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Review Article

Neurological examination of the peripheral nervous system to diagnose lumbar spinal disc herniation with suspected radiculopathy: a systematic review and meta-analysis

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Abstract

BACKGROUND CONTEXT: Disc herniation is a common low back pain (LBP) disorder, and several clinical test procedures are routinely employed in its diagnosis. The neurological examination that assesses sensory neuron and motor responses has historically played a role in the differential diagnosis of disc herniation, particularly when radiculopathy is suspected; however, the diagnostic ability of this examination has not been explicitly investigated.

PURPOSE: To review the scientific literature to evaluate the diagnostic accuracy of the neurological examination to detect lumbar disc herniation with suspected radiculopathy.

STUDY DESIGN: A systematic review and meta-analysis of the literature.

METHODS: Six major electronic databases were searched with no date or language restrictions for relevant articles up until March 2011. All diagnostic studies investigating neurological impairments in LBP patients because of lumbar disc herniation were assessed for possible inclusion. Retrieved studies were individually evaluated and assessed for quality using the Quality Assessment of Diagnostic Accuracy Studies tool, and where appropriate, a meta-analysis was performed.

RESULTS: A total of 14 studies that investigated three standard neurological examination components, sensory, motor, and reflexes, met the study criteria and were included. Eight distinct meta-analyses were performed that compared the findings of the neurological examination with the reference standard results from surgery, radiology (magnetic resonance imaging, computed tomography, and myelography), and radiological findings at specific lumbar levels of disc herniation. Pooled data for sensory testing demonstrated low diagnostic sensitivity for surgically (0.40) and radiologically (0.32) confirmed disc herniation, and identification of a specific level of disc herniation (0.35), with moderate specificity achieved for all the three reference standards (0.59, 0.72, and 0.64, respectively). Motor testing for paresis demonstrated similarly low pooled diagnostic sensitivities (0.22 and 0.40) and moderate specificity values (0.79 and 0.62) for surgically and radiologically determined disc herniation, whereas motor testing for muscle atrophy resulted in a pooled sensitivity of 0.31 and the specificity was 0.76 for surgically determined disc herniation. For reflex testing, the pooled sensitivities for surgically and radiologically confirmed levels of disc herniation were 0.29 and 0.25, whereas the specificity values were 0.78 and 0.75, respectively. The pooled positive likelihood ratios for all neurological examination components ranged between 1.02 and 1.26.

CONCLUSIONS: This systematic review and meta-analysis demonstrate that neurological testing procedures have limited overall diagnostic accuracy in detecting disc herniation with suspected radiculopathy. Pooled diagnostic accuracy values of the tests were poor, whereby all tests demonstrated low sensitivity, moderate specificity, and limited diagnostic accuracy independent of the disc herniation reference standard or the specific level of herniation. The lack of a standardized classification criterion for disc herniation, the variable psychometric properties of the testing procedures, and

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the complex pathoetiology of lumbar disc herniation with radiculopathy are suggested as possible reasons for these findings.

Keywords: Neurological examination; Lumbar disc herniation; Diagnosis; Accuracy; Radiculopathy

Introduction

Disc herniation is one of the more common diagnosed low back pain (LBP) disorders affecting a large proportion of the adult population [1–3]. The prevalence of disc herniation reported in the literature within specific LBP populations demonstrates considerable variability, ranging from 0% to 47% [4]. Although disc herniation has been observed in both symptomatic and asymptomatic individuals [4], it is more likely to be symptomatic between the ages of 40 and 45 years [5], with the reported incidence of observed disc herniation increasing with age [6] as a result of progressive degenerative changes occurring within the lumbar intervertebral disc [3,4,6–8]. Several structures may be involved in generating LBP symptoms caused by a herniated disc, which makes it challenging for clinicians to identify the exact source of pain [9]. Although the complete pathophysiological response to disc herniation can vary among people, it is accepted that neural structures surrounding the disc can become compressed and/or mechanically irritated and the resultant chemical inflammation [10] can potentially result in radicular pain and subsequent radiculopathy [3,11] that is defined as an objective loss of sensory and/or motor function because of a conduction block in axons of a spinal nerve or its roots [12,13].

Radiographic procedures are considered as the reliable reference standards in the diagnosis of disc herniation and are mainly used in primary care settings [14]. Both magnetic resonance imaging and computed tomography imaging techniques demonstrate moderate-to-high sensitivity (0.6 to 1.0) and specificity (0.43 to 0.97) in detecting disc herniation in patients with nerve root involvement [14]. Surgical findings have also been used to confirm the diagnosis of a disc herniation [15,16]; however, as surgery is usually indicated based on the positive signs during physical assessment procedures, a risk of verification bias may occur as a result of not applying the reference standard to patients with a negative test result [17].

The patient's history, supplemented by a well-structured physical examination, is considered essential in the assessment and diagnosis of lumbar disc herniation. Such examination involves ruling out serious pathological conditions, differentiating the possible source of the pain, and determining the potential presence of a deficit in spinal nerve or peripheral nerve conductivity [3,18] through the neurological evaluation of motor, sensory, and deep tendon reflex functions [18]. The neurological examination is considered capable of detecting the level of nerve root involvement [19] via testing the conductivity of specific spinal nerve roots; however, it is acknowledged that specific dermatomes and/or myotomes can be innervated by more than one nerve root [18]. The standardized neurological examination procedure involves three components: sensory testing that assesses for dermatomal distribution of skin sensation and pain perception [20]; evaluation of motor function including muscle power, wasting, weakness, or assessment of paresis [21]; and evaluation and grading of deep tendon reflex response [22]. The neurological examination has been shown to have moderate reliability in patients with suspected disc herniation [23,24], with reliability being a function of both the standardization of procedures [24] and the application of multiple testing procedures [23].

Although previous reviews have been conducted to evaluate the accuracy of clinical testing procedures to diagnose lumbar disc herniation [17,25–28], the majority of these reviews did not evaluate the neurological tests independently or specifically perform a meta-analysis. Moreover, no study to date has evaluated the accuracy of the neurological tests to detect disc herniation at specific segmental lumbar spine levels. Therefore, the aim of this study was to systematically review the literature, applying meta-analysis procedures where appropriate, to determine the diagnostic accuracy of specific neurological examination procedures to detect a lumbar disc herniation in patients with suspected radiculopathy.

Methods

Search strategy

A systematic search of six relevant electronic databases (SCOPUS, CINHAL, PubMed, Medline via Ovid, Web of Knowledge, and Cochrane library) was initiated in November 2010 to retrieve studies that had investigated the accuracy of neurological examination procedures to diagnose lumbar disc herniation. No language or years of publication restrictions were defined, and the search was terminated on March 1, 2011. The search strategy (Fig. 1) included a list of key words and/or search terms that were divided into three categories. The first category was divided into four subgroups, included words and terms related to symptoms, and involved structures of lumbar disc herniation. The second category covered diagnosis (sensitivity and specificity), and the third category detailed specific clinical neurological examination procedures. Results from the three categories were sequentially combined as illustrated in Fig. 1.

Studies were included if they reported one or more neurological examination procedures used in the diagnosis of

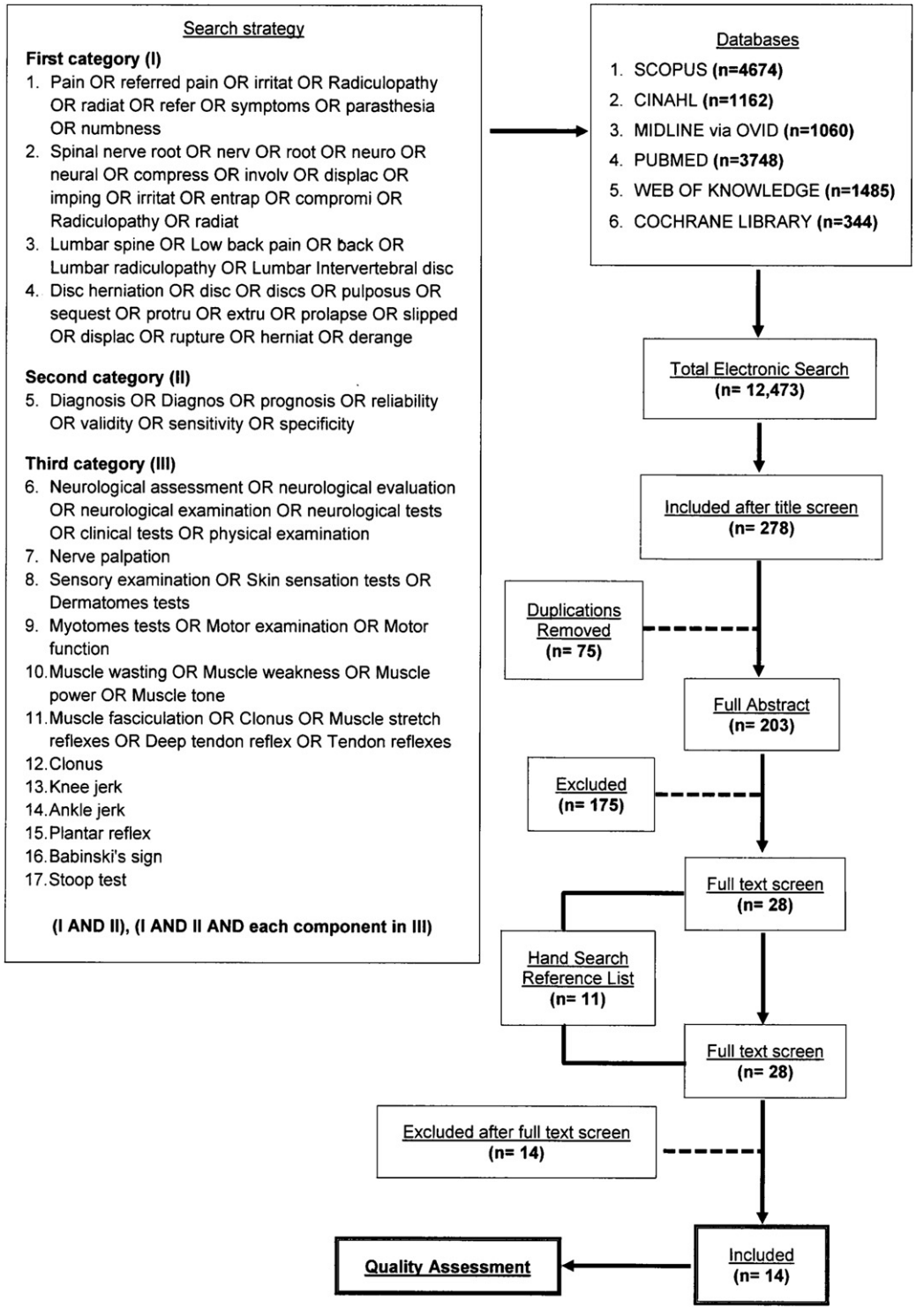

Fig. 1. Search history.

a suspected lumbar disc herniation and were published as full reports before March 1, 2011. The study inclusion criteria are outlined as follows: reported tests that evaluated the neurological structures of the lower extremities; neurological tests compared with a reference standard diagnosis of disc herniation such as surgery, magnetic resonance imaging, computed tomography scan, or myelography; reported sensitivity and specificity values of the neurological tests for the diagnosis of disc herniation or access to raw data to allow calculation of these values; studies that recruited patients based on the symptoms of low back and/or related leg/foot pain or other symptoms of radiculopathy;

and no restrictions were specified for the age of patients, date of publication, or language.

Articles retrieved from each database were initially screened by title by the first reviewer (NHAN) and duplications removed. Two reviewers (NHAN and PAH) then independently evaluated the abstracts from the retrieved articles for inclusion of full text, with a third reviewer (AGS) acting as adjudicator if no consensus could be reached. After abstract screening, relevant articles were retrieved for full-text screening and included in the review based on the outlined criteria. The bibliography of included articles was hand searched for further significant references. The reviewers were all qualified Orthopedic Manipulative Therapists and, as active researchers, were therefore familiar with the literature and not able to be effectively blinded to the authors, date of publication, or journals in which the articles were published.

Diagnostic accuracy statistics

Studies investigating the accuracy of neurological examination tests to diagnose surgically and/or radiologically confirmed herniated lumbar intervertebral discs were required to report, or allow calculation of, sensitivity, specificity, positive likelihood ratio (+LR) and negative likelihood ratio (−LR), and the diagnostic odds ratio (DOR) for each test evaluated [29]. True positive, false positive, false negative, and true negative of the targeted populations were tabulated. In cases of incomplete data, a 2×2 contingency table was used to recalculate these values. To define the criteria for comparing low/moderate/high sensitivity and specificity values, an arbitrary percentage value was introduced (low, less than 40%; moderate, 40% to 70%; and high, more than 70%). Likelihood ratios were considered as the main clinical outcome measure for the purposes of this review and were clinically interpreted as outlined in Table 1.

Quality assessment

Two reviewers (NHAN and AGS) independently evaluated all included articles on their methodological quality, using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool [30]. The QUADAS tool contains 14 items/questions that were scored independently by the two reviewers as ‘‘yes,’’ if studies satisfied each criterion, or ‘‘no,’’ if they failed to meet the criterion. When there was lack of information provided, or insufficient detail described to decide whether a certain criterion was satisfied or not, it was scored as ‘‘unclear.’’ A third reviewer (PAH) was consulted to adjudicate if no consensus could be reached between the two primary reviewers (Table 2). Each item of the QUADAS tool is designed to assess a certain protocol in a diagnostic study with nine items focusing on the potential bias, three items on the quality of reporting, and two items on the variability within the study. To provide an even interpretation of each study and avoid quality assessment bias, the reviewers acquainted themselves with the QUADAS tool before the evaluation and verified both the quality items and the scoring procedure as per the developer's recommendations [30,31].

For this systematic review, the item weightings, based and scaled for possible bias or variation, were used as a scoring method for the included studies [31]. Thus, three points were awarded for yes for items 1, 5, 10, 11, and 12, and items 3 and 6 were given a score of 2 for yes, with the remaining items (ie, 2, 4, 7, 8, 9, 13, and 14) receiving a score of 1 for yes. All items were scored 0 when the response was no or unclear, resulting in a total maximum score of 26 for each study evaluated (Table 2).

Data extraction and quantitative synthesis

Data from each article were retrieved by the first reviewer (NHAN) to allow the calculation of sensitivity and specificity values. For studies not providing either value, the corresponding authors were personally contacted. However, because of the age of some of the included studies, this was not always feasible, and in this instance, data were extracted from previous reviews or studies that cited the required information. A second reviewer (PAH) independently reviewed the extracted data and confirmed accuracy. Where appropriate, a meta-analysis was conducted to summarize the diagnostic accuracy of the evaluated tests [32]. Meta-DiSc, the diagnostic meta-analysis software, developed by Zamora et al. [33] was used to pool the results of homogenous studies. The configuration and calculation procedures performed by the Meta-DiSc software to outline the overall test accuracy are described elsewhere [33]. Forest plots for pooled data of diagnostic statistical measures of performance (sensitivity, specificity, +LR, −LR, DOR) were generated where appropriate for each test with a binary classification.

Table 1
Clinical interpretation of LRs [29]

+LR	−LR	Shift in probability condition is present
>10	<0.1	Large, often conclusive
5 to 10	0.1 to 0.2	Moderate, usually important
2 to 5	0.2 to 0.5	Small, sometimes important
1 to 2	0.5 to 1	Very small, rarely important

+LR, positive likelihood ratio; −LR, negative likelihood ratio.

Results

The systematic search of relevant electronic databases retrieved a total of 12,473 articles (Fig. 1). After reviewing the key words and context of all article titles, 278 articles were selected for possible inclusion in the review. After duplicates were removed, 203 article abstracts were further screened for the inclusion criteria. After excluding the

Table 2
Quality scores for the QUADAS tool

Study		Items														Score
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	Albeck [34]	N	Y	Y	U	Y	Y	Y	N	Y	U	U	Y	N	Y	14
		0	1	2	0	3	2	1	0	1	0	0	3	0	1	
2	Bertilson et al. [35]	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	U	Y	24
		3	1	2	1	3	2	1	0	1	3	3	3	0	1	
3	Gurdjian et al. [15]	Y	N	Y	U	Y	Y	Y	N	Y	U	U	Y	Y	Y	17
		3	0	2	0	3	2	1	0	1	0	0	3	1	1	
4	Hakelius and Hindmarsh [36]	Y	N	Y	U	Y	Y	Y	N	Y	U	U	U	U	Y	13
		3	0	2	0	3	2	1	0	1	0	0	0	0	1	
5	Hancock et al. [37]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	23
		3	1	2	1	3	2	1	1	1	3	3	0	1	1	
6	Kerr et al. [38]	Y	U	Y	U	N	Y	Y	N	Y	N	N	Y	Y	Y	14
		3	0	2	0	0	2	1	0	1	0	0	3	1	1	
7	Knutsson [39]	Y	Y	Y	U	Y	Y	Y	N	Y	U	U	N	Y	Y	15
		3	1	2	0	3	2	1	0	1	0	0	0	1	1	
8	Kosteljanetz et al. [40]	Y	Y	Y	Y	Y	Y	Y	U	Y	U	U	Y	Y	Y	19
		3	1	2	1	3	2	1	0	1	0	0	3	1	1	
9	Spangfort [41]	Y	Y	Y	U	Y	Y	Y	U	Y	U	U	Y	Y	Y	18
		3	1	2	0	3	2	1	0	1	0	0	3	1	1	
10	Stankovic et al. [42]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	26
		3	1	2	1	3	2	1	1	1	3	3	3	1	1	
11	Suri et al. [43]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	26
		3	1	2	1	3	2	1	1	1	3	3	3	1	1	
12	Vroomen et al. [44]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	26
		3	1	2	1	3	2	1	1	1	3	3	3	1	1	
13	Vucetic and Svensson [45]	Y	Y	Y	U	Y	Y	Y	Y	Y	U	U	N	Y	Y	16
		3	1	2	0	3	2	1	1	1	0	0	0	1	1	
14	Weise et al. [20]	N	Y	Y	U	Y	Y	Y	Y	U	Y	Y	Y	Y	Y	21
		0	1	2	0	3	2	1	1	0	3	3	3	1	1	
Number of studies satisfying each item criterion		12	11	14	6	13	14	14	6	13	6	6	10	11	14	
% Agreement		93	86	100	100	100	100	93	86	93	93	86	86	100	100	

QUADAS, Quality Assessment of Diagnostic Accuracy Studies; N, no; Y, yes; U, unclear; % agreement, between initial two reviewers.

articles not meeting the specified criteria, 28 articles were evaluated through a full-text screening. A hand search of bibliographies of included articles resulted in the consideration of 11 additional articles; however, these did not meet the inclusion criteria. After full-text screening, a final total of 14 articles were included in the review of which 12 were cohort [15,20,34–45] and two case-control [20,38] studies. The population within the included studies totaled more than 7,000 patients.

Three screening components of the standard neurological examination used in the diagnosis of lumbar disc herniation were identified and evaluated from the 14 included studies: sensory testing, motor testing (consisting of paresis and atrophy), and reflex testing. Sensitivity, specificity, positive/negative LRs, and their related confidence intervals (CI) were retrieved from the articles or recalculated from the available data. There was a 100% agreement between the 2 independent reviewers (NHAN and PAH) for the inclusion of all 14 articles.

Of the articles included in the review, studies evaluating the diagnostic accuracy of neurological tests compared their results with either surgery (n=8) or radiographic (n=6) reference standards. Three additional studies using radiographic procedures evaluated the ability of neurological tests to diagnose a specific herniated disc level. A comprehensive description of all 14 studies and their specific characteristics is included in Tables 3 and 4.

Quality scores of the QUADAS tool for the 14 articles ranged from 13 [16,36] to 26 [42–44], and the complete results are shown in Table 2. Studies that had surgical findings as the reference standard ranged from 13 [16,36] to 19 [40]. The deficiencies in these studies mostly related to not fulfilling the criteria regarding the interval between applications of the index test and the reference standard, providing a full description of the index tests procedures, and blinding of the researchers to the index or the reference tests. In comparison, scores of the QUADAS tool for radiological studies were higher and ranged from 21 [20] to 26 [42–44]. All quality assessment items evaluated in the included studies had an initial reviewer agreement that ranged from 86% to 100% (Table 2).

A meta-analysis was conducted for each evaluated neurological test based on the particular reference standard that

Table 3
Study characteristics (reference standard: surgical findings)

Author	Index tests	Subjects	Examiners	Report and definition of disc herniation	Level of herniation
Albeck [34]	Paresis Atrophy Hypesthesia Impaired reflexes	80 patients; mean age 40 (range 21 to 59 y) with monoradicular pain from fifth lumbar or first sacral root	1 Neurosurgeon	Extruded nucleus pulposus through a defect in the annulus fibrosus suggested a positive finding of a disc herniation	L4–L5 L5–S1
Gurdjian et al. [15]	Sensory deficits Motor deficits Achilles reflex Patellar reflex	1,176 patients; mean age 41 (range 17 to >61 y), operated on for LBP with sciatica radiation, followed up within a 10-y period	Unclear	Disc bulging Annular ligament tear Free fragments of disc material in the spinal canal	L1–S1
Hakelius and Hindmarsh [36]	Paresis Patellar reflex Achilles reflex	1,986 patients; operated on for suspected lumbar disc herniation	Unclear	Prolapsed disc with/without free sequestra Protruded disc exerting pressure on nerve root	L1–S1
Kerr et al. [38]	Sensory loss Paresis Atrophy Ankle reflex	100 patients; mean age 40, with protruded lumbar disc, average duration of symptoms 21 wk (4 to 120 wk) 36 patients (control); mean age 41, with back pain and sciatica, average duration of symptoms 28 wk (4 to 104 wk)	1 Consultant review preoperatively 1 of 6 surgeons performed the surgery	Grade 1: protrusion with annular continuity Grade 2: protrusion with annular rupture Grade 3: sequestered fragment All grades involve distortion of the nerve root	L3–L4 L4–L5 L5–S1
Knutsson [39]	Impaired sensibility Weakness/paralysis of great toe Atrophy Achilles reflex Patellar reflex	206 patients; age range (10 to 79 y) operated on for disc herniation, two groups: 182 not been operated on previously, 23 operated on, and 1 operated on twice Duration of symptoms from <3 wk to >1 y	Unclear	Defined as disc herniation and/or disc protrusion with no additional details	L3–L4 L4–L5 L5–S1
Kosteljanetz et al. [40]	Sensory deficits Paresis	100 patients; with LBP underwent back surgery with at least 1 symptom suggesting root compression, with >3 wk of conservative treatment	1 Neurosurgeon for examination and follow-up	Complete disc herniation (disc material in spinal canal, penetrating annulus fibrosus and posterior longitudinal ligament) Incomplete disc herniation (disc protruding but not penetrating posterior ligament)	L4–L5 L5–S1
Spangfort [41]	Paresis (dorsiflexors) Ankle reflex	2,504 patients; mean age 40.8 (range 15 to 74 y), with LBP who underwent surgical operations for suspected lumbar disc herniations. Mean duration of sciatic pain 3.3 and 5 to 6 y of LBP	39 Orthopedic surgeons in total performed the operations 1 Physician retrieved medical records 1 Personal for data revision and collection	Complete herniation (disc material extrusion, penetrating posterior longitudinal ligament) Incomplete herniation (disc protruding beyond anatomical limits without rupture of posterior longitudinal ligament) Bulging disc (disc protruding beyond anatomical limits large enough to cause pressure on a nerve root)	L1–S1
Vucetic and Svensson [45]	Sensibility (pinprick) Muscle power (extensors and great toe) Tendon reflexes	163 patients; mean age 43±0.8 (range 18 to 68 y), who underwent operation for lumbar disc herniation	1 Examiner undertook lumbar measurements	Sequestrated (complete hernia) Extruded herniation (intact posterior ligament) Protruded herniation (protrusion, generalized bulge beyond autonomic limits) with root involvement	L3–L4 L4–L5 L5–S1

LBP, low back pain.

Table 4
Study characteristics (reference standard: radiographic imaging)

Author	Index tests	Subjects	Examiners	Report and definition of disc herniation	Level of herniation
Bertilson et al. [35]	Sensibility to touch Motor function Reflex function	61 patients; mean age 60 (range 27 to 80 y) with LBP, median time since onset was 14 y and 44% experienced discomfort into the leg/foot for >2 y	1 Orthopedist 2 Radiologists	Bulging (disc material beyond anatomical border in the spinal canal not penetrating annulus) Hernia (focal protrusion of disc material through the annulus into the spinal canal, foraminal, or lateral space) Spinal stenosis=nerve root involvement	T11–S1
Hancock et al. [37]	Sensory testing Motor strength/weakness (quadriceps, tibialis anterior, peroneals, extensor hallucis longus, calf) Ankle reflex Knee reflex	283 patients; mean age 42 (range 18 to 65 y) with a dermatomal pain pattern indicating a nerve root compression (diagnosed by a neurologist) with radiographic evidence of disc herniation, symptom duration 6 to 12 wk (mean duration 9 wk, SD=2)	1 Neurologist examined patients for inclusion/exclusion criteria 1 Neurologist performed neurological examination before MRI scan 1 to 6 trained research nurses performed a second neurological examination after MRI 1 Neurosurgeon and 1 radiologist reported MRI scans	Disc herniation based on location: Central (central, subarticular) Lateral (intraforaminal, extraforaminal)	L3–L4 L4–L5 L5–S1
Stankovic et al. [42]	Sensory impairment Muscle weakness Reflex depression	105 patients; mean age 42.7±9.8 (range 19 to 64 y), with LBP and/or radiating pain, suspected of disc herniation. Most patients had pain lasting >3 mo	1 Examiner assessed patients before imaging 1 Neuroradiologist evaluated the scans	Disc herniation (assessed according to the degree of neural tissue being compromised) Disc bulging	L1–S1
Suri et al. [43]	Sensory testing (anterior thigh, medial knee and ankle, great toe extension, lateral foot) Motor testing (sit to stand, heel raise, heel walk, great toe extension, hip abductor) Reflex testing (patellar and Achilles)	160 patients aged 18 y or older with lower extremity radiating pain for <12 wk	6 Physiatrists specialized in spine care examined the patients 8 Neuroradiologists evaluated MRI scans 1 Musculoskeletal radiologist (interrater reliability)	Nerve root impingement (compression, deviation, or contact) caused by disc herniation	L2–L3 L3–L4 L4–L5 L5–S1
Vroomen et al. [44]	Sensory loss: Hypesthesia Hypalgesia Paresis Ankle/patellar reflex	274 patients; mean age 46 ±12 (range 16 to 81 y), with pain radiating into the leg, and a symptoms duration median of 19 d	1 Neuroradiologist reported MRI results 1 Clinical investigator	Protruding annulus, extruded nuclear material Lateral recess narrowing Flattening and compression of the ventrolateral boarder of the dural sac Emerging nerve root sleeve	L1–S1
Weise et al. [20]	Pinprick Light touch	25 patients; mean age 42 (range 24 to 68 y), with confirmed lumbar disc herniation, radicular symptoms duration from 3 mo to 12 y before sensory testing (mean interval was 1.2 y); 47 control groups with no complaints	1 Examiner	Disc herniation compressing the fourth lumbar, fifth lumbar, or first sacral nerve roots	L3–L4 L4–L5 L5–S1

LBP, low back pain; MRI, magnetic resonance imaging; SD, standard deviation.

it was compared against (surgery and radiological) and resulted in a total of eight separate meta-analysis procedures. Three meta-analyses were performed on sensory tests, three on motor tests (paresis [two] and atrophy [one]), and two evaluated reflex testing. The pooled values for sensitivity, specificity, positive and negative LRs, and the DORs for the evaluated tests are shown in Table 5, with forest plots for the positive LRs presented in Figs. 2–4. Results from individual studies and associated clinical findings of each evaluated testing procedure are presented in Tables 6–9.

The evaluation of sensory deficits to diagnose disc herniation confirmed by surgical findings (n=6) had relatively low sensitivity (0.40; CI 0.38, 0.43) and moderate specificity (0.59; CI 0.51, 0.67). Similar results were seen in radiographic studies, and this was not dependent on whether the diagnosis was made at any lumbar segmental level or at a specific segmental level with respective sensitivity values of 0.32 (CI 0.28, 0.37) and 0.35 (CI 0.33, 0.38) and specificity values of 0.72 (CI 0.67, 0.77) and 0.64 (CI 0.61, 0.66). The pooled positive LRs for sensory deficits were also poor, ranging from 1.10 to 1.02 in all three types of studies. Similarly, negative LRs were also poor with no clinically significant differences between the different reference standards (Table 5).

Pooled motor testing data demonstrated low sensitivity (0.22; CI 0.21, 0.23) and high specificity (0.79; CI 0.77, 0.80) when evaluating paresis. There was a slight increase in the pooled sensitivity values for atrophy (0.31; CI 0.26, 0.36) but similar specificity values (0.76; CI 0.65, 0.85). It is, however, noted that there were very high numbers of patients in the studies that reported paresis compared with atrophy, and this is reflected in the narrower CIs. Positive LRs were similar between the two types of motor dysfunction in surgical studies, resulting in values of 1.05 (CI 0.87, 1.26) for paresis and 1.08 (CI 0.34, 3.46) for atrophy (Table 5).

The pooled data for radiographic studies investigating motor testing (paresis only) at specifically evaluated disc herniation levels resulted in low sensitivity (0.40; CI 0.37, 0.42) and moderate specificity values (0.62; CI 0.60, 0.64), and the positive LRs were very small at 1.17 (CI 0.99, 1.38) (Table 5).

The number of studies that could be pooled in a meta-analysis to determine the diagnostic ability of reflex testing was appreciably higher than that for sensation and motor testing. Seven studies were pooled for surgery and three for radiography at a specific lumbar level. For radiography, the pooled sensitivity was 0.25 (CI 0.22, 0.28) and specificity 0.75 (CI 0.73, 0.78), with a positive LR of 1.25 (CI 0.71, 2.20). Similarly, in the surgical studies, the pooled sensitivity was low (0.29; CI 0.28, 0.30), with moderate specificity values (0.78; CI 0.76, 0.80). Positive LRs were also very small at 1.26 (CI 1.01, 1.58), indicating a rarely important probability of reflex changes diagnosing a herniated lumbar disc with suspected radiculopathy [46]. Similarly, the negative LRs for both types of studies were also very small (0.87 and 0.96, respectively) (Table 5).

Table 5
Summary of pooled data for each diagnostic accuracy measure

Index test	Gold standard	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	−LR (95% CI)	DORs (95% CI)	Total population	Total no. of studies
Sensory deficits	Surgery	0.40 (0.38, 0.43)	0.59 (0.51, 0.67)	1.10 (0.87, 1.38)	0.93 (0.79, 1.10)	1.19 (0.78, 1.81)	1,861	6
	Imaging	0.32 (0.28, 0.37)	0.72 (0.67, 0.77)	1.02 (0.76, 1.37)	1.00 (0.89, 1.13)	1.04 (0.65, 1.67)	451	3
	Imaging by level	0.35 (0.33, 0.38)	0.64 (0.61, 0.66)	1.03 (0.81, 1.30)	1.00 (0.92, 1.08)	1.03 (0.71, 1.49)	398	3
Motor deficits (paresis)	Surgery	0.22 (0.21, 0.23)	0.79 (0.77, 0.80)	1.05 (0.87, 1.26)	0.96 (0.90, 1.03)	1.10 (0.83, 1.45)	6,351	8
	Imaging by level	0.40 (0.37, 0.42)	0.62 (0.60, 0.64)	1.17 (0.99, 1.38)	0.94 (0.87, 1.02)	1.29 (0.97, 1.71)	398	3
Motor deficits (atrophy)	Surgery	0.31 (0.26, 0.36)	0.76 (0.65, 0.85)	1.08 (0.34, 3.46)	1.02 (0.65, 1.61)	1.10 (0.23, 5.34)	422	3
Reflex deficits	Surgery	0.29 (0.28, 0.30)	0.78 (0.76, 0.80)	1.26 (1.01, 1.58)	0.87 (0.76, 0.98)	1.47 (1.05, 2.06)	6,251	7
	Imaging by level	0.25 (0.22, 0.28)	0.75 (0.73, 0.78)	1.25 (0.71, 2.20)	0.96 (0.82, 1.12)	1.33 (0.62, 2.82)	398	3

+LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval; DORs, diagnostic odds ratios.

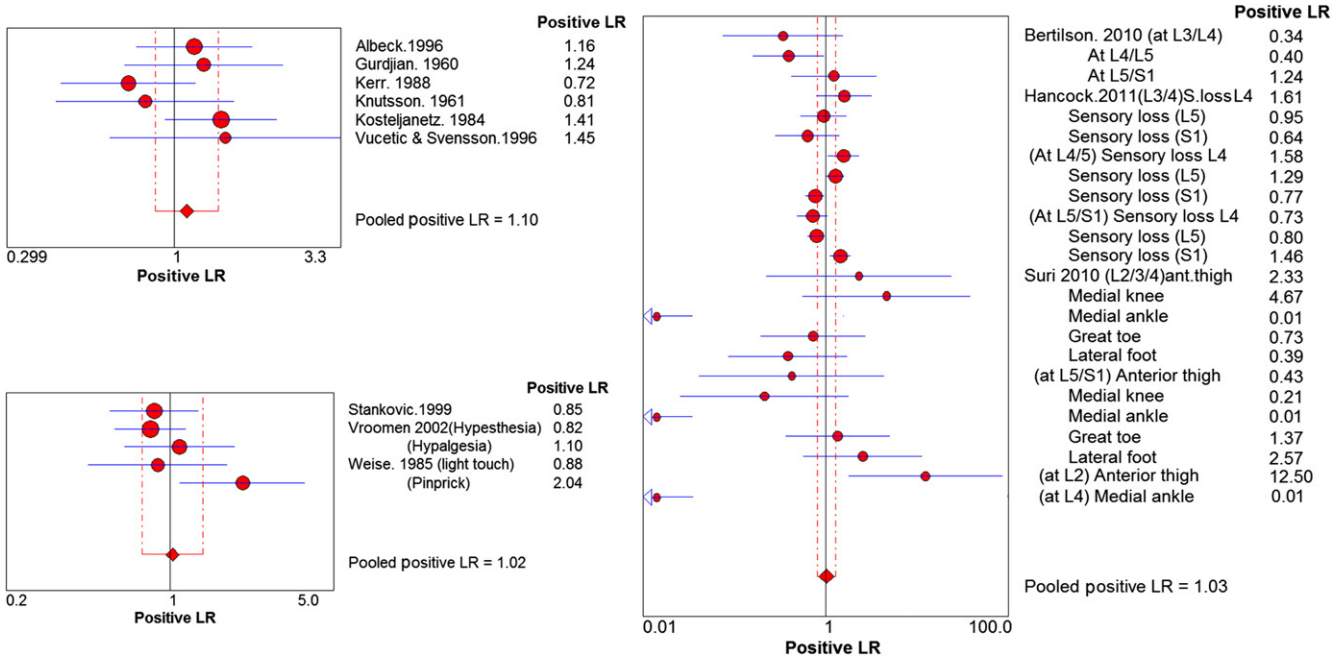

Fig. 2. Forest plots for sensory deficits based on the reference standard. (Top Left) Surgical findings, (Right) radiographic findings at specific lumbar disc herniated levels, and (Bottom Left) radiographic findings. LR, likelihood ratio.

Discussion

This review evaluated 14 diagnostic studies that specifically assessed the diagnostic ability of the standard neurological examination to detect the presence of a disc herniation with suspected radiculopathy. In contrast to previous reviews [17,25–28], this study performed eight separate meta-analyses to evaluate the diagnostic value of sensory, motor, and reflex testing procedures to diagnose

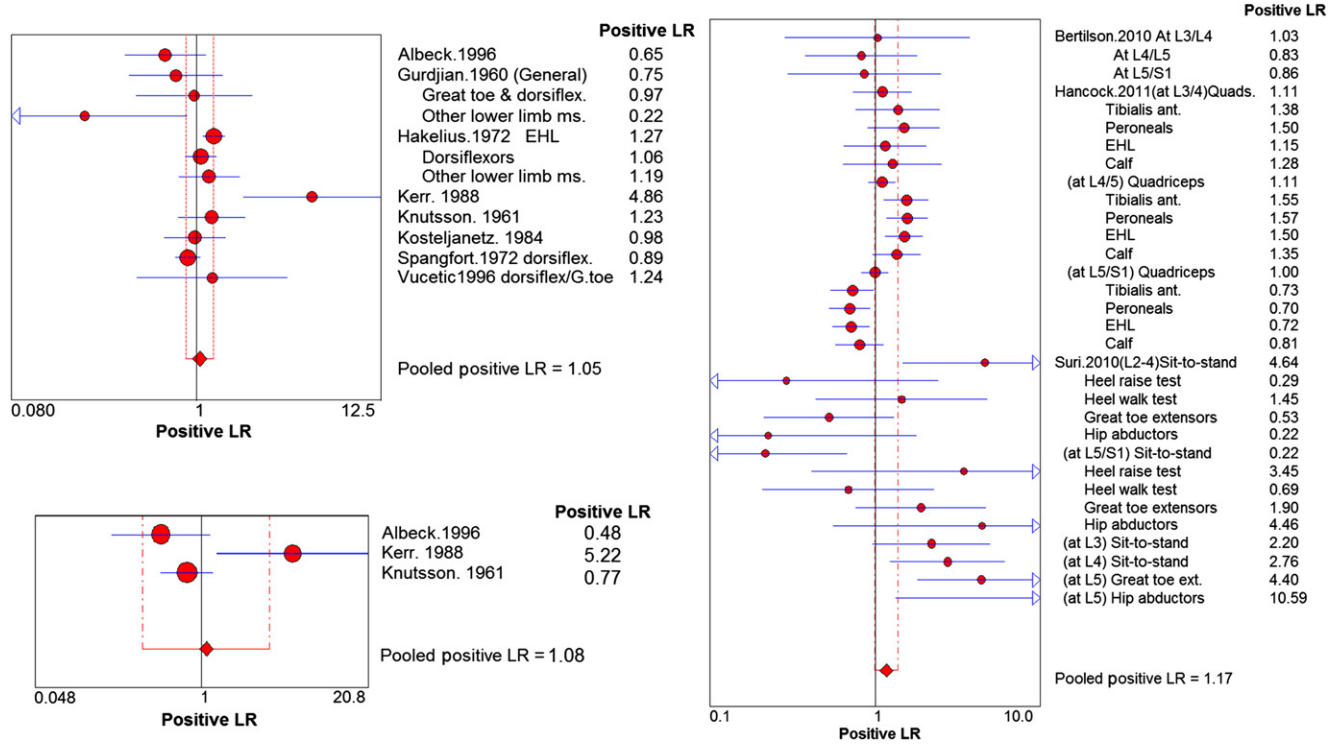

Fig. 3. Forest plots for motor deficits based on the reference standard. (Top Left) Surgical findings (paresis), (Right) radiographic findings at specific lumbar disc herniated levels (paresis), and (Bottom Left) surgical findings (atrophy). LR, likelihood ratio.

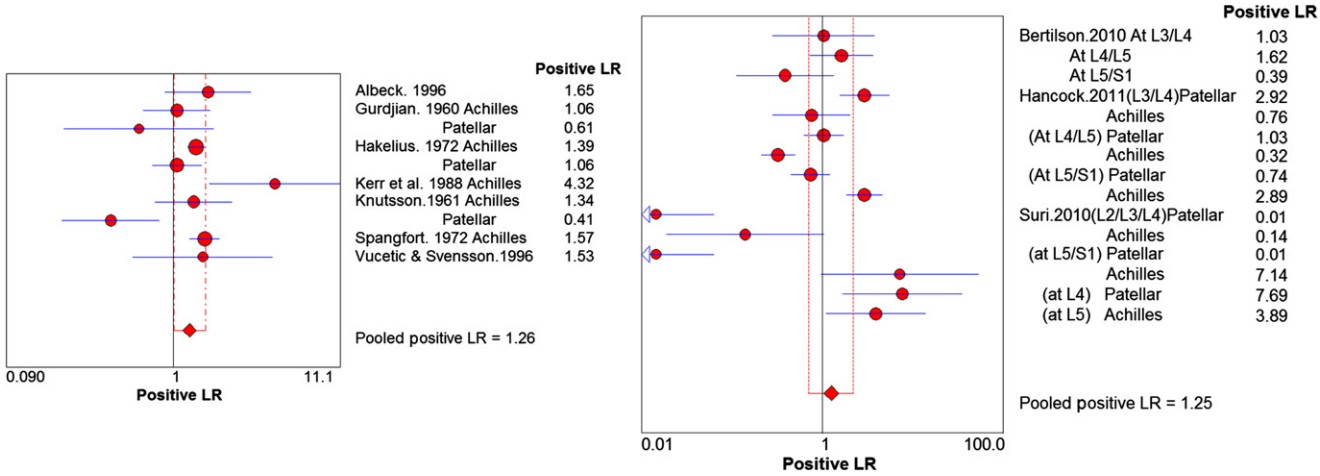

Fig. 4. Forest plots for reflex deficits based on the reference standard. (Left) Surgical findings and (Right) radiographic findings at specific lumbar disc herniated levels. LR, likelihood ratio.

disc herniation and radiculopathy. The review compared and analyzed the neurological test results with surgical and/or radiological reference testing for disc herniation and uniquely evaluated the relationship between neurological findings and specific levels of disc herniation. The overall findings revealed limited diagnostic accuracy of all components of the neurological examination to detect a disc herniation in patients with suspected radiculopathy, which was independent of either the testing procedure used to detect disc herniation or the level of herniation.

Diagnostic studies included in this review that used surgery as a reference standard for disc herniation (n=8) included a total population of 6,351 patients. Pooled data for sensory, motor, and reflex testing demonstrated poor diagnostic accuracy values within this population, with sensitivity ranging from 0.22 to 0.40, specificity ranging from 0.59 to 0.79, and consequently very small positive LRs ranging from 1.05 to 1.26 (Tables 3 and 4). The sensory testing procedures were not consistently reported in these studies, except for the distribution and the type of associated pain. In addition, motor testing differed among studies; three studies evaluated a mixture of lower limb muscle atrophy findings against surgical findings [34,38,39], whereas the majority of studies combined findings of muscle atrophy with paresis as defined motor deficits or did not consider evaluation because of their absence. Of note, Kerr et al. [38] reported that weakness of ankle dorsiflexion showed moderate sensitivity (0.54), high specificity (0.89), and a positive LR of 4.86 (Table 7). A similarly high specificity (0.94) with a positive LR of 5.22 was reported for muscle atrophy (Table 8). However, although this study investigated 100 patients with disc herniation verified by myelograms, it compared them with 36 control patients with back pain and sciatica not severe enough to undergo surgery, thus excluding the control group from verification of the reference standard that would have validated the test results [38]. Reflex testing mainly included the evaluation of Achilles and patellar tendon reflexes and similarly demonstrated limited diagnostic value in determining a disc herniation. Thus, the three evaluated tests had limited ability to detect lumbar disc herniation when surgery was the reference standard. The rationale to separate the results of the surgical studies from the radiologic standard studies is that the population undergoing surgery often represents a different cohort to those who only undergo radiological investigations for radiculopathy. This is in part because of the complex decision-making process involved in determining whether to undertake surgery versus to opt for conservative management [47] with this process associated with a multitude of individual factors that need to be fully considered by the neurological consultant.

Six studies with a total population of 849 patients used radiology as the reference standard to detect a lumbar disc herniation. Three studies evaluated the ability of these tests to diagnose disc herniation at any lumbar spine level [20,42,44], whereas the other three studies investigated neurological tests to diagnose specific levels of disc herniation [35,37,43]. In the former three studies, sensory testing data were only able to be pooled in a meta-analysis. These data were found to have low sensitivity and +LR values but relatively high specificity demonstrating moderate ability to detect a herniation when a test is positive (Table 5). The neurological tests also had limited diagnostic ability to detect specific levels of herniated discs (Table 5). Thus, similar to the surgical findings, the validity of sensory tests to detect a disc herniation was poor, and no differences were observed in the diagnostic utility of sensory, motor, and reflex tests to detect a specific level of disc herniation.

The higher specificity values for all testing procedures demonstrate that a positive test has a moderate ability to correctly identify patients with a lumbar disc herniation, which is proposed to be of greater diagnostic importance than sensitivity values [48] However, the very small pooled +LRs demonstrate that the likelihood that

Table 6
Summary of diagnostic accuracy for sensory deficits

Study/level or nerve root involvement	Specified index test	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	−LR (95% CI)
Reference standard: surgery									
Albeck [34]	Not specified	41	11	20	8	0.67 (0.54, 0.79)	0.42 (0.20, 0.67)	1.16 (0.76, 1.77)	0.78 (0.41, 1.47)
Any level or nerve root									
Gurdjian et al. [15]	Not specified	457	8	694	17	0.40 (0.37, 0.43)	0.68 (0.46, 0.85)	1.24 (0.70, 2.21)	0.89 (0.67, 1.16)
Any level or nerve root									
Kerr et al. [38]	Not specified	30	15	70	21	0.30 (0.21, 0.40)	0.58 (0.41, 0.74)	0.72 (0.44, 1.17)	1.20 (0.89, 1.63)
Any level or nerve root									
Knutsson [39]	Not specified	46	7	116	13	0.28 (0.22, 0.36)	0.65 (0.41, 0.85)	0.81 (0.43, 1.55)	1.10 (0.79, 1.54)
Any level or nerve root									
Kosteljanetz et al. [40]	Not specified	35	18	23	24	0.60 (0.47, 0.73)	0.57 (0.41, 0.72)	1.41 (0.94, 2.11)	0.69 (0.46, 1.05)
Any level or nerve root									
Vucetic and Svensson et al. [45]	Not specified	67	4	83	9	0.45 (0.37, 0.53)	0.69 (0.39, 0.91)	1.45 (0.63, 3.34)	0.80 (0.54, 1.18)
Any level or nerve root									
Reference standard: radiography									
Stankovic et al. [42]	Not specified	53	8	40	4	0.57 (0.46, 0.67)	0.33 (0.10, 0.65)	0.85 (0.55, 1.32)	1.29 (0.56, 2.97)
Any level or nerve root									
Vroomen et al. [44]	Hypesthesia	43	42	109	80	0.28 (0.21, 0.36)	0.66 (0.56, 0.74)	0.82 (0.58, 1.17)	1.09 (0.93, 1.29)
Any level or nerve root	Hypalgesia	26	19	126	103	0.17 (0.11, 0.24)	0.84 (0.77, 0.90)	1.10 (0.64, 1.89)	0.98 (0.88, 1.09)
Weise et al. [20]	Light touch	8	17	17	30	0.32 (0.15, 0.54)	0.64 (0.49, 0.77)	0.88 (0.45, 1.76)	1.07 (0.75, 1.50)
Any level or nerve root	Pinprick	13	12	12	35	0.52 (0.31, 0.72)	0.74 (0.60, 0.86)	2.04 (1.10, 3.77)	0.64 (0.41, 1.00)
Studies investigating specific levels of disc herniation (radiography)									
Bertilson et al. [35]	Sensibility to touch	2	6	28	25	0.07 (0.01, 0.22)	0.81 (0.63, 0.93)	0.34 (0.08, 1.57)	1.16 (0.95, 1.41)
L3–L4 (L4 nerve)									
L4–L5 (L5 nerve)	Sensibility to touch	5	13	25	18	0.17 (0.06, 0.35)	0.58 (0.39, 0.75)	0.40 (0.16, 0.98)	1.44 (1.02, 2.01)
L5–S1 (S1 nerve)	Sensibility to touch	6	5	24	26	0.20 (0.08, 0.39)	0.84 (0.66, 0.95)	1.24 (0.42, 3.63)	0.95 (0.75, 1.21)
Hancock et al. [37]	(L4) Sensory loss	5	69	7	198	0.42 (0.15, 0.72)	0.74 (0.69, 0.79)	1.61 (0.80, 3.25)	0.79 (0.49, 1.28)
L3–L4	(L5) Sensory loss	6	139	6	126	0.50 (0.21, 0.79)	0.48 (0.41, 0.54)	0.95 (0.54, 1.70)	1.05 (0.59, 1.88)
	(S1) Sensory loss	4	139	8	126	0.33 (0.10, 0.65)	0.48 (0.41, 0.54)	0.64 (0.28, 1.43)	1.40 (0.92, 2.13)
L4–L5	(L4) Sensory loss	41	33	82	123	0.33 (0.25, 0.42)	0.79 (0.72, 0.85)	1.58 (1.06, 2.33)	0.85 (0.73, 0.98)
	(L5) Sensory loss	73	72	49	83	0.60 (0.51, 0.69)	0.54 (0.45, 0.62)	1.29 (1.03, 1.61)	0.75 (0.58, 0.97)
	(S1) Sensory loss	54	89	68	66	0.44 (0.35, 0.54)	0.43 (0.35, 0.50)	0.77 (0.61, 0.98)	1.31 (1.03, 1.67)
L5–S1	(L4) Sensory loss	39	35	130	75	0.23 (0.17, 0.30)	0.68 (0.59, 0.77)	0.73 (0.49, 1.07)	1.13 (0.97, 1.31)
	(L5) Sensory loss	80	65	88	44	0.48 (0.40, 0.56)	0.40 (0.31, 0.50)	0.80 (0.64, 1.00)	1.30 (0.99, 1.70)
	(S1) Sensory loss	99	44	69	65	0.59 (0.51, 0.66)	0.60 (0.50, 0.69)	1.46 (1.12, 1.89)	0.69 (0.54, 0.87)
Suri et al. [43]	Anterior thigh	2	1	22	27	0.08 (0.01, 0.27)	0.96 (0.82, 1.00)	2.33 (0.23, 24.17)	0.95 (0.83, 1.09)
L2, L3, L4 nerve root impingement	Medial knee	4	1	20	27	0.17 (0.05, 0.37)	0.96 (0.82, 1.00)	4.67 (0.56, 38.97)	0.86 (0.71, 1.05)
	Medial ankle	4	0	20	28	0.17 (0.05, 0.37)	1.00 (0.88, 1.00)	—	0.83 (0.69, 1.01)
	Great toe	3	5	20	23	0.13 (0.03, 0.34)	0.82 (0.63, 0.94)	0.73 (0.19, 2.74)	1.06 (0.84, 1.34)
	Lateral foot	2	6	22	22	0.08 (0.01, 0.27)	0.79 (0.59, 0.92)	0.39 (0.09, 1.75)	1.17 (0.93, 1.47)
L5, S1 nerve root impingement	Anterior thigh	1	2	27	22	0.04 (0.00, 0.18)	0.92 (0.73, 0.99)	0.43 (0.04, 4.44)	1.05 (0.91, 1.21)
	Medial knee	1	4	27	20	0.04 (0.00, 0.18)	0.83 (0.63, 0.95)	0.21 (0.03, 1.79)	1.16 (0.95, 1.40)
	Medial ankle	0	4	28	20	0 (0.00, 0.12)	0.83 (0.63, 0.95)	0.00	1.20 (0.99, 1.45)
	Great toe	5	3	23	20	0.18 (0.06, 0.37)	0.87 (0.66, 0.97)	1.37 (0.37, 5.13)	0.94 (0.75, 1.19)
	Lateral foot	6	2	22	22	0.21 (0.08, 0.41)	0.92 (0.73, 0.99)	2.57 (0.57, 11.58)	0.86 (0.68, 1.08)
L2 nerve root impingement	Anterior thigh	1	2	1	48	0.50 (0.01, 0.99)	0.96 (0.86, 1.00)	12.50 (1.80, 87.01)	0.52 (0.13, 2.08)
L4 nerve root impingement	Medial ankle	4	0	9	39	0.31 (0.09, 0.61)	1.00 (0.91, 1.00)	—	0.69 (0.48, 0.99)

TP, true positive; FP, false positive; FN, false negative; TN, true negative; +LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval.

Table 7
Summary of diagnostic accuracy for motor deficits (paresis)

Study/level or nerve root involvement	Specified index test	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	−LR (95% CI)
Reference standard: surgery									
Albeck [34]	Not specified	21	10	40	9	0.34 (0.23, 0.48)	0.47 (0.24, 0.71)	0.65 (0.38, 1.13)	1.38 (0.83, 2.30)
Any level or nerve root									
Gurdjian et al. [15]	General paresis	243	7	908	18	0.21 (0.19, 0.24)	0.72 (0.51, 0.88)	0.75 (0.40, 1.43)	1.10 (0.86, 1.40)
Any level or nerve root	Great toe ext./dorsiflexors	223	5	928	20	0.19 (0.17, 0.22)	0.80 (0.59, 0.93)	0.97 (0.44, 2.14)	1.01 (0.83, 1.23)
	Other lower limb muscles	20	2	1,131	23	0.02 (0.01, 0.03)	0.92 (0.74, 0.99)	0.22 (0.05, 0.88)	1.07 (0.95, 1.20)
Hakelius and Hindmarsh [36]	Ext. hallucis longus	541	148	934	363	0.37 (0.34, 0.39)	0.71 (0.67, 0.75)	1.27 (1.09, 1.47)	0.89 (0.83, 0.95)
Any level or nerve root	Dorsiflexors	287	94	1,188	417	0.19 (0.17, 0.22)	0.82 (0.78, 0.85)	1.06 (0.86, 1.31)	0.99 (0.94, 1.04)
	Other lower limb muscles	96	28	1,379	483	0.07 (0.05, 0.08)	0.95 (0.92, 0.96)	1.19 (0.79, 1.79)	0.99 (0.96, 1.01)
Kerr et al. [38]	Not specified	54	4	46	32	0.54 (0.44, 0.64)	0.89 (0.74, 0.97)	4.91 (1.90, 12.46)	0.52 (0.41, 0.66)
Any level or nerve root									
Knutsson [39]	Not specified	100	10	62	10	0.62 (0.54, 0.69)	0.50 (0.27, 0.73)	1.23 (0.78, 1.95)	0.77 (0.47, 1.24)
Any level or nerve root									
Kosteljanetz et al. [40]	Not specified	27	20	31	22	0.47 (0.33, 0.60)	0.52 (0.36, 0.68)	0.98 (0.64, 1.49)	1.02 (0.70, 1.49)
Any level or nerve root									
Spangfort [41]	Dorsiflexors	645	110	1,512	217	0.30 (0.28, 0.32)	0.66 (0.61, 0.71)	0.89 (0.75, 1.05)	1.06 (0.97, 1.15)
Any level or nerve root									
Vucetic and Svensson [45]	Dorsiflexors/great toe ext.	43	3	107	10	0.29 (0.22, 0.37)	0.77 (0.46, 0.95)	1.24 (0.45, 3.46)	0.93 (0.68, 1.27)
Any level or nerve root									
Reference standard: radiography									
Stankovic et al. [42]	Not specified	56	8	37	4	0.60 (0.50, 0.70)	0.33 (0.10, 0.65)	0.90 (0.59, 1.39)	1.19 (0.52, 2.76)
Any level or nerve root									
Vroomen et al. [44]	Dorsiflexors/great toe ext.	41	8	111	114	0.27 (0.20, 0.35)	0.93 (0.87, 0.97)	3.86 (2.00, 8.44)	0.78 (0.70, 0.87)
Any level or nerve root									
Studies investigating specific levels of disc herniation (radiography)									
Bertilson et al. [35]	Not specified	4	4	26	27	0.13 (0.04, 0.31)	0.87 (0.70, 0.96)	1.03 (0.28, 3.76)	1.00 (0.82, 1.21)
L3–L4 (L4 nerve)									
L4–L5 (L5 nerve)	Not specified	8	10	22	21	0.27 (0.12, 0.46)	0.68 (0.49, 0.83)	0.83 (0.38, 1.81)	1.08 (0.78, 1.50)
L5–S1 (S1 nerve)	Not specified	5	6	25	25	0.17 (0.06, 0.35)	0.81 (0.63, 0.93)	0.86 (0.29, 2.52)	1.03 (0.82, 1.31)
Hancock et al. [37]	Quadriceps	8	159	4	105	0.67 (0.35, 0.90)	0.40 (0.34, 0.46)	1.11 (0.73, 1.67)	0.84 (0.37, 1.89)
L3–L4	Tibialis anterior	6	96	6	169	0.50 (0.21, 0.79)	0.64 (0.58, 0.70)	1.38 (0.77, 2.48)	0.78 (0.44, 1.39)
	Peroneals	7	103	5	161	0.58 (0.28, 0.85)	0.61 (0.55, 0.67)	1.50 (0.91, 2.47)	0.68 (0.35, 1.34)
	Ext. hallucis longus	6	115	6	150	0.50 (0.21, 0.79)	0.57 (0.50, 0.63)	1.15 (0.64, 2.06)	0.88 (0.50, 1.57)
	Calf	5	85	7	176	0.42 (0.15, 0.72)	0.67 (0.61, 0.73)	1.28 (0.64, 2.56)	0.87 (0.53, 1.41)
L4–L5	Quadriceps	78	89	44	65	0.64 (0.55, 0.72)	0.42 (0.34, 0.50)	1.11 (0.92, 1.34)	0.85 (0.63, 1.15)
	Tibialis anterior	56	46	66	109	0.46 (0.37, 0.55)	0.70 (0.63, 0.77)	1.55 (1.13, 2.11)	0.77 (0.63, 0.93)
	Peroneals	61	49	61	105	0.50 (0.41, 0.59)	0.68 (0.60, 0.75)	1.57 (1.17, 2.10)	0.73 (0.60, 0.90)
	Ext. hallucis longus	66	55	57	99	0.54 (0.44, 0.63)	0.64 (0.56, 0.72)	1.50 (1.15, 1.96)	0.72 (0.58, 0.90)
	Calf	47	43	75	108	0.39 (0.30, 0.48)	0.72 (0.64, 0.79)	1.35 (0.96, 1.90)	0.86 (0.72, 1.02)
L5–S1	Quadriceps	101	66	66	43	0.61 (0.53, 0.68)	0.39 (0.30, 0.49)	1.00 (0.82, 1.21)	1.00 (0.74, 1.35)
	Tibialis anterior	54	48	114	61	0.32 (0.25, 0.40)	0.56 (0.46, 0.66)	0.73 (0.54, 0.99)	1.21 (1.00, 1.48)
	Peroneals	57	53	110	56	0.34 (0.27, 0.42)	0.51 (0.42, 0.61)	0.70 (0.53, 0.93)	1.28 (1.04, 1.59)
	Ext. hallucis longus	63	58	104	52	0.38 (0.30, 0.46)	0.47 (0.38, 0.57)	0.72 (0.55, 0.93)	1.32 (1.05, 1.66)
	Calf	49	41	114	69	0.30 (0.23, 0.38)	0.63 (0.53, 0.72)	0.81 (0.58, 1.13)	1.11 (0.94, 1.33)

Suri et al. [43]	Sit to stand	12	3	13	26	0.48 (0.28, 0.69)	0.90 (0.73, 0.98)	4.64 (1.47, 14.60)	0.58 (0.39, 0.86)
L2, L3, L4 nerve root impingement	Heel raise test	1	4	24	25	0.04 (0.00, 0.20)	0.86 (0.68, 0.96)	0.29 (0.03, 2.43)	1.11 (0.94, 1.31)
	Heel walk test	5	4	20	25	0.20 (0.07, 0.41)	0.86 (0.68, 0.96)	1.45 (0.44, 4.82)	0.93 (0.73, 1.18)
	Great toe ext.	5	11	20	18	0.20 (0.07, 0.41)	0.62 (0.42, 0.79)	0.53 (0.21, 1.31)	1.29 (0.91, 1.82)
	Hip abductors	1	5	24	23	0.04 (0.00, 0.20)	0.82 (0.63, 0.94)	0.22 (0.03, 1.79)	1.17 (0.97, 1.41)
L5, S1 nerve root impingement	Sit to stand	3	12	26	13	0.10 (0.02, 0.27)	0.52 (0.31, 0.72)	0.22 (0.07, 0.68)	1.72 (1.16, 2.56)
	Heel raise test	4	1	25	24	0.14 (0.04, 0.32)	0.96 (0.80, 1.00)	3.45 (0.41, 28.87)	0.90 (0.76, 1.06)
	Heel walk test	4	5	25	20	0.14 (0.04, 0.32)	0.80 (0.59, 0.93)	0.69 (0.21, 2.29)	1.08 (0.84, 1.38)
	Great toe ext.	11	5	18	20	0.38 (0.21, 0.58)	0.80 (0.59, 0.93)	1.90 (0.76, 4.72)	0.78 (0.55, 1.10)
	Hip abductors	5	1	23	24	0.18 (0.06, 0.37)	0.96 (0.80, 1.00)	4.46 (0.56, 35.67)	0.86 (0.71, 1.04)
L3 nerve root impingement	Sit to stand	5	10	5	34	0.50 (0.19, 0.81)	0.77 (0.62, 0.89)	2.20 (0.96, 5.02)	0.65 (0.34, 1.23)
L4 nerve root impingement	Sit to stand	7	8	6	33	0.54 (0.25, 0.81)	0.80 (0.65, 0.91)	2.76 (1.24, 6.14)	0.57 (0.31, 1.05)
L5 nerve root impingement	Great toe ext.	11	5	7	31	0.61 (0.36, 0.83)	0.86 (0.71, 0.95)	4.40 (1.80, 10.75)	0.45 (0.25, 0.82)
L5 nerve root impingement	Hip abductor	5	1	12	35	0.29 (0.10, 0.56)	0.97 (0.85, 1.00)	10.59 (1.34, 83.75)	0.73 (0.53, 0.99)

TP, true positive; FP, false positive; FN, false negative; TN, true negative; +LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval; ext., extensors.

Table 8
Summary of diagnostic accuracy for motor deficits (atrophy), surgical only

Study/level or nerve root involvement	Specified index test	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	−LR (95% CI)
Albeck [34] Any level or nerve root	Not specified	9	6	51	13	0.15 (0.07, 0.27)	0.68 (0.43, 0.87)	0.48 (0.19, 1.16)	1.24 (0.90, 1.72)
Kerr et al. [38] Any level or nerve root	Not specified	29	2	71	34	0.29 (0.20, 0.39)	0.94 (0.81, 0.99)	5.22 (1.31, 20.78)	0.75 (0.65, 0.87)
Knutsson [39] Any level or nerve root	Not specified	62	10	100	10	0.38 (0.31, 0.46)	0.50 (0.27, 0.73)	0.77 (0.47, 1.24)	1.23 (0.78, 1.95)

TP, true positive; FP, false positive; FN, false negative; TN, true negative; +LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval.

Table 9
Summary of diagnostic accuracy for reflex deficits

Study/level or nerve root involvement	Specified index test	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	+LR (95% CI)	−LR (95% CI)
Reference standard: surgery									
Albeck [34]	Not specified	37	7	24	12	0.61 (0.47, 0.73)	0.63 (0.38, 0.84)	1.65 (0.88, 3.07)	0.62 (0.39, 0.99)
Any level or nerve root									
Gurdjian et al. [15]	Achilles	486	10	665	15	0.42 (0.39, 0.45)	0.60 (0.39, 0.79)	1.06 (0.65, 1.71)	0.96 (0.70, 1.33)
Any level or nerve root	Patellar	84	3	1,067	22	0.07 (0.06, 0.09)	0.88 (0.69, 0.97)	0.61 (0.21, 1.79)	1.05 (0.91, 1.22)
Hakelius and Hindmarsh [36]	Achilles	761	190	714	321	0.52 (0.49, 0.54)	0.63 (0.58, 0.67)	1.39 (1.23, 1.57)	0.77 (0.71, 0.84)
Any level or nerve root	Patellar	113	37	1,362	474	0.08 (0.06, 0.09)	0.93 (0.90, 0.95)	1.06 (0.74, 1.51)	1.00 (0.97, 1.02)
Kerr et al. [38]	Achilles	48	4	52	32	0.48 (0.38, 0.58)	0.89 (0.74, 0.97)	4.36 (1.68, 11.13)	0.58 (0.47, 0.73)
Any level or nerve root									
Knutsson [39]	Achilles	87	8	75	12	0.54 (0.46, 0.62)	0.60 (0.36, 0.81)	1.34 (0.77, 2.34)	0.77 (0.52, 1.14)
Any level or nerve root	Patellar	23	7	139	13	0.14 (0.09, 0.21)	0.65 (0.41, 0.85)	0.41 (0.20, 0.82)	1.32 (0.95, 1.83)
Spangfort [41]	Achilles	675	69	1,482	278	0.31 (0.29, 0.33)	0.80 (0.76, 0.84)	1.57 (1.26, 1.96)	0.86 (0.81, 0.91)
Any level or nerve root									
Vucetic and Svensson [45]	Not specified	53	3	97	10	0.35 (0.28, 0.44)	0.77 (0.46, 0.95)	1.53 (0.55, 4.23)	0.84 (0.61, 1.16)
Any level or nerve root									
Reference standard: radiography									
Stankovic et al. [42]	Not specified	37	3	56	9	0.40 (0.30, 0.50)	0.75 (0.43, 0.95)	1.59 (0.58, 4.38)	0.80 (0.56, 1.16)
Any level or nerve root									
Vroomen et al. [44]	Not specified	22	8	130	114	0.14 (0.09, 0.21)	0.93 (0.87, 0.97)	2.21 (1.02, 4.78)	0.92 (0.84, 0.99)
Any level or nerve root									
Studies investigating specific levels of disc herniation (radiography)									
Bertilson et al. [35]	Not specified	4	4	26	27	0.13 (0.04, 0.31)	0.87 (0.70, 0.96)	1.03 (0.28, 3.76)	1.00 (0.82, 1.21)
L3–L4 (L4 nerve)									
L4–L5 (L5 nerve)	Not specified	11	7	19	24	0.37 (0.20, 0.56)	0.77 (0.59, 0.90)	1.62 (0.73, 3.63)	0.82 (0.59, 1.14)
L5–S1 (S1 nerve)	Not specified	3	8	27	23	0.10 (0.02, 0.27)	0.74 (0.55, 0.88)	0.39 (0.11, 1.32)	1.21 (0.95, 1.54)
Hancock et al. [37]	Patellar	6	45	6	218	0.50 (0.21, 0.79)	0.83 (0.78, 0.87)	2.92 (1.56, 5.46)	0.60 (0.34, 1.06)
L3–L4	Achilles	3	95	8	168	0.27 (0.06, 0.61)	0.64 (0.58, 0.70)	0.76 (0.28, 2.01)	1.14 (0.78, 1.65)
L4–L5	Patellar	23	28	99	125	0.19 (0.12, 0.27)	0.82 (0.75, 0.88)	1.03 (0.63, 1.69)	0.99 (0.89, 1.11)
	Achilles	20	78	101	75	0.16 (0.10, 0.24)	0.49 (0.41, 0.57)	0.32 (0.21, 0.50)	1.70 (1.42, 2.04)
L5–S1	Patellar	27	24	139	85	0.16 (0.11, 0.23)	0.79 (0.69, 0.85)	0.74 (0.45, 1.21)	1.07 (0.95, 1.21)
	Achilles	80	18	86	90	0.48 (0.40, 0.56)	0.83 (0.75, 0.90)	2.89 (1.84, 4.54)	0.62 (0.52, 0.74)
Suri et al. [43]	Patellar	7	0	18	28	0.28 (0.12, 0.49)	1.00 (0.88, 1.00)	—	0.72 (0.56, 0.93)
L2, L3, L4 nerve root impingement	Achilles	1	8	24	20	0.04 (0.00, 0.20)	0.71 (0.51, 0.87)	0.14 (0.02, 1.04)	1.34 (1.05, 1.72)
L5, S1 nerve root impingement	Patellar	0	7	28	18	0.00 (0.00, 0.12)	0.72 (0.51, 0.88)	0.00	1.38 (1.08, 1.77)
	Achilles	8	1	20	24	0.29 (0.13, 0.49)	0.96 (0.80, 1.00)	7.14 (0.96, 53.19)	0.74 (0.58, 0.95)
L4 nerve root impingement	Patellar	5	2	8	38	0.38 (0.14, 0.68)	0.95 (0.83, 0.99)	7.69 (1.69, 35.02)	0.65 (0.42, 1.00)
L5 nerve root impingement	Achilles	6	3	12	32	0.33 (0.13, 0.59)	0.91 (0.77, 0.98)	3.89 (1.10, 13.76)	0.73 (0.52, 1.03)

TP, true positive; FP, false positive; FN, false negative; TN, true negative; +LR, positive likelihood ratio; −LR, negative likelihood ratio; CI, confidence interval.

neurological testing will detect nerve root irritation and/or compression in patients with a disc herniation is very small and rarely important [46]. These findings were independent of the reference standard, the patient presentation, and the populations under investigation, which were extensive (>7,000 patients) strengthening the meta-analyses review findings.

A number of factors may have affected the low diagnostic findings observed, including the quality and the validity of the testing procedures of the included studies. Studies comparing neurological test results with surgical findings demonstrated a selection bias [17]. Only patients who tested positive on clinical examination with radiological evidence of disc herniation received the reference standard and underwent surgery, thus increasing the potential of having a high true positive rate. Reporting of the neurological testing procedures was also variable across all studies. Testing procedures were not standardized across studies, and some did not provide a description of how the index tests were applied and/or did not provide acceptable measures for evaluating the diagnosed impairments (eg, grading motor weakness and reflex changes). Nearly half of all included studies in this review did not provide a detailed description of the application of the neurological tests (Table 2). Furthermore, diagnoses of disc herniation were not always based on standardized criteria for classifying the degree and the grade of disc herniation, resulting in substantial differences in reported positive disc herniation findings (Tables 3 and 4). Recent studies demonstrate simple and reliable methods of classifying and measuring disc herniation that might potentially lead to better standardization of disc pathology and allow better standardization of diagnostic accuracy [49,50].

All patients with LBP included in this review were recruited based on the suspicion of radiculopathy because of a potential disc herniation. The majority of studies recruited their patients based on the symptoms of sciatica or pain radiating below the knee and into the lower leg/foot [51] (Tables 3 and 4). However, radicular pain refers to an ectopic stimulation of nociceptive afferent fibers in a spinal nerve or its roots, or other neuropathic mechanisms initiating symptoms down the limbs or trunk wall [12], whereas radiculopathy is associated with a dermatomal distribution of numbness and myotomal weakness [52]. Therefore, the potential radicular pain symptoms associated with the majority of the included population may have not progressed sufficiently to cause a true radiculopathy. Only three studies [37,38,40] based their inclusion criteria on the presence of numbness or a dermatomal distribution of pain with one (or more) neurological signs (ie, sensory, motor, or reflex). In these studies, slight improvements were noticed in the diagnostic values of the evaluated tests (Tables 6–9).

The pathomechanics [52,53] and pathophysiology [3,11] of radiculopathy are complex. Lumbar disc herniation can result in varying pain patterns and potentially the overlap of dermatomes and/or myotomes, resulting in misdiagnosis of nerve root involvement [18,54,55] affecting the validity of the neurological tests to diagnose a specific level of disc herniation. Lauder et al. [56] reported that in patients with radiculopathy confirmed by electrodiagnostic procedures, nearly 31% had no signs of weakness and up to 45% had no sensory deficits detected on clinical examination. Thus, irritation or compression of a single nerve root may be masked by overlapping spinal nerves [57]. Studies also demonstrate that even in patients with severe radiculopathy symptoms, weakness may not be observed on examination, unless degeneration of the disc or a large conduction block of the nerve root axons is present [18,57,58]. As a result, it is suggested that an individual with a single-level radiculopathy, caused by a disc herniation, may not demonstrate major sensory or motor loss [57]. Additionally, pseudoradiculopathy, which differs from radiculopathy [52,59], may also underlie the neuropathic nature of associated pain patterns and add to the complexity of diagnosis and management of disc herniation [60,61]. Although electrodiagnostic procedures provide important diagnostic information regarding the electrophysiological evidence for radiculopathy, it is suggested that the structural cause of such signs and symptoms requires confirmatory imaging as part of a full structured assessment [62]. However, no studies have specifically investigated the diagnostic ability of neurological testing to determine whether radiculopathy confirmed both electrodiagnostically and via imaging. It is therefore important to note that there are currently no standardized reference tests in isolation that specifically diagnose a radiculopathy under its current definition. Thus, reaching a conclusion of confirmed radiculopathy symptoms from the clinical history and examination is challenging [63].

It is also important to note that all patients in the studies included in this review were considered chronic and therefore potential alternations in both sensory and motor functions may be evident without radiculopathy [64–66], thus affecting the validity of the testing procedures and leading potentially to higher false positive results in the studies reviewed. Moreover, reduced physical activity levels and deconditioning has been shown to be associated with chronic LBP patients [67–69], which could also possibly be a factor in the related disability and the high presence of motor changes observed in this patient population.

It is also commonly recognized that, for a diagnostic procedure to be valid, it should have acceptable reliability [70]. The psychometric properties of the neurological tests have been shown to be variable and dependent on the patient population and standardization of testing procedures. Vroomen et al. [24] reported moderate to almost perfect interrater reliability for reduced muscle strength and sensory deficits (k=0.57 to 0.82) in patients with sciatica and moderate agreement for reflex impairments (k=0.42 to 0.53), whereas McCarthy et al. [23] reported moderate to substantial interrater agreement for both reflexes and motor deficits

(k=0.41 to 0.56) in 295 LBP patients with nerve root involvement. Sensibility to pain showed moderate to substantial agreement among examiners (k=0.50 to 0.71) within a cohort of LBP patients with sciatica [71]. The reliability of the reference standard employed to diagnose disc herniation is also potentially dependent on diagnostic criteria, disease prevalence, and patient spectrums [24]. Whereas radiographic procedures have shown to have good reliability in detecting disc herniation [72], the criteria for surgical diagnosis of disc herniation was not standardized across the included studies (Table 3). It is important to note that results from this study found no difference in the pooled diagnostic values for surgical or radiographic studies, thus suggesting that the findings are independent of the reference standard used.

This review demonstrated that the neurological testing procedures in isolation do not provide an acceptable likelihood to indicate a disc herniation in patients with suspected radiculopathy. However, in clinical practice, it is common to combine the neurological tests with other clinical procedures to make an accurate diagnosis and inform clinical decisions [37,43]. The patient's history along with the associated nature and the distribution of signs and symptoms are proposed to be essential components for identifying the level and the degree of disc herniation [37,43]. The results emphasize that diagnosis of radiculopathy in the presence of disc herniation is a complex process that should involve a detailed history and physical examination that also include the symptoms of pain, straight leg raise testing, motor, sensory, reflex, and sphincter examinations, and also a detailed review of radiological findings. Future studies should investigate the diagnostic utility of the full clinical examination and specific combinations of relevant clinical tests in the diagnosis of disc herniation and radiculopathy. Better standardization of neurological examination reporting including exact details of sensory changes (anesthesia and paresthesia), levels and grading of muscle paresis and weakness, and adoption of a standardized approach to reflex change reporting is required to investigate the psychometric and diagnostic properties of the neurological examination.

In conclusion, this systematic review and meta-analysis evaluated individual neurological examination testing procedures for their diagnostic accuracy in detecting a lumbar disc herniation in patients with suspected nerve root involvement. This review is the first to specifically assess and compare the diagnostic accuracy of the neurological examination to diagnose the specific level of disc herniation. The ability of neurological testing procedures to detect either a disc herniation or the level of herniation was poor. Improved standardization of testing protocols for the neurological testing procedures would allow better evaluation of the validity and the reliability of the tests within clinical settings. However clinically, these tests may be more useful to evaluate change in signs and symptoms or as potential prognostic indicators of recovery. The results question the validity of using neurological testing procedures in isolation to diagnose a lumbar disc herniation with suspected radiculopathy.

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References

[1] Adams MA. Biomechanics of back pain. Acupunct Med 2004;22:178–88.
[2] Deyo RA. Early diagnostic evaluation of low back pain. J Gen Intern Med 1986;1:328–38.
[3] Shahbandar L, Press J. Diagnosis and nonoperative management of lumbar disk herniation. Oper Tech Sports Med 2005;13:114–21.
[4] Battié MC, Videman T, Parent E. Lumbar disc degeneration: epidemiology and genetic influences. Spine 2004;29:2679–90.
[5] 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;72:403–8.
[6] Cheung KMC, Karppinen J, Chan D, et al. Prevalence and pattern of lumbar magnetic resonance imaging changes in a population study of one thousand forty-three individuals. Spine 2009;34:934–40.
[7] Karamouzian S, Eskandary H, Faramarzee M, et al. Frequency of lumbar intervertebral disc calcification and angiogenesis, and their correlation with clinical, surgical, and magnetic resonance imaging findings. Spine 2010;35:881–6.
[8] Weber H. The natural history of disc herniation and the influence of intervention. Spine 1994;19:2234–8.
[9] Sembrano JN, Polly DW. How often is low back pain not coming from the back? Spine 2009;34:E27–32.
[10] Miyoshi S, Sekiguchi M, Konno SI, et al. Increased expression of vascular endothelial growth factor protein in dorsal root ganglion exposed to nucleus pulposus on the nerve root in rats. Spine 2011;36:E1–6.
[11] McCarron RF, Wimpee MW, Hudkins PG, Laros GS. The inflammatory effect of nucleus pulposus. A possible element in the pathogenesis of low-back pain. Spine 1987;12:760–4.
[12] Merskey H, Bogduk N, eds. Classification of chronic pain. Descriptions of chronic pain syndromes and definitions of pain terms. 2nd ed. Seattle, WA: IASP Press, 1994.
[13] Murphy DR, Hurwitz EL, Gerrard JK, Clary R. Pain patterns and descriptions in patients with radicular pain: does the pain necessarily follow a specific dermatome? Chiropr Osteopat 2009;17:9.
[14] Jarvik JG, Deyo RA. Diagnostic evaluation of low back pain with emphasis on imaging. Ann Intern Med 2002;137:586–97.
[15] Gurdjian ES, Webster JE, Ostrowski AZ, et al. Herniated lumbar intervertebral discs—an analysis of 1176 operated cases. J Trauma 1961;1:158–76.
[16] Hakelius A, Hindmarsh J. The comparative reliability of preoperative diagnostic methods in lumbar disc surgery. Acta Orthop Scand 1972;43:234–8.
[17] Van Der Windt DAWM, Simons E, Riphagen I, et al. Physical examination for lumbar radiculopathy due to disc herniation in patients with low-back pain. Cochrane Database Syst Rev 2010;2(2):CD007431.
[18] Humphreys SC, Eck JC, Tennessee C. Clinical evaluation and treatment options for herniated lumbar disc. Am Fam Physician 1999;59:575–82.

[19] Knutsson B. Electromyographic studies in the diagnosis of lumbar disc herniations. Acta Orthop Scand 1959;28:290–9.

[20] Weise MD, Garfin SR, Gelberman RH. Lower-extremity sensibility testing in patients with herniated lumbar intervertebral discs. J Bone Joint Surg Am 1985;67:1219–24.

[21] Medical Research Council Grading System. Aids to the investigation of peripheral nerve injuries. London: HMSO, 1976.

[22] Cook C. Orthopedic manual therapy. An evidence based approach. Upper Saddle River, New Jersey: Pearson/Prentice Hall, 2007.

[23] McCarthy CJ, Gittins M, Roberts C, Oldham JA. The reliability of the clinical tests and questions recommended in international guidelines for low back pain. Spine 2007;32:921–6.

[24] Vroomen PCAJ, De Krom MCTFM, Knottnerus JA. Consistency of history taking and physical examination in patients with suspected lumbar nerve root involvement. Spine 2000;25:91–7.

[25] Deyo RA, Rainville J, Kent DL. What can the history and physical examination tell us about low back pain? JAMA 1992;268:760–5.

[26] Rubinstein SM, van Tulder M. A best-evidence review of diagnostic procedures for neck and low-back pain. Best Pract Res Clin Rheumatol 2008;22:471–82.

[27] Van den Hoogen HMM, Koes BW, Van Eijk JTM, et al. On the accuracy of history, physical examination, and erythrocyte sedimentation rate in diagnosing low back pain in general practice: a criteria-based review of the literature. Spine 1995;20:318–27.

[28] Vroomen PCAJ, De Krom MCTFM, Knottnerus JA. Diagnostic value of history and physical examination in patients suspected of sciatica due to disc herniation: a systematic review. J Neurol 1999;246:899–906.

[29] Greenhalgh T. How to read a paper. Papers that report diagnostic or screening tests. Br Med J 1997;315:540–3.

[30] Whiting P, Rutjes AWS, Reitsma JB, et al. The development of QUADAS: a tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. BMC Med Res Methodol 2003;3:1–13.

[31] Whiting P, Harbord R, Kleijnen J. No role for quality scores in systematic reviews of diagnostic accuracy studies. BMC Med Res Methodol 2005;5:19.

[32] Irwig L, Tosteson ANA, Gatsonis C, et al. Guidelines for meta-analyses evaluating diagnostic tests. Ann Intern Med 1994;120:667–76.

[33] Zamora J, Abraira V, Muriel A, et al. Meta-DiSc: a software for meta-analysis of test accuracy data. BMC Med Res Methodol 2006;6:31.

[34] Albeck MJ. A critical assessment of clinical diagnosis of disc herniation in patients with monoradicular sciatica. Acta Neurochir (Wien) 1996;138:40–4.

[35] Bertilson BC, Brosjö E, Billing H, Strender LE. Assessment of nerve involvement in the lumbar spine: agreement between magnetic resonance imaging, physical examination and pain drawing findings. BMC Musculoskelet Disord 2010;11:202.

[36] Hakelius A, Hindmarsh J. The significance of neurological signs and myelographic findings in the diagnosis of lumbar root compression. Acta Orthop Scand 1972;43:239–46.

[37] Hancock MJ, Koes B, Ostelo R, Peul W. Diagnostic accuracy of the clinical examination in identifying the level of herniation in patients with sciatica. Spine 2011;36:E712–9.

[38] Kerr RSC, Cadoux-Hudson TA, Adams CBT. The value of accurate clinical assessment in the surgical management of the lumbar disc protrusion. J Neurol Neurosurg Psychiatry 1988;51:169–73.

[39] Knutsson B. Comparative value of electromyographic, myelographic and clinical-neurological examinations in diagnosis of lumbar root compression syndrome. Acta Orthop Scand Suppl 1961;49:1–135.

[40] Kosteljanetz M, Espersen JO, Halaburt H, Miletic T. Predictive value of clinical and surgical findings in patients with lumbago-sciatica. A prospective study (Part I). Acta Neurochir (Wien) 1984;73:67–76.

[41] Spangfort EV. The lumbar disc herniation. A computer-aided analysis of 2,504 operations. Acta Orthop Scand Suppl 1972;142:1–95.

[42] Stankovic R, Johnell O, Maly P, Willner S. Use of lumbar extension, slump test, physical and neurological examination in the evaluation of patients with suspected herniated nucleus pulposus. A prospective clinical study. Man Ther 1999;4:25–32.

[43] Suri P, Rainville J, Katz JN, et al. The accuracy of the physical examination for the diagnosis of midlumbar and low lumbar nerve root impingement. Spine 2011;36:63–73.

[44] Vroomen PCAJ, De Krom MCTFM, Wilmink JT, et al. Diagnostic value of history and physical examination in patients suspected of lumbosacral nerve root compression. J Neurol Neurosurg Psychiatry 2002;72:630–4.

[45] Vucetic N, Svensson O. Physical signs in lumbar disc hernia. Clin Orthop Relat Res 1996;333:192–201.

[46] Jaeschke R, Guyatt G, Sackett DL. Users' guides to the medical literature: III. How to use an article about a diagnostic test. A. Are the results of the study valid? JAMA 1994;271:389–91.

[47] Haig AJ. The need versus the choice for treatment of spinal disorders: does our science help us to differentiate? Spine J 2006;6:355–6.

[48] Davidson M. The interpretation of diagnostic tests: a primer for physiotherapists. Aust J Physiother 2002;48:227–32.

[49] Fardon DF, Milette PC. Nomenclature and classification of lumbar disc pathology. Recommendations of the Combined Task Forces of the North American spine Society, American Society of Spine Radiology, and American Society of Neuroradiology. Spine 2001;26:E93–113.

[50] Mysliwiec LW, Cholewicki J, Winkelpleck MD, Eis GP. MSU classification for herniated lumbar discs on MRI: toward developing objective criteria for surgical selection. Eur Spine J 2010;19:1087–93.

[51] Valat JP, Genevay S, Marty M, et al. Sciatica. Best Pract Res Clin Rheumatol 2010;24:241–52.

[52] Bogduk N. On the definitions and physiology of back pain, referred pain, and radicular pain. Pain 2009;147:17–9.

[53] Schäfer A, Hall T, Briffa K. Classification of low back-related leg pain—a proposed patho-mechanism-based approach. Man Ther 2009;14:222–30.

[54] Foerster O. The dermatomes in man. Brain 1933;56:1–39.

[55] Marzo JM, Simmons EH, Kallen F. Intradural connections between adjacent cervical spinal roots. Spine 1987;12:964–8.

[56] Lauder TD, Dillingham TR, Andary M, et al. Effect of history and exam in predicting electrodiagnostic outcome among patients with suspected lumbosacral radiculopathy. Am J Phys Med Rehabil 2000;79:60–8.

[57] De Luigi AJ, Fitzpatrick KF. Physical examination in radiculopathy. Phys Med Rehabil Clin N Am 2011;22:7–40.

[58] Levin KH. Electrodiagnostic approach to the patient with suspected radiculopathy. Neurol Clin 2002;20:397–421.

[59] Freynhagen R, Rolke R, Baron R, et al. Pseudoradicular and radicular low-back pain—a disease continuum rather than different entities? Answers from quantitative sensory testing. Pain 2008;135:65–74.

[60] Dworkin RH, Backonja M, Rowbotham MC, et al. Advances in neuropathic pain: diagnosis, mechanisms, and treatment recommendations. Arch Neurol 2003;60:1524–34.

[61] Finnerup NB, Otto M, McQuay HJ, et al. Algorithm for neuropathic pain treatment: an evidence based proposal. Pain 2005;118:289–305.

[62] Plastaras CT, Joshi AB. The electrodiagnostic evaluation of radiculopathy. Phys Med Rehabil Clin N Am 2011;22:59–74.

[63] Rubinstein SM, Pool JJM, Van Tulder MW, et al. A systematic review of the diagnostic accuracy of provocative tests of the neck for diagnosing cervical radiculopathy. Eur Spine J 2007;16:307–19.

[64] Arendt-Nielsen L, Graven-Nielsen T, Svarrer H, Svensson P. The influence of low back pain on muscle activity and coordination during gait: a clinical and experimental study. Pain 1996;64:231–40.

[65] Lafond D, Champagne A, Descarreaux M, et al. Postural control during prolonged standing in persons with chronic low back pain. Gait Posture 2009;29:421–7.

[66] Popa T, Bonifazi M, Della Volpe R, et al. Adaptive changes in postural strategy selection in chronic low back pain. Exp Brain Res 2007;177:411–8.

[67] Bousema EJ, Verbunt JA, Seelen HAM, et al. Disuse and physical deconditioning in the first year after the onset of back pain. Pain 2007;130:279–86.

[68] Duque I, Parra JH, Duvallet A. Physical deconditioning in chronic low back pain. J Rehabil Med 2009;41:262–6.

[69] Smeets RJEM, Wade D, Hidding A, et al. The association of physical deconditioning and chronic low back pain: a hypothesis-oriented systematic review. Disabil Rehabil 2006;28:673–93.

[70] Haneline M, Cooperstein R. Weighing the reliability and validity of clinical tests. J Amer Chiropr Assoc 2006;43:19–22.

[71] Bertilson BC, Bring J, Sjöblom A, et al. Inter-examiner reliability in the assessment of low back pain (LBP) using the Kirkaldy-Willis classification (KWC). Eur Spine J 2006;15:1695–703.

[72] Lurie JD, Doman DM, Spratt KF, et al. Magnetic resonance imaging interpretation in patients with symptomatic lumbar spine disc herniations: comparison of clinician and radiologist readings. Spine 2009;34:701–5.