in higher specificity but lower sensitivity.

Even though a BNE is essential to diagnose a radiculopathy and to impact its management, we identified only few studies with heterogeneous results that assess the diagnostic accuracy. When considered in its entirety rather than single tests in isolation, the standard BNE had high specificity but low sensitivity and a positive finding may thus be interpreted to moderately increase the post-test probability of a CR rather than ruling-out the condition [52]. Reduced tendon reflexes were the most specific component, while muscle and somatosensation testing was least sensitive. Our findings are aligned with the notion that, like atrophy, reflexes are not influenced by pain or the patient's interpretation which may make them more objective [33]. Notably, although inspection for atrophies is part of a BNE none of the included studies reported on atrophies. On the other hand, sensory changes may be impacted by variability among dermatomal maps [53–55] and significant overlap and variations across individuals [3, 56]. Albeit also highly variable, myotomal strength testing seems to be of greater value among the BNE components in determining the pathological level [57]. Of note though, the reliance on motor rather than sensory function in some reference standards (e.g., EMG) may bias results towards the motor components [3].

Our results should be considered cautiously as many factors may influence their interpretation. The lack of a gold standard in primary diagnostic accuracy studies is the main limitation in determining BNE diagnostic accuracy (i.e., sensitivity/specificity, +/- LRs). The included studies used different reference standards and often lack in reporting all relevant diagnostic accuracy data, which can influence results [28]. Study participants were recruited through different methods and diagnostic criteria, potentially influencing our findings. As an example, differing from other studies, Lauder et al. also recruited subjects presenting neck and arm pain, but used electrophysiology to define the CR group. This may have influenced their higher sensitivity but lower specificity findings for muscle strength which contrasts with other studies [48].

Our scoping review clearly corroborates that the main challenge associated with a diagnosis of CR relates to the lack of a universally accepted definition, diagnostic

Table 2 Bedside neurologic examination procedures. NR = Not reported

Author (year) Country	Index tests	Nerve Root	Muscle function	Tendon reflexes	Somatosensation
Conradie (2006) South Africa	*"A standardized interview and a neurological examination as described by Butler (2000). (…) The neurologic examination consisted of skin sensation (light touch, superficial pain, hot and cold detection threshold), deep sensation (pain, proprioception and vibration), muscle function (muscle atrophy, tremors and/or fasciculation, muscle strength, and functional tests), and deep tendon reflexes (spinal reflexes, superficial skin reflexes and Central Nervous System reflexes). (…) Findings of the neurologic examination were graded as either normal or altered in comparison to the opposite extremity."*	C5	Shoulder abduction	Biceps	Deltoid, lateral upper, radial forearm but not into hand
		C6	Elbow flexion	Biceps	Radial forearm thumb
		C7	Elbow extension	Triceps	Posterior forearm middle finger
		C8	Thumb extension	Triceps	Ulnar forearm little finger
Hassan (2013) Pakistan	*"All patients underwent a complete history, general physical examination, and neurological examination. (…) Dermatomal sensory loss was defined as reduced pinprick sensation that maps to a dermatomal distribution, ipsilateral to the symptomatic side. Segmental reflex loss was defined as a deep-tendon reflex response ipsilateral to the symptomatic side that was either absent, or asymmetrically reduced compared with the opposite side. Myotomal weakness was defined as any detectable weakness in a myotomal distribution, ipsilateral to the symptomatic side."*	NR	NR	NR	NR
Inal (2013) Turkey	"Motor, sensory and deep tendon reflexes and pathological reflexes were tested. (…) *Sensory loss was recorded according to the dermatomes. Results of physical examination was recorded as normal or abnormal. Hypoestesia, motor weakness and asymmetry of deep tendon reflexes were accepted as signs of positive of physical examination for a radiculopathy. "*	NR	NR	NR	NR
Lauder (2000) U.S.A.	*"The three physical examination findings evaluated were sensation (vibration and pinprick), reflexes (biceps, brachioradialis, and triceps), and weakness by manual muscle testing. (…) Each parameter was recorded as a binary variable (normal/abnormal). Sensation was recorded as abnormal when either vibration or pinprick was reduced on the side of the lesion. The distribution of the sensory loss was also noted. Reflexes were recorded as abnormal when a reflex on the side of the lesion was reduced compared with the same reflex on the opposite side. Weakness was described as any muscle with a manual muscle grading of less than 5/5 (normal) on the side of the lesion."*	NR	NR	NR	NR
Sleijser-Koehorst, (2021) Netherlands	*"The clinical examination consisted of (…) and a clinical neurological examination (sensation, reflexes and muscle tests). (…) A soft cotton ball and Somedic soft brush was swept gently along the skin three times at the most painful dermatomal area, and compared with the corresponding area on the other side. This test was considered positive if there was hypoesthaesia in the most painful site. Biceps and triceps tendon reflexes were tested in a seated position according to a previously published protocol. This test was considered positive if one or both tendon reflexes were reduced. Muscle strength test was considered positive if one or more of these muscles showed reduced strength."*	C6	Biceps	Any	Any
		C7	Triceps		
		C8	Adductor pollicis Abductor digiti minmi		
		T1	Interossei palmaris		
Wainner (2003) U.S.A.	*"All manual muscle testing was conducted using the methods of Kendall and McCreary. Each muscle test was graded as markedly reduced, reduced, or normal, as compared with the uninvolved extremity. (…) Muscle stretch reflexes were tested bilaterally using a standard reflex hammer. Each reflex was graded as absent/reduced, normal, or increased, as compared with the uninvolved extremity. Pin-prick sensation testing was performed for the cervical dermatomes (C5–C8) by touching the skin in a key area for each respective sensory level with a paper clip, which was discarded after testing. Each sensory level was graded as reduced, normal, or increased."*	C5	Deltoid	Biceps Brachioradialis	Cervical dermatomes (C5–C8) by touching the skin in a key area according to Viikari-Juntura E., 1987
		C6	Biceps, Wrist extensor	Brachioradialis Biceps	
		C7	Triceps Wrist flexors	Triceps	
		C8	Abductor pollicus brevis		
		T1	Dorsal interossei		

Table 3 Diagnostic accuracy of tendon reflex testing to detect cervical radiculopathy

Author (year)	Cervical radiculopathy diagnostic criteria	Reference standard	nerve root level/dermatomal territory	Index test	Sensitivity (95% CI)	Specificity (95% CI)	+ LR	- LR
Hassan (2013)	clinical suspicion	Needle EMG and NCS (motor and sensory)	NA	Tendon reflex testing	22 (11–27)	97 (92–99)	7.33	0.80
Lauder (2000)	neck and upper-limb symptoms, confirmed by EDX	Needle EMG and NCS (motor and sensory)	NA	Tendon reflex testing (biceps, triceps, or brachioradialis)	21 (NR)	94 (NR)	3.5	0.84
			Any level	Biceps	10 (NR)	99 (NR)	10	0.91
			C5-6	Biceps	14 (NR)	90 (NR)	1.4	0.96
			Any level	Triceps	10 (NR)	95 (NR)	2	0.95
			C7	Triceps	14 (NR)	92 (NR)	1.75	0.93
			Any level	Brachioradialis	8 (NR)	99 (NR)	8	0.93
			C6-C7	Brachioradialis	17 (NR)	94 (NR)	2.83	0.88
Wainner (2003)	clinical suspicion	Needle EMG and NCS (motor and sensory)	C5-6	Biceps brachii	24 (3–44)	95 (90–100)	4.9	0.80
			C5-6	Brachioradialis	6 (0–17)	95 (90–100)	1.2	0.99
			C7	Triceps	3 (0–10)	93 (87–99)	0.4	1.05
Sleijser-Koehorst (2021)	clinical suspicion	MRI	NA	Tendon reflex testing	28 (18–40)	81 (69–89)	1.38	0.85
Conradie (2006)	Diagnosis of CR confirmed by MRI	MRI	NA	Tendon reflex testing	67 (43–85)			

+ LR = positive likelihood ratio; -LR = negative likelihood ratio; 95% CI = 95% confidence interval; EMG = electromyography; NCS = nerve conduction study; MRI = magnetic resonance imaging; CR = Cervical Radiculopathy; NR = Not Reported; NA = Not Applicable

Table 4 Diagnostic accuracy of sensory testing to detect cervical radiculopathy

Author (year)	Cervical radiculopathy diagnostic criteria	Reference standard	nerve root level/dermatomal territory	Index test	Sensitivity (95% CI)	Specificity (95% CI)	+ LR	- LR
Hassan (2013)	clinical suspicion	Needle EMG and NCS (motor and sensory)	NA	Dermatomal testing (pinprick)	25 (12–38)	89 (83–95)	2.27	0.84
Lauder (2000)	neck and upper-limb symptoms, confirmed by EDX	Needle EMG and NCS (motor and sensory)	NA	Dermatomal testing (vibration or pinprick)	38 (NR)	46 (NR)	0.7	1.35
Wainner (2003)	clinical suspicion	Needle EMG and NCS (motor and sensory)	C5	Dermatomal testing (papertip-like pinprick)	29 (8–51)	86 (77–94)	2.1	0.82
			C6	Dermatomal testing (papertip-like pinprick)	24 (3–44)	66 (54–78)	0.69	1.16
			C7	Dermatomal testing (papertip-like pinprick)	18 (0–36)	77 (66–87)	0.76	1.07
			C8	Dermatomal testing (papertip-like pinprick)	12 (0–27)	81 (71–90)	0.61	1.09
Sleijser-Koehorst (2021)	clinical suspicion	MRI	NA	Dermatomal testing (soft ball)	44 (32–57)	72 (59–82)	1.56	0.78
				Dermatomal testing (soft brush)	42 (30–54)	72 (59–82)	1.42	0.79
Conradie (2006)	diagnosis of CR confirmed by MRI	MRI	NA	Light touch	52 (30–74)			
				Superficial pain	62 (38–82)			
				Sensory combined	67 (43–85)			

+ LR = positive likelihood ratio; -LR = negative likelihood ratio; 95% CI = 95% confidence interval; EMG = electromyography; NCS = nerve conduction study; MRI = magnetic resonance imaging; CR = Cervical Radiculopathy; NR = Not Reported; NA = Not Applicable

criteria, and a valid reference standard [3]. According to the IASP definition, radiculopathy is defined by the presence of loss of nerve function signs rather than pain, and it may occur in isolation or in association with radicular pain [9, 20]. However, most of the included studies based their diagnosis of CR on the presence of spine related arm pain [12, 46–48, 50]. Further, not all reference standards used in the included studies (e.g., MRI) [12, 50] assess

Table 5 Diagnostic accuracy of muscle function testing to detect cervical radiculopathy

Author (year)	Cervical radiculopathy diagnostic criteria	Reference standard	nerve root level/dermatomal territory	Index test	Sensitivity (95% CI)	Specificity (95% CI)	+ LR	- LR
Hassan (2013)	Clinical suspicion	Needle EMG and NCS (motor and sensory)	NA	Muscle function testing	54 (38–65)	93 (85–97)	7.71	0.49
Lauder (2000)	Neck and upper-limb symptoms, confirmed by EDX	Needle EMG and NCS (motor and sensory)	NA	Muscle function testing	73 (NR)	61 (NR)	1.87	0.44
Wainner (2003)	Clinical suspicion	Needle EMG and NCS (motor and sensory)	C5	Deltoid	24 (3–44)	89 (81–97)	2.1	0.86
			C6	Biceps brachii	24 (3–44)	94 (88–100)	3.7	0.82
			C7	Extensor carpi radialis longus/brevis	12 (0–27)	90 (83–98)	1.2	0.98
			C7	MMT triceps brachii	12 (0–27)	94 (88–100)	1.9	0.94
			C8	Flexor carpi radialis	6 (0–17)	89 (82–97)	0.55	1.05
			T1	Abductor pollicus brevis	6 (0–17)	84 (75–93)	0.37	1.12
			T1	First dorsal interosseus	3 (0–10)	93 (87–99)	0.40	1.05
Sleijser-Koehorst (2021)	Clinical suspicion	MRI	NA	Muscle function testing	30 (20–43)	72 (60–82)	1.05	0.94
Conradie (2006)	Diagnosis of CR confirmed by MRI	MRI	NA	Muscle function testing	81 (58–95)			

+ LR = positive likelihood ratio; -LR = negative likelihood ratio; 95% CI = 95% confidence interval; EMG = electromyography; NCS = nerve conduction study; MRI = magnetic resonance imaging; CR = Cervical Radiculopathy; NR = Not Reported; NA = Not Applicable

Table 6 Diagnostic accuracy of combined components of the bedside neurological examination to detect cervical radiculopathy

Author (year)	Cervical radiculopathy diagnostic criteria	Reference standard	nerve root level/dermatomal territory	Index test	Sensitivity (95% CI)	Specificity (95% CI)	+ LR	- LR
Hassan (2013)	clinical suspicion	Needle EMG and NCS (motor and sensory)	NA	*Combination of 2 components*				
				Sensory loss & tendon reflex loss	14 (5–16)	99 (94–100)	14	0.87
				Sensory loss & weakness	21 (9–28)	96 (91–99)	5.25	0.82
				Tendon reflex loss & weakness	22 (11–24)	99 (94–100)	22	0.79
				Full neurological examination	14 (5–16)	99 (95–100)	14	0.87
Lauder (2000)	neck and upper-limb symptoms, confirmed by EDX	Needle EMG and NCS (motor and sensory)	NA	*Combination of 2 components*				
				Sensory loss & tendon reflex loss	9 (NR)	97 (NR)	3	0.94
				Sensory loss & weakness	27 (NR)	74 (NR)	1.04	0.99
				Tendon reflex loss & weakness	18 (NR)	98 (NR)	9	0.84
				Full neurological examination	7 (NR)	98 (NR)	3.5	0.95
				Any components	84 (NR)	31 (NR)	1.22	0.52
Inal (2013)	Clinical suspicion	Needle EMG and NCS (motor and sensory)	NA	*Full neurological examination*	83 (52–98)	28 (13–47)	1.15	0.61
Conradie (2006)	Diagnosis of CR confirmed by MRI	MRI	NA	*Full neurological examination*	91 (70–99)			

+ LR = positive likelihood ratio; -LR = negative likelihood ratio; 95% CI = 95% confidence interval; EMG = electromyography; NCS = nerve conduction study; MRI = magnetic resonance imaging; CR = Cervical Radiculopathy; NR = Not Reported; NA = Not Applicable

loss of function signs which are hallmarks of CR [9]. Our findings are substantiated by a heavy focus on radicular symptoms rather than radiculopathy in diagnostic criteria among guidelines [4–8]. This inconsistency of terminology and diagnostic criteria may limit the efficacy and the replicability of CR diagnosis and care [5, 9].

Current diagnostic imaging can only detect macrostructural nerve root compromise (e.g., compression, flattening, or displacement) which does not necessarily reflect neural function such as examined by the BNE [58]. False negatives and positives in detecting nerve root compromise at the involved level when cervical or lumbar radiculopathy is suspected occur rather frequently [4, 59, 60]. Furthermore, MRI findings may be affected by patient's position during imaging for both the lumbar and cervical spine [61, 62]. Higher incidences of nerve root compression in standing compared to lying and a range of disk deformation depending on the spine position were observed [61, 62].

Electrophysiology is also commonly used as a reference test. Electrophysiology depends on the operator and different methods and normative values are used [63]. These tests exclusively examine large-myelinated fibers (i.e., a-β and motor fibers) but cannot provide information on small fiber compromise [3]. Furthermore, EMG does not evaluate sensory fibres and may not detect demyelinating lesions [63]. The North American Spine Society clinical guideline reported insufficient evidence to recommend in favor or against the use of electrophysiology testing to diagnose CR, yet these were used as reference standards in some studies [64].

Another approach that has been used in a recent retrospective study as a reference standard for correct identification of affected nerve root is 'benefit from surgery' [57] defined as at least 60% symptom relief and/or myotomal muscle recovery of at least 1 grade on the MRC scale. In this study, myotomal strength tests showed 48–100% accuracy to determine the correct nerve root level. Of note, severe motor deficits (MRC scale ≤3) were much more predictive of actual nerve root level. Unfortunately however, this study did not determine diagnostic accuracy of the BNE for CR as determined by the presence or absence of 'surgical benefit'. While 'surgical benefit' as a reference standard for CR is intriguing, myotomal improvements may also be driven by pain reduction rather than true loss of function recovery [65]. Importantly, the absence of such improvements does not necessarily rule out CR, particularly in cases of extensive, non-recoverable axonal loss.

Notably, the standard BNE should consist of the examination of muscle function, tendon reflexes, and somatosensation of the large (light touch) and small (cold/warm and pin-prick) fibres [33]. However, there is a lack of evidence on strict rules to perform a valid and reliable BNE [28]. We found that the description of the components of the BNE is often vague. Key muscles, tendon reflexes, and sensory testing were non-consistent across the included studies with only two studies reporting small fiber testing by pinprick loss of function [46, 48]. Small nerve fibers are commonly affected in peripheral entrapment neuropathies and may even precede large fiber changes [1, 66]. Even though evidence is currently sparse, neurobiologically small fiber testing should be an integral component of a BNE in the diagnosis of CR [1, 66].

In line with our findings, there is a paucity of studies on the diagnostic accuracy of BNE and limitations regarding the reference standard for lumbar radiculopathy [28, 67]. In a recent systematic review, Tawa et al. investigated the diagnostic accuracy of the BNE for lumbar radiculopathy, with MRI being the most used reference standard. Similarly, they found a sensitivity of 0.61 (95% CI 0.47–0.73) and a specificity of 0.63 (95% CI 0.38–0.84) for sensory testing. Muscle strength testing sensitivity ranged from 0.13 (95% CI 0.04–0.31) to 0.61 (95% CI 0.36–0.83). Tendon reflex testing demonstrated higher specificity, ranging from 0.60 (0.51–0.69) to 0.93 (0.87–0.97), with a sensitivity ranging from 0.14 (95% CI 0.09–0.21) to 0.67 (95% CI 0.21–0.94) [28]. Additional primary studies assessing the accuracy of the BNE for CR are needed.

Strengths and limitations

Answering evidence gap To our knowledge, this is the first study to map and summarize the literature regarding the diagnostic accuracy of BNE for CR. We identified inconsistencies in terminology, diagnostic criteria, references standards, and BNE procedures. Future primary studies should be conducted with a rigorous methodology and with a valid and reliable reference standard.

Highlighting key challenges It is recommended to conduct further primary studies (i.e., cross-sectional studies). These studies should provide detailed reporting on the specific BNE procedures to improve the consistency and replicability in both clinical practice and future studies.

Clinical practice As this was a scoping and not a systematic review due to the paucity and heterogeneity evidence [36], the methodological quality of the individual studies was not evaluated. Hence, a conclusive recommendation cannot be made about the diagnostic accuracy of the BNE in the context of CR. However, our results provide a comprehensive overview on the diagnostic accuracy of the BNE for CR.

Limitations To date, true blinded diagnostic accuracy study designs of BNE in patients with CR are still largely lacking. This scoping review however identified important study limitations (e.g., limited sample sizes) and signifi-

cant heterogeneity that prevent a solid systematic review and meta-analysis.

Conclusion

The BNE remains a vital component of the initial diagnostic work-up of patients with suspected radiculopathy. Despite the limitations of lack of diagnostic criteria and reference standards, components of the BNE have high specificity but low sensitivity. To improve the reported accuracy, a common ground must be reached for the operational definition of radiculopathy, its reference standard, and the optimal performance of the BNE. This would ultimately help researchers and clinicians to establish the clinical utility of the BNE.

Supplementary information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Author contributions

Concept/idea/research design: FM, MSY, DF. Acquisition of data: MSY, GO, FB, DF, and FM. Analysis and interpretation of data: FM, DF, and MSY. Writing/review/editing of manuscript: FM, GO, FB, DF, MSY, ABS. FM is the guarantor. All authors reviewed and accepted the final manuscript.

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Data availability

All data relevant to the study are included in the article or are available as supplementary files.

Declarations

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Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Clinical trial number

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