Egyptian Journal of Radiology and Nuclear Medicine

RESEARCH

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Role of magnetic resonance neurography in assessment of lumbosacral radiculo-plexopathy: correlation with electrophysiological studies

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Abstract

Background Lumbosacral plexus is a collection of nerves that converge and diverge and finally merge into terminal nerves that innervate the pelvis and lower limbs. Lumbosacral plexopathy is a clinical disease characterized by motor and sensory abnormalities that can result from damage to the lumbosacral plexus by different types of insults. Electrophysiological studies are used to demonstrate the presence of lumbosacral radiculo-plexopathy, but it is restricted owing to deep position of nerves and regional differences in muscle nerve supply. High-resolution MR neurography can simply show the precise site, size, etiology, and type of the lumbosacral radiculo-plexopathy. The aim of this study was to assess the various diseases affecting the lumbosacral plexus with their 1.5-T MR neurography imaging findings and to correlate these findings with electrophysiological studies.

Results Fifty adult patients with clinical presentation of lumbosacral radiculo-plexopathy were included in this cross-sectional study. Based on clinical diagnosis, the sensitivity of electrophysiological studies in diagnosing lumbosacral radiculo-plexopathy was 80% and the sensitivity of MR neurography in diagnosing lumbosacral radiculo-plexopathy was 90%. While based on electrophysiological studies, the sensitivity of MR neurography in diagnosing lumbosacral radiculo-plexopathy was 97.5% and the specificity was 75.86%. There was a high statistically significant relation between the side affected in electrophysiological studies and the side affected in MR neurography and between the stage of the lesion in the electrophysiological studies and in MR neurography among patients ($p \leq 0.001$, $p \leq 0.001$) , respectively.

Conclusions MR neurography of the lumbosacral plexus is a helpful non-invasive approach for the assessment of patients with inconclusive lumbar spine MR imaging because of its ability for diagnosis of neuromuscular lesions and determining their causes. Electrophysiological studies assess the nerve function and MR neurography assesses the nerve anatomy, and therefore, the correlation between electrophysiological studies and MR neurography are complementary for detection of lumbosacral radiculo-plexopathy.

Keywords Lumbosacral radiculo-plexopathy, Magnetic resonance neurography, Electrophysiological studies

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Background

Lumbosacral plexus is a collection of nerves that converge and diverge and finally merge into terminal nerves that innervate the pelvis and lower limbs. Lumbosacral plexopathy is a clinical disease characterized by motor and sensory abnormalities that can result from damage of the lumbosacral plexus by different types of insults [1]. Radiculopathy caused by nerve roots compression or inflammation presents with pain, weakness, and paresthesia anywhere along the nerve supply. Electrophysiological studies such as electromyography (EMG) and nerve conduction studies (NCSs) are used to demonstrate the presence of radiculopathy with a high specificity and low sensitivity [2].

Clinically, it is difficult to distinguish between lumbosacral plexopathy and other spinal abnormalities. The lumbosacral plexus assessment using electrophysiological studies is restricted owing to deep position of nerves and regional differences in muscle nerve supply. High-resolution magnetic resonance neurography (MRN) can simply show the precise site, size, etiology, and type of plexopathy [1]. Advanced MRN, including 2 or 3 D high-resolution T1-weighted image (T1WI), fat-suppressed T2-weighted image (T2WI), or short TI inversion recovery (STIR) image, gives an anatomically precise images of the nerves [3].

In assessment of the lumbosacral plexus, MRN uses a combination of direct imaging criteria for example variations in nerve size, bundle structural features, signal strength, and nerve course, as well as indirect imaging criteria for example perineural fat effacement caused by fibrosis or mass compression, and changes in the denervation of regional muscles [4]. The aim of this study was to assess the various diseases affecting the lumbosacral plexus with 1.5-T MR neurography and to correlate the findings with electrophysiological studies.

Methods

This cross-sectional study was conducted in the Diagnostic Radiology and Neurology Departments. Fifty patients aged ≥18 years of both sexes with clinical manifestations of lumbosacral radiculo-plexopathy attended to the Clinical Neurophysiology unit for electrodiagnosis were included then referred to the Diagnostic Radiology department for MR neurography. The inclusion criteria were persistent symptoms, suspicion of lumbosacral plexus tumors or peripheral nerve masses, neurological symptoms caused by trauma. Patients known to have contraindications to magnetic resonance imaging (MRI) were excluded.

The research was accepted by the faculty of medicine ethical committee. Prior to participation, all participants provided written informed consent. The research was carried out between the months of August 2017 and August 2019.

All subjects were evaluated clinically by history taking (radicular pain, neurological deficit and sphincteric incontinence), general and neurological examination.

All subjects underwent a standardized electrophysiological study by a specialized clinical Neurophysiologist with 10 years of attending experience using a Nihon Kohden Neuropak Model MEB-2300k (Nihon Kohden Corporation, Tokyo, Japan, 2012) EMG machine. The studies were conducted in accordance with the recommendations mentioned in Preston and Shapiro [5]. It was carried out for all subjects before the MR neurography. All the recordings were made with the subjects lying supine on a bed at a skin temperature above 32°C. The frequency ranges of the filters used for motor and sensory studies were: (10 Hz–5 kHz and 20 Hz–2 kHz).

Routine NCSs included peroneal, posterior tibial and femoral motor NCSs, and superficial peroneal and sural sensory NCSs, the waveform latency, amplitude, duration, and conduction velocity were measured. The F-wave latencies of peroneal, posterior tibial nerves were used in the assessment of the proximal nerve segments. Standard procedures for supramaximal percutaneous stimulation employing a constant-current stimulator and surface electrode recording were used for all NCSs. EMG examination was conducted using concentric needle electrodes at rest, minimal and maximal contractions of the involved muscles, and the filter settings were 2 Hz–10 kHz [6].

Lumbosacral radiculopathy was diagnosed by observing neurogenic involvement of two or more muscles supplied by the same nerve root but supplied by different peripheral nerves. The existence of positive sharp waves or fibrillation potentials at rest, and/or morphological changes of motor unit action potential (MUAP) (large amplitude, broad, and polyphasic), and/or decreased recruitment in a minimum two muscles supplied by various peripheral nerves from the same myotome or signs of denervation in paraspinal muscles associated with limb muscle results linked to the myotome were used as criteria for lumbosacral radiculopathy. All stages of radiculopathy were included in the study: acute, subacute, and chronic [6]. In distinguishing lumbosacral plexopathy from radiculopathy, the most useful evidence is the sensory NCS and needle EMG testing of the paraspinal muscles. Abnormal active denervation or MUAP abnormalities in the paraspinal muscles situate the lesion proximal to the plexus, in the nerve roots, but abnormal sensory NCS rules out a lesion at or limited to the nerve roots [6].

Acquisition and processing of MR neurography: Lumbosacral plexus MR neurography using A 1.5 Tesla MR scanner (Philips Medical Systems, Achieva, The

Netherlands) with a high-resolution body coil was carried out within one week after the electrophysiological studies. All subjects were asked to lie supine during the examination. We examined each patient for 40–45 min. The MR neurography protocol is shown in Table 1, and the data and image analysis are shown in Tables 2 and 3. The interpretations were performed by one of three consultant Radiologists with 20–25 years of attending experience.

Statistical analysis

IBM's SPSS statistical analysis software, version 20.0, was used to analyze the data (IBM Corp., Armonk, New York). An analysis of relationships among categorical variables was carried out by means of the Chi-squared test. The Mann Whitney test was used for non-normally distributed ordinal or continuous dependent variables for comparison between two independent groups. The Kappa test was utilized as a test of agreement, sensitivity, specificity; positive predictive value (PPV), negative predictive value (NPV) and accuracy were obtained. Significance of the gained results was mediated at the 5% level.

Results

This study included 50 patients with a clinical presentation of lumbosacral radiculo-plexopathy, from 18 to 78 years old, they had a mean age of 41.2 ± 18.4 years, there were 23 males (46%) and 27 females (54%). The other demographic and clinical data are displayed in Table 4.

Table 1 Lumbosacral plexus magnetic resonance neurography imaging protocol [1]

MR sequence	Area	Slice thickness (mm)	TR/TE (ms)	Base resolution (pixels)	Field of view (cm)
Axial T1	Bilateral	4	800/12	832	33
Coronal T1	Bilateral	4	960/12	384	36–38
Axial T2 SPAIR	Bilateral	4	4890/80	256	33
Sagittal T2 3D VISTA	Lumbar spine	1	1000/97	256	28
Sagittal STIR	Bilateral	4	3700/18	256	28
Coronal STIR 3D VISTA	Bilateral	1.5	1500/91	256	36–38

T1 = T1 weighted image, T2 = T2 weighted image, SPAIR = spectral adiabatic inversion recovery, VISTA = volume isotropic turbo spin echo acquisition, STIR = short inversion time inversion recovery, TE = Echo time, 3D = three-dimensional, TR = repetition time

Table 2 Magnetic resonance neurography imaging findings of peripheral nerves [1]

Parameter	Normal	Pathological
Size	Like neighboring artery and declines distally	Focal or diffuse swelling, greater than neighboring arteries
Signal intensity	Both T1 and T2 -weighted imaging are isointense to skeletal muscle	T2-weighted imaging is hyperintense like neighboring veins
Fascicular structure	Maintained on T1 and T2 -weighted imaging	fascicular swelling, blurring or distortion
Course	Smooth delineated by fat with no focal deviation	discontinuity or deviation whether focal or diffuse
Enhancement	Absent except for posterior root ganglion or blood-nerve barrier deficiency	Existing in tumor, infection, inflammation due to interruption of blood-nerve barrier
Perineural fat Planes	Maintained and clean	Effaced

T1 = T1 weighted image, T2 = T2 weighted image

Table 3 Denervation changes in skeletal muscles as seen in magnetic resonance neurography [1]

Duration	Imaging findings
Acute (less than 1 month)	T2-weighted images hyperintense areas of edema
Subacute (1–3 months)	T2-weighted images hyperintense areas of edema and T1-weighted images hyperintense areas of fatty infiltration
Chronic (more than 3 months)	T1-weighted images hyperintense areas of fatty infiltration and decreased muscle volume of atrophy

T1 = T1 weighted image, T2 = T2 weighted image

Table 4 Demographics and clinical data among patients

	Patients (*n* = 50)
Age (years)	
Mean ± SD	37 (18–78)
Median (Min.–Max.)	41.2 ± 18.4
Sex	
Male	23 (46%)
Female	27 (54%)
BMI (kg/m^2)	
Median (Min.–Max.)	28 (22.5–31.2)
Mean ± SD	27.4 ± 2.1
Chronic disease	
No	29 (58%)
Hypertension	14 (28%)
Diabetes mellitus	4 (8%)
Cardiac disease	2 (4%)
Renal disease	1(2%)
Complaint	
Low back pain	32 (64%)
Sensory	24 (48%)
Motor	4 (8%)
Mixed (motor &sensory)	22 (44%)
Sphincteric disturbance	2 (4%)
Affected side	
Right	8 (16%)
Left	11 (22%)
Bilateral	31 (62%)
Clinical severity	
Mild	4 (8%)
Moderate	33 (66%)
Severe	13 (26%)
Duration in months	
Median (Min.–Max.)	12 (1–84)
Mean ± SD	21.7 ± 24

Min minimum, *Max* maximum, *SD* standard deviation, *BMI* body mass index

Different diagnoses of lumbosacral radiculo-plexopathy among patients according to electrophysiological studies are shown in Table 5, and according to MR neurography are shown in Table 6. The different MR neurography imaging findings of the roots, peripheral nerves and muscles among patients are shown in Table 7.

Figure 1 shows the confirmed diagnosis of lumbosacral radiculo-plexopathy using electrophysiological studies and MR neurography among patients. Based on clinical diagnosis, the sensitivity of electrophysiological studies in diagnosing of lumbosacral radiculo-plexopathy was 80%, PPV was 97.56%, NPV was 65.52% and the accuracy was 84.29%, while the sensitivity of MR neurography in diagnosing lumbosacral radiculo-plexopathy was 90%, PPV was 95.74%, NPV was 78.26% and the accuracy was 90% (Table 8).

Based on electrophysiological studies, the sensitivity of MR neurography in diagnosing lumbosacral radiculoplexopathy was 97.5% and the specificity was 75.86%., PPV was 84.78%, NPV was 95.65% and the accuracy was 88.41% (Table 9).

There was a high statistically significant relation between the clinically affected side and the side affected in electrophysiological studies and MR neurography ($p \leq 0.001$and < 0.001), respectively, among patients (Table 10).

There was a high statistically significant relation between the side affected in electrophysiological studies and the side affected in MR neurography ($p \leq 0.001$) among patients there was a very good agreement between both tests ($\kappa = 0.820$ and $p < 0.001$) and the percentage of agreement was 88% (44/50) (Table 11).

There was a high statistically significant relation between the stage of the lesion in the electrophysiological studies and MR neurography among patients ($p \leq 0.001$) and there was a good agreement between both tests ($\kappa = 0.725$ and $p < 0.001$) and the percentage of agreement was 82% (41/50) (Table 12).

There was a very good interobserver agreement regarding the affected side, stage, and diagnosis in MR neurography ($\kappa = 0.911$, 0.904, and 0.957, respectively) and agreement percentage = 94.0%, 94.0%, 96.0%, respectively) (Table 13).

Discussion

The diagnosis of different nerve diseases mostly relied on electrophysiologic studies which are relatively invasive and operator dependent. Cross-sectional imaging, especially MRI, is playing an increasingly important role in modern medicine. Because of its noninvasive operator-independent procedure, MR imaging can be used to diagnose injuries, distinguishing between those who can be treated surgically and those who can't be [7]. High-resolution MRN can simply show the precise site, size, etiology, and type of plexopathy [1].

The aim of this study was to assess the various diseases affecting the lumbosacral plexus with their 1.5-T MR neurography imaging findings and to correlate these findings with electrophysiological studies (Figs. 2, 3, 4, 5, 6).

In the present study, we found that the diagnosis of lumbosacral radiculo-plexopathy based on clinical diagnosis and by using electrodiagnostic studies was confirmed in 80% and by using MRN was confirmed in 90%

This agrees with the findings of Wadhwa et al. [8], who stated that MRI of the LS spine is a reproducible and

Table 5 Different electrophysiological diagnoses of lumbosacral radiculo-plexopathy among patients

Diagnosis	Total (*n* = 50)	Age (years)		
		18– < 40 (*n* = 17)	40–59 (*n* = 18)	≥ 60 (*n* = 15)
Normal	10 (20%)	7 (14.0%)	3 (6.0%)	0 (0.0%)
L5 radiculopathy	8 (16%)	1 (2.0%)	3 (6 .0%)	4 (8.0%)
L5, S1 radiculopathy	4 (8%)	1 (2.0%)	2 (4.0%)	1 (2.0%)
L4, L5 radiculopathy	5 (10%)	1 (2.0%)	1(2.0%)	3 (6.0%)
L4, L5 and S1 radiculopathy	10 (20%)	0 (0.0%)	4 (8.0%)	6 (12.0%)
Sciatic neuropathy	4 (8%)	1 (2.0%)	2 (4.0%)	1 (2.0%)
Femoral neuropathy	1 (2%)	1 (2.0%)	0 (0.0%)	0 (0.0%)
Lumbosacral plexopathy	1 (2%)	0 (0.0%)	1 (2.0%)	0 (0.0%)
Acute demyelinating polyneuropathy	4 (8%)	3 (6.0%)	1 (2.0%)	0 (0.0%)
Chronic demyelinating polyneuropathy	3 (6%)	2 (4.0%)	1 (2.0%)	0 (0.0%)

L4 = lumbar 4, L5 lumbar 5, S1 = Sacral 1

Table 6 Different MR neurography diagnoses of lumbosacral radiculo-plexopathy among patients

Diagnosis	Total (*n* = 50)	Age (years)		
		18– < 40 (*n* = 17)	40–59 (*n* = 18)	≥ 60 (*n* = 15)
Normal	5 (10%)	4(8.0%)	1(2.0%)	0 (0.0%)
L5 radiculopathy	7 (14%)	1(2.0%)	2(4.0%)	4(8.0%)
L4, L5 radiculopathy	5 (10%)	0(0%)	4 (8.0%)	1 (2.0%)
L5, S1 radiculopathy	4 (8%)	1(2.0%)	1(2.0%)	2(4.0%)
L4, L5, S1 radiculopathy	5 (10%)	1(2.0%)	1 (2.0%)	3 (6.0%)
L4, L5, S1 radiculopathy and sciatic neuropathy	3 (6%)	0(0.0%)	1(2.0%)	2 (4.0%)
L4, L5, S1 radiculopathy, sciatic and inferior gluteal neuropathy	1 (2%)	0 (0.0%)	0 (0.0%)	1(2.0%)
Sciatic neuropathy	3 (6%)	1 (2.0%)	1 (2.0%)	1 (2.0%)
Sciatic and pudendal neuropathy	1 (2%)	0 (0.0%)	1 (2.0%)	0 (0.0%)
Sciatic nerve injury	2 (4%)	0(0.0%)	1 (2.0%)	1 (0.0%)
Femoral nerve injury	1 (2%)	1 (2.0%)	0 (0.0%)	0(0.0%)
Acute demyelinating polyneuropathy	4 (8%)	3 (6.0%)	1(2.0%)	0 (0.0%)
Chronic demyelinating polyneuropathy	3 (6%)	2 (4.0%)	1 (2.0%)	0 (0.0%)
Lymphoma	1 (2%)	1 (2.0%)	0 (0.0%)	0 (0.0%)
Lumbosacral nerve sheath tumor	3 (6%)	0 (0.0%)	3 (6.0%)	0 (0.0%)
Schwannoma of sciatic nerve	1 (2%)	1 (2.0%)	0 (0.0%)	0 (0.0%)
Plexiform neurofibroma	1 (2%)	1 (2.0%)	0 (0.0%)	0 (0.0%)

L4 = lumbar 4, L5 lumbar 5, S1 = Sacral 1

non-invasive diagnostic technique; however, its usefulness may be constrained by a variety of circumstances., including the existence of multiple disc herniations or several level nerve compressions findings in adults of middle aged and older age groups, low-resolution imaging that does not include the sacroiliac joint or pelvis or thin slice 3D evaluation. Finally, the reader concentrates on assessment of the cause (disc herniation) not the effect (nerve inflammation or entrapment). So, the examination of peripheral nerve disorders with MRN has become increasingly commonly used in clinical practice.

Furthermore, it was shown that MRN of the LS plexus provides a novel method of examination of the spine with the axial T1W, axial T2 SPAIR and coronal 3D IR TSE imaging substituted the traditional MR spine sagittal T1W and STIR imaging. As a result, the entire lower abdomen and pelvis can be completely covered. By doing so, both healthy and diseased peripheral nerves can be shown in high resolution over multiple planes [4, 9].

The sensitivity of electrophysiologic studies has been shown to be between 49 and 86% in prior studies of patients with clinically suspected radiculopathy [10]. In a

Table 7 Different MR neurography imaging findings of the roots, peripheral nerves, and muscle denervation changes among patients

	Patients ($n=50$)
Size	
Diffuse thickening	19 (38%)
Focal thickening	20 (40%)
Mass	6 (12%)
Course	
Smooth without focal deviations	40 (80%)
Focal deviation	3 (6%)
Diffuse deviation	6 (12%)
Complete discontinuity	1 (2%)
Signal intensity	
Normal	5 (10%)
Hyperintense on T2WI	45 (90%)
Enhancement	
No contrast was used	45 (90%)
Enhanced post-contrast injection	5 (10%)
Muscle denervation changes	
No	13 (26%)
Acute	1 (2%)
Subacute	9 (18%)
Chronic	27 (54%)

T2WI = T2-weighted image

former study done by Nardin et al. [11], EMG and MRI abnormalities correlated with clinical findings in only 55% and 57% of patients, respectively, and in the study done by Bäumer et al. [12] the sensitivity and specificity of MRN were 83% and 85%, respectively. The difference in the sensitivity and specificity between them and our study can be explained by the difference in population size (50 in our study versus 20 in their study) and the more heterogenous group of pathologies present in our study.

In this study, the nerve size was assessed as a marker for nerve abnormalities on MRN. Diffuse and localized thickening were found in 19 (38%) and 20 (40%) individuals, respectively. On the other hand, Chazen et al. [13] did not find nerve diameter to be a relevant indicator in this context. Because the diseased nerves in their cohort had a size close to that of normal nerves. However, because of their oblique orientation, it is challenging to consistently estimate the caliber of nerve fascicles without including the perineural fat and soft tissues. This finding supports the usefulness of MR neurography and raises the possibility that abnormally large nerves could serve as a valuable marker for nerve pathology [13].

Intraneural hyperintense T2 signal, a marker for nerve abnormalities on MRN, was also investigated in this study and was discovered in 45 (90%) of the patients. According to Chazen et al. [13], lumbosacral MR neurography seems to show aberrant intraneural signal in a significant proportion of individuals with clinical complaints of lower limb radiculopathy and coincides with electromyography results of active radiculopathy. This finding supports the usefulness of MR neurography and supports implying that aberrant intraneural signals are a helpful marker for nerve pathology.

Imaging findings of muscle denervation were seen in 37% of the patients in the current study and were useful in confirming neuropathy when identified. Soldatos et al. [1] recorded evidence of muscle denervation when a T2 hyperintense signal was detected inside the lumbosacral musculature, while the relatively low rate of detected muscle denervation in acute lesions (2%) may be due to imaging being performed during the active stage of radiculopathy.

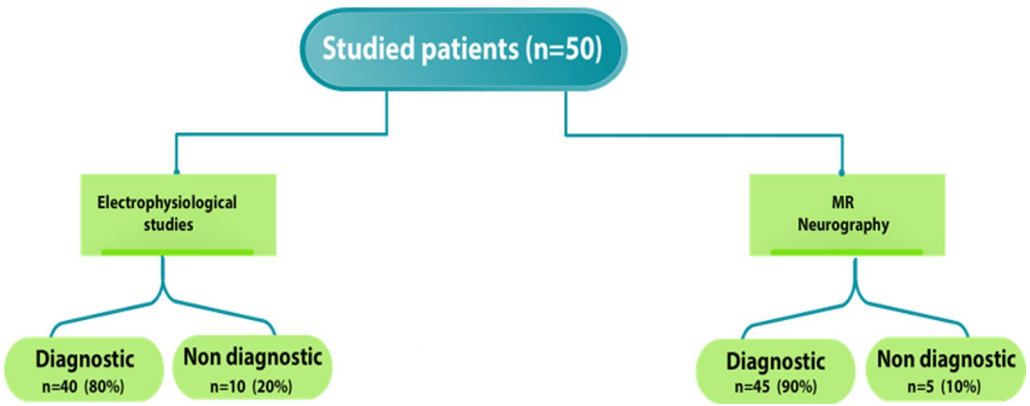

Fig. 1 Diagnosis of lumbosacral radiculo-plexopathy using MR neurography and electrophysiological studies among patients ($n=50$)

Table 8 Sensitivity of electrophysiological studies and MR neurography based on clinical diagnosis in diagnosing lumbosacral radiculo-plexopathy

	Patients ($n=50$)	Sensitivity (%)	PPV (%)	NPV (%)	Accuracy (%)
Electrophysiological studies					
Normal	10 (20%)	80.0	97.56	65.52	84.29
Abnormal	40 (80%)				
MR neurography					
Normal	5 (10%)	90.0	95.74	78.26	90.0
Abnormal	45 (90%)				

PPV positive predictive value, *NPV* negative predictive value

In the present study, the relation between the clinically affected side and the side affected in MR neurography was compared, the total agreement between both tests was 74%. Clinical, electrophysiological, and surgical results have been demonstrated to correlate well with high field (3 T) and 1.5 T imaging [7, 12, 14–16]. Chhabra et al. [17] stated that MRN always provides excellent anatomical images of the LS plexus, and in roughly 80% of cases, it validates the clinical diagnosis.

Soldatos et al. [1] demonstrated that when other tests fail to discover a cause or confirm the clinical diagnosis of radiculopathy, MRN can accurately determine the findings correlating to the side of symptoms. In addition, it allows for a more in-depth evaluation of anatomy and lesions that is not achieved with other modalities. Lee et al. [15] demonstrated that 1.5 and 3 T MRN techniques have shown good correlations between MRN and clinical and electrophysiological findings. Barr et al. [2] demonstrated that electrophysiological investigations and MR lumbar spine results have been shown to be useful in the diagnosis of LS radiculopathy. Chazen et al. [13] stated that MRN provides accurate diagnostic evidence, and the correlation with EMG additionally strengthens its accuracy.

In the present study, the relation between the affected side in electrophysiological studies and the affected side in MRN was compared and the total agreement was 88%. Narayanaswami et al. [18] said that even if they are useful, electrophysiologic studies have limitations as a diagnostic gold standard. Moreover, both NCS and EMG results are subject to inconsistency in performance and explanation. Commonly, electrophysiologic investigations show normal NCS in addition to abnormal needle EMG in individuals with active radiculopathy. This form is often seen when a disc herniation occurs proximal to the dorsal root ganglion, in a lateral recess or subarticular space, which protects the sensory nerve fibers. If a neuropathic lesion is present, signs of denervation will be detected by needle EMG due to ongoing or active axonal loss [13].

In the present study, the relation between the stage of the lesion in electrophysiological studies and in MRN were compared and the total agreement was 82%.

Chazen et al. [13] said that it is not always obvious from NCS/EMG how long a patient has been experiencing radiculopathy, although certain results can restrict the window, such as the MUAP morphology. It may take some time for NCS/EMG evidence of active denervation

Table 10 Relation between the clinically affected side and the affected side in MR neurography and electrophysiological studies in patients ($n=50$)

Affected side	Clinically affected side			χ^2	p
	Right ($n=8$)	Left ($n=11$)	Bilateral ($n=31$)		
Electrophysiological studies					
Normal	4 (8%)	4 (8%)	2 (4%)	37.233*	< 0.001*
Right	3 (6%)	0 (0%)	2 (4%)		
Left	0 (0%)	7 (14%)	3 (6%)		
Bilateral	1 (2%)	0 (0%)	24 (48%)		
MR neurography					
Normal	3 (6%)	0 (0%)	2 (4%)	41.606*	< 0.001*
Right	4 (8%)	0 (0%)	3 (6%)		
Left	0 (0%)	11 (22%)	4 (8%)		
Bilateral	1 (2%)	0 (0%)	22 (44%)		

χ^2 Chi square test, p p value

*Statistically significant at $p \leq 0.05$

Table 9 Sensitivity, specificity of MR neurography based on electrophysiological studies in the diagnosis of lumbosacral radiculoplexopathy

MR neurography	Electrophysiological studies		Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
	Normal	Abnormal					
Patients ($n=50$)	($n=10$)	($n=40$)					
Normal	4 (40%)	1 (2.5%)	97.5	40.0	86.67	80.0	86.0
Abnormal	6 (60%)	39 (97.5%)					

PPV positive predictive value, *NPV* negative predictive value

Table 11 Relation between the affected side in electrophysiological studies and MR neurography in patients ($n=50$)

Affected side	Electrophysiological studies				χ^2	*p*
	Normal ($n=10$)	Right ($n=5$)	Left ($n=10$)	Bilateral ($n=25$)		
MR neurography						
Normal	4 (8%)	0 (0%)	0 (0%)	1 (2%)	72.209*	< 0.001*
Right	2 (4%)	5 (10%)	0 (0%)	0 (0%)		
Left	4 (8%)	0 (0%)	10 (20%)	1 (2%)		
Bilateral	0 (0%)	0 (0%)	0 (0%)	23 (46%)		
κ (p)	0.820 (< 0.001*) very good agreement					
% Of agreement	44/50 (88%)					

χ^2 chi square test, κ kappa test, *p* *p* value

*Statistically significant at $p \leq 0.05$

to appear; denervation is first detectable after axonal injury when Wallerian degeneration sets in. Active denervation with normal MUAP morphology reflects a subacute insult, during which reinnervation of the muscles has not yet taken place. When a patient with genuine radiculopathy finally seeks medical help, there are usually electrophysiologic abnormalities. Electrophysiologic studies has numerus limits for instance when a primary myopathy or peripheral neuropathy is present on top LS radiculopathy, the results can be misleading. Additionally false negative results with vague findings despite actual radiculopathy are widespread due to a fascicular phenomenon and variations in electromyographer skill and expertise, which make the NCS/EMG extremely operator dependent.

Despite these restrictions, active radiculopathy evaluation with EMG is still useful investigation and the American Association of Neuromuscular and Electrodiagnostic Medicine recommends electrophysiologic studies for the evaluation of lumbosacral radiculopathy as class II evidence and level B recommendation [19].

Since MR neurography is highly sensitive while electrophysiological tests are highly specific, the two methods often work together to provide very useful supportive information. So, training on the performance and interpretation of MR neurography should be encouraged to be routinely used with electrophysiological studies in diagnosis of lumbosacral radiculo-plexopathy.

Table 13 Interobserver agreement of MR neurography diagnosis

MR neurography	Observer 1 vs observer 2		
	κ	*p*	% of agreement
Affected side	0.911	< 0.001*	47/50 (94.0%)
Stage	0.904	< 0.001*	47/50 (94.0%)
Diagnosis	0.957	< 0.001*	48/50 (96.0%)

κ kappa test, *p* *p* value

*Statistically significant at $p \leq 0.05$

Table 12 Relation between the stage of the lesion in electrophysiological studies and MR neurography among patients ($n=50$)

	Electrophysiological study stage				χ^2	*p*
	Normal ($n=10$)	Acute ($n=8$)	Subacute ($n=6$)	Chronic ($n=26$)		
MR neurography stage						
Normal	4 (8%)	1 (2%)	0 (0%)	0 (0%)	59.448*	< 0.001*
Acute	3 (6%)	5 (10%)	1 (2%)	0 (0%)		
Subacute	2 (4%)	2 (4%)	5 (10%)	1 (2%)		
Chronic	1 (2%)	0 (0%)	0 (0%)	25 (50%)		
κ (*p*)	0.725 (< 0.001*) good agreement					
% Of agreement	41/50 (82%)					

χ^2 chi square test, κ kappa test, *p* *p* value

*Statistically significant at $p \leq 0.05$

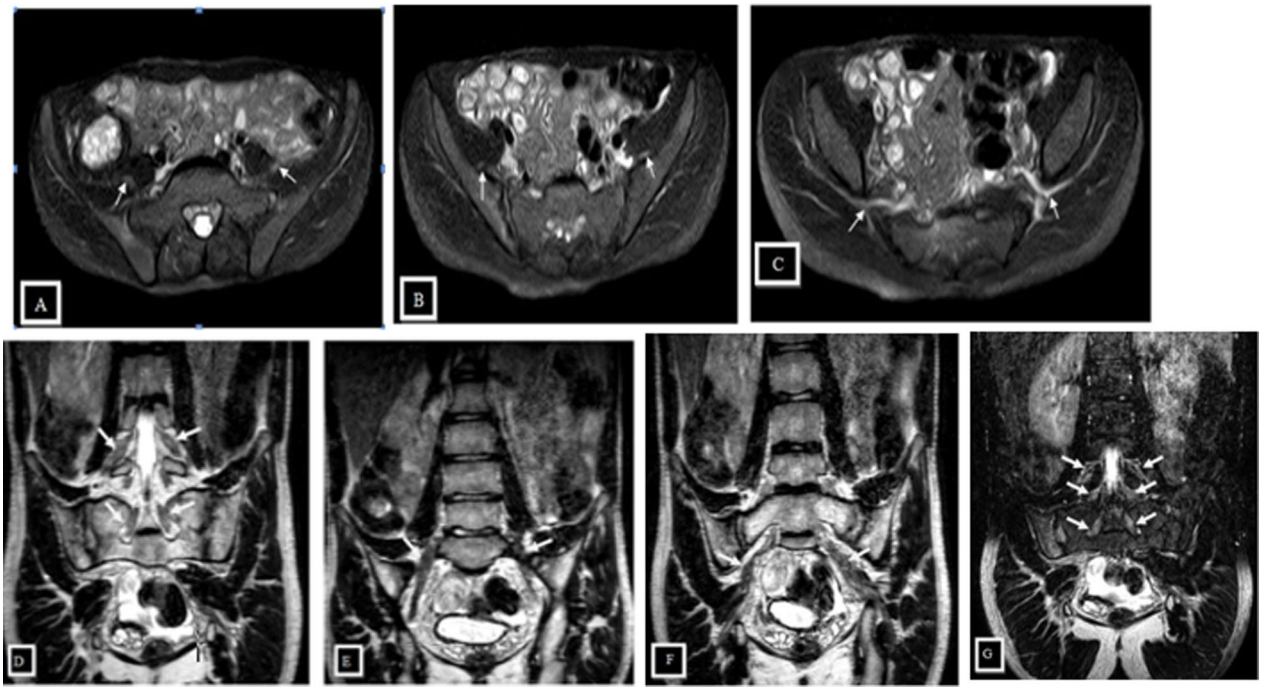

Fig. 2 A 20-year-old male with bilateral lower limb weakness for 2 years with electrophysiological evidence of chronic inflammatory demyelinating polyneuropathy. MR neurography showed chronic polyneuropathy: Axial T2 SPAIR images (**A**–**C**) show thickening and mild hyperintensity of right and left femoral nerves (short arrows in **A**), right and left obturator nerves (short arrows in **B**) and both sciatic nerves (short arrows in **C**). Coronal 3D VISTA (**D**, **E**) images show diffuse thickening of bilateral L4, L5 and S1 nerve roots (arrows in **D**, **E**). Coronal 3D VISTA image (**F**) shows diffuse thickening of both sciatic nerves (more at Lt. side). Coronal 3D VISTA STIR (**G**) image shows diffuse thickening and mild hyperintensity of bilateral L4, L5 and S1 nerve roots

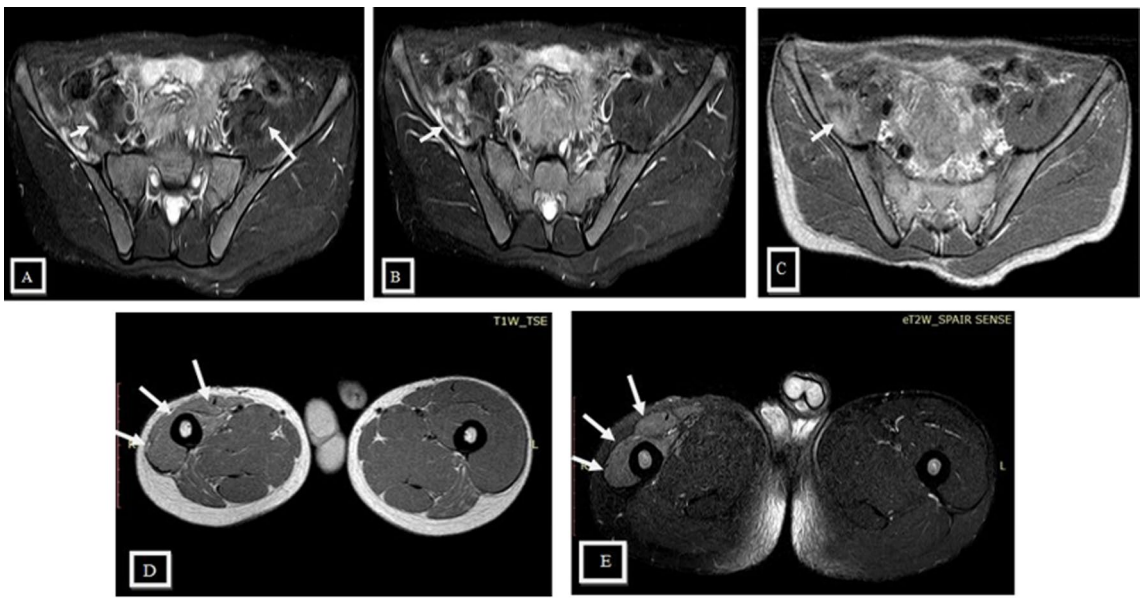

Fig. 3 A19-year-old male with right hip flexion weakness for 2-month duration following motor car accident with electrophysiological evidence of subacute severe partial axonal lesion of right femoral nerve proximal to innervation of right rectus femoris muscle. MR neurography showed right femoral nerve injury: Axial T1 and T2 SPAIR images through the pelvis (**A**–**C**) show thickening and hyperintensity of right femoral nerve as it passes between the right psoas muscle and iliacus muscle without discontinuity and with no neuroma formation (short arrow in **A**) with hyperintense signal of right iliacus muscle seen in T1 and T2 SPAIR images denoting muscle hematoma (arrows in **B** and **C**). Note the left femoral nerve normal size and signal intensity (long arrow in A). Axial T1 (**D**) and T2 SPAIR (**E**) images of the proximal thigh demonstrate moderate loss of the right extensor muscle bulk denoting muscle denervation changes (arrows in **D** and **E**)

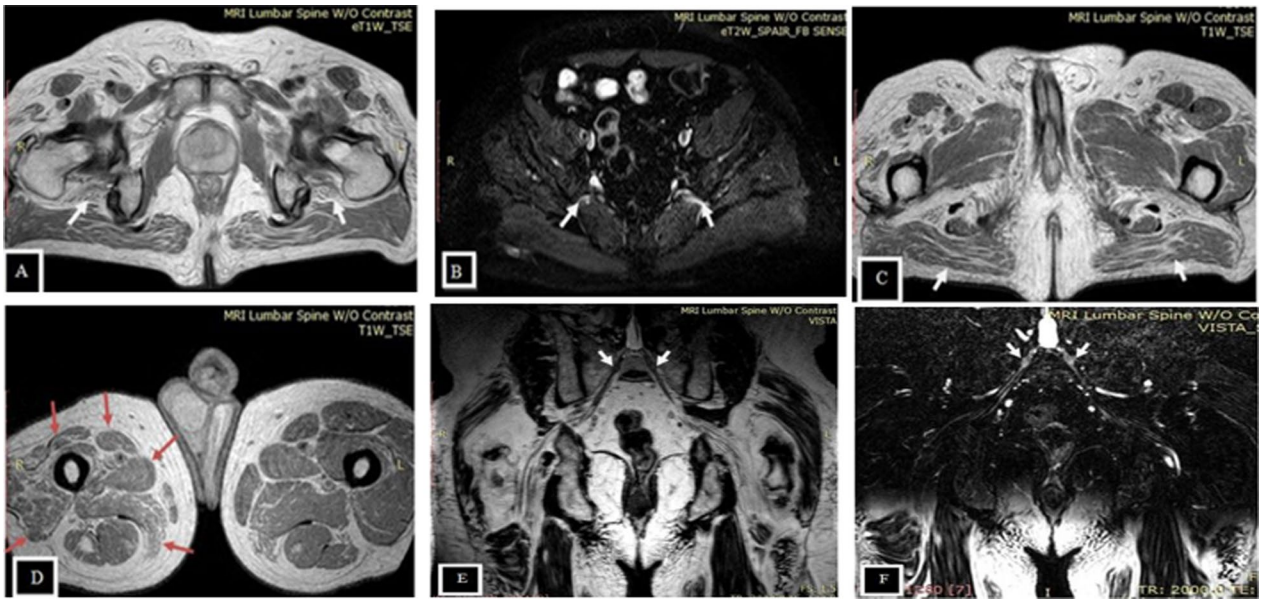

Fig. 4 A 63-year-old male with bilateral foot drop for 3 years with electrophysiological evidence of bilateral chronic severe partial axonal lesion of sciatic nerves. MR neurography showed bilateral sciatic neuropathy: **A** Axial T1 and **B** T2 SPAIR images demonstrate thickening and hyperintensity of both sciatic nerves (arrows in B) with enlarged fascicles of both sciatic nerves (arrows in **A**). Axial T1 images through the pelvis and upper thigh (**C** and **D**) show chronic muscle denervation changes involving both gluteal maximus muscles (arrow in **C**) and right thigh muscles (arrows in **D**). Coronal 3D VISTA (**E**, **F**) images show focal thickening and hyperintensity of bilateral L5 and S1 nerves (arrows in **E**, **F**)

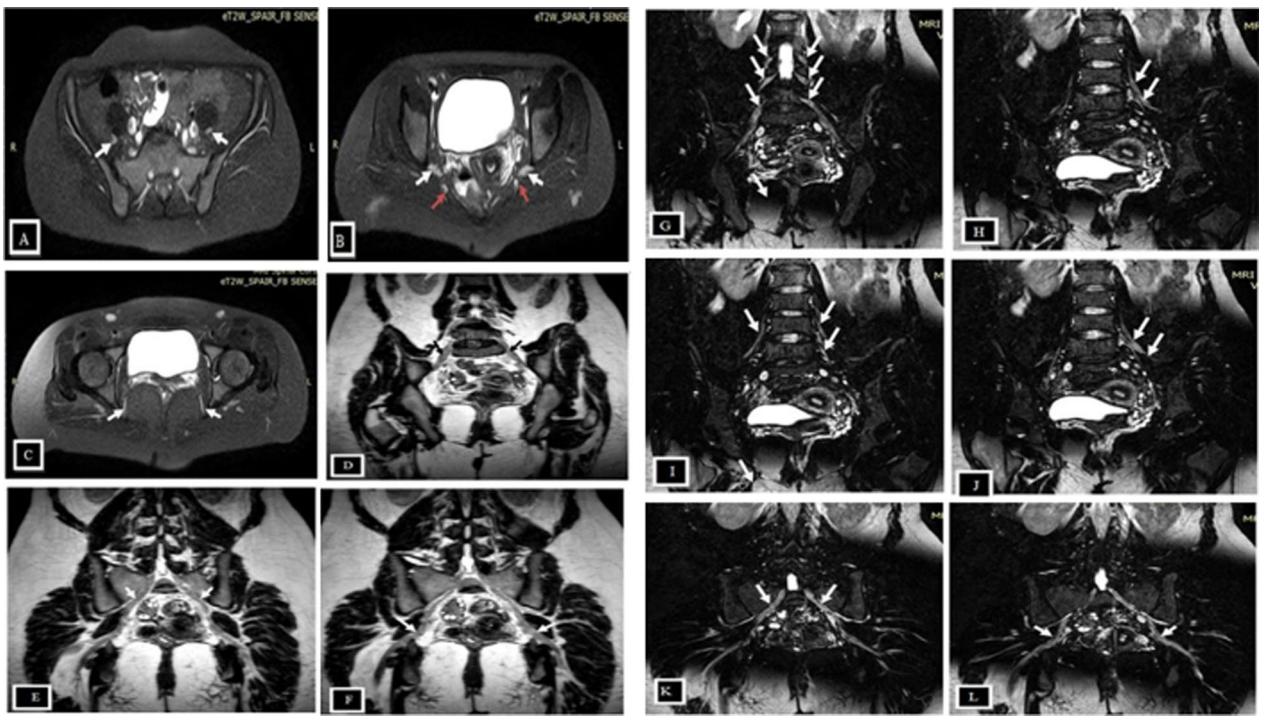

Fig. 5 A 25-year-old female with bilateral upper and lower limb weakness for 1 month with electrophysiological evidence of acute inflammatory demyelinating polyneuropathy. MR neurography showed Acute polyneuropathy**:** Axial T2 SPAIR images (**A**–**C**) show hyperintense both femoral nerves (arrows in **A**), both sciatic nerves (white arrows in B), both inferior gluteal nerves (red arrows in **B**) and both pudendal nerves (arrows in **C**). Coronal 3D VISTA (**D**–**F**) images show diffuse thickening of both L5 (arrows in **D**) and S1 nerves (arrows in **E**) and both sciatic nerves (arrows in **F**). Coronal 3D VISTA STIR (**G**–**L**) images show hyperintensity of the entire lumbosacral plexus nerves (arrows in G, H, I and K) and both sciatic nerves (arrows in **L**)

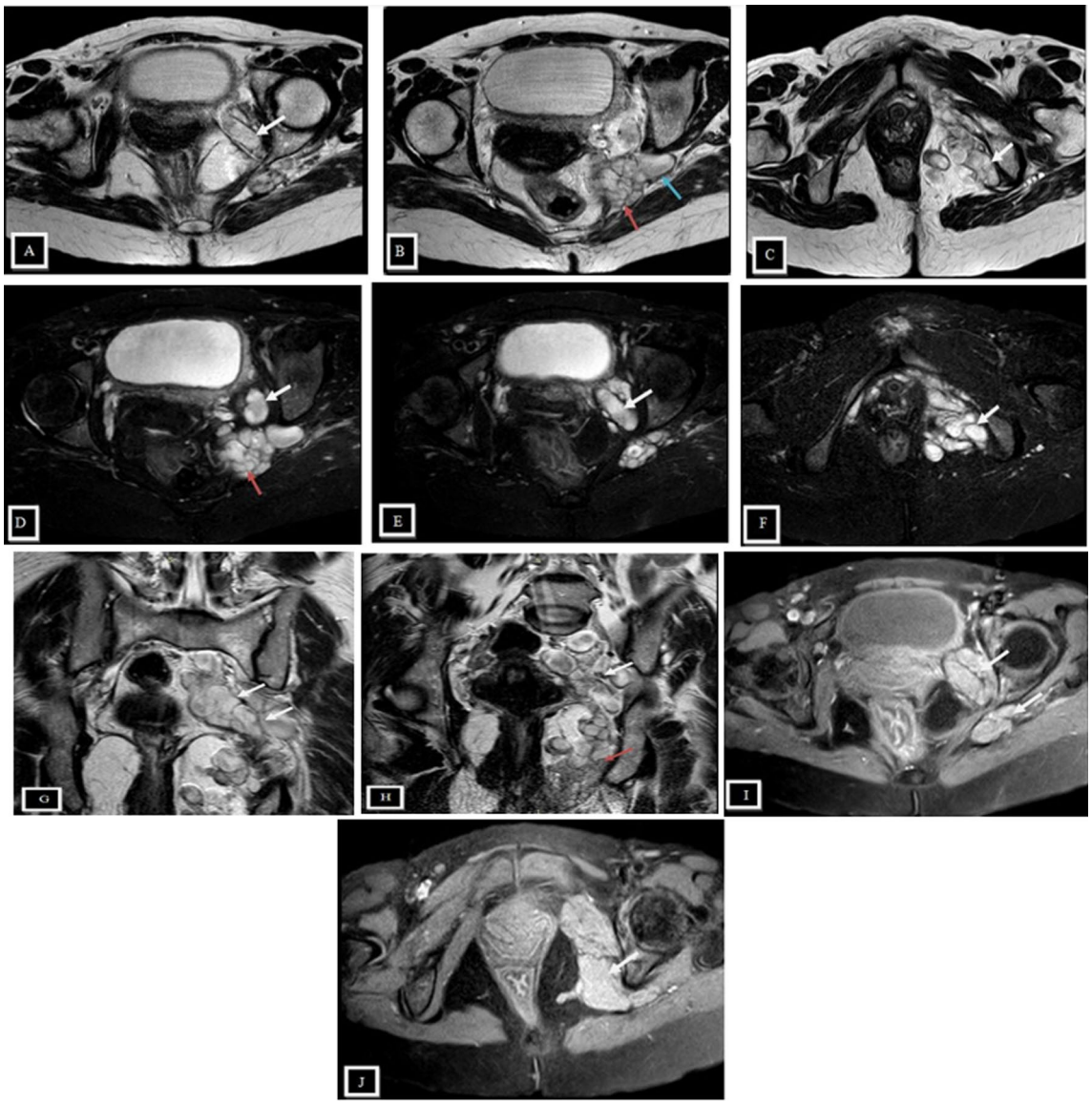

Fig. 6 A 35 -year-old female with deep pelvic pain, Lt. groin pain and Lt. sciatica for 6 months with electrophysiological evidence of subacute left lumbosacral plexopathy. MR neurography showed Plexiform neurofibroma: Axial T2 (**A**–**C**) and T2 SPAIR (**D**–**F**) images through the pelvis show numerous hyperintense peripheral nerve sheath tumors which demonstrate the target sign (white arrow in **D**) involving the Lt. sciatic nerve (blue arrow in **B**), Lt. inferior gluteal nerve (red arrows in **B** and **D**), Lt. obturator nerve (white arrows in **A** and **E**) and Lt. pudendal nerve (white arrows in **C** and **F**). Coronal 3D VISTA images through the lower abdomen and pelvis (**G** and **H**) show diffuse enlargement of the Lt. sciatic nerve (white arrows in **G**), Lt. obturator nerve (white arrow in **H**) and Lt. pudendal nerve (red arrow in **H**) with multifocal lesions demonstrating the target sign. Post contrast images (**I**, **J**) show homogenous enhancement of the multifocal lesions (white arrows in **I** and **J**)

This study had some limitations, including inconsistencies in the timing of clinical notes, second, there were also difficulties with MRN interpretation, third, there was no follow-up, and fourth non-availability of 3-Tesla MRI scanner and diffusion weighted images. As a result, we recommend future extended studies to be done in a randomized, controlled method to solidify our findings and eliminate any potential bias.

Conclusions

MR neurography of the lumbosacral plexus is a helpful non-invasive approach for the assessment of patients with inconclusive lumbar spine MR imaging because of its ability for diagnosis of neuromuscular lesion and to determine its cause. Electrophysiological studies assess nerve function and MR neurography assesses anatomy,

and therefore, the correlation between electrophysiological studies and MRN, is complementary for detection of lumbosacral radiculo-plexopathy.

Abbreviations

EMG	Electromyography
Hz	Hertz
LS plexus	Lumbosacral plexus
MRN	Magnetic resonance neurography
MRI	Magnetic resonance imaging
MUAP	Motor unit action potential
NCSs	Nerve conduction studies
SPAIR	Spectral adiabatic inversion recovery
STIR	Short inversion time inversion recovery
TR	Repetition time
TE	Echo time
T1WI	T1-weighted image
T2W I	T2-weighted image
VISTA	Volume isotropic turbo spin echo acquisition
3D	Three-dimensional
2D	Two-dimensional

Acknowledgements
Not applicable.

Author contributions
H.M. carried out the study conception and design, participated in its design, acquisition of data and coordination, and drafted the manuscript. E.A. carried out the design of the study, the analysis and interpretation of data and helped to draft the manuscript. E.M. participated in the sequence alignment, interpretation of data and drafting of manuscript. F.S. carried out the study conception and design, participated by acquisition of data and performed the statistical analysis and drafted the manuscript. A.R. carried out the study conception and design, participated in its design acquisition of data and coordination, and drafted the manuscript. All authors read and approved the final manuscript.

Funding
The authors were responsible for the cost of this study including the design of the study and collection, analysis, and interpretation of data and in writing the manuscript and no funding.

Availability of data and materials
Availability of data and materials: the data can be publicly available at the Faculty of Medicine, Suez Canal University.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics committee of Suez Canal Faculty of medicine on June 13, 2017. Committee Number: 3165. An informed written consent was taken from all the participants in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests (financial or non-financial).

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Received: 3 November 2022 Accepted: 1 May 2023
Published online: 09 May 2023

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