Radiology

ORIGINAL RESEARCH • MUSCULOSKELETAL IMAGING

High-Resolution US versus MR Neurography for Diagnosis of Upper Extremity Peripheral Nerve Disorders

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See also the editorial by Deshmukh in this issue.

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Background: High-resolution imaging methods help provide important pathologic and morphologic information in diagnosing peripheral nerve disorders, but their diagnostic roles remain unclear due to limited clinical evidence.

Purpose: To investigate the diagnostic performance of high-resolution nerve US (HRUS) and MR neurography (MRN).

Materials and Methods: This prospective, observational, single-center cohort study included 800 participants who were referred for clinically suspected peripheral neuropathy in the upper extremity from November 2015 to February 2022. Participants underwent both HRUS and MRN, performed and interpreted independently by experienced neuroradiologists. Accuracy, sensitivity, and specificity of HRUS and MRN in correct diagnosis of peripheral neuropathy were calculated in reference to the final diagnosis, based on compound results of clinical, electrophysiologic, imaging, surgical, and histopathologic findings, and compared by using McNemar test and χ^2 testing.

Results: In total, 800 participants (431 male, 369 female; mean age, 47.8 years ± 16.5) were included. Overall, MRN had higher accuracy (85.4% [95% CI: 82.7, 87.8] vs 70.6% [95% CI: 67.3, 73.8], respectively; $P < .001$) and sensitivity (91.6% [95% CI: 89.1, 93.7] vs 68.6% [95% CI: 64.8, 72.2], respectively; $P < .001$), whereas HRUS had higher specificity (76.4% [95% CI: 69.9, 81.8] vs 66.2% [95% CI: 59.1, 72.8], respectively; $P < .001$) in helping to diagnose peripheral neuropathy.

Conclusion: In helping to diagnose peripheral neuropathies in the upper extremity, MRN achieved higher accuracy and sensitivity, whereas HRUS achieved higher specificity.

Supplemental material is available for this article.

Disorders of the peripheral nervous system are a heterogeneous group with increasing prevalence among the general population (1). Current state of the art in the diagnostic work-up includes a thorough clinical examination, electrophysiologic studies, and laboratory tests (2). Nerve conduction studies provide information about the integrity of axons and their myelin sheath and ideally about the location, acuity, and severity of peripheral nerve lesions (3). However, in clinical practice, the specificity and spatial resolution of electrophysiologic findings are often limited, especially in cases of multiple nerve lesions. Moreover, proximal nerve segments are difficult to assess, and morphologic information cannot be retrieved (3,4). Accordingly, 20%–30% of peripheral nerve disorders remain idiopathic (5), and a targeted therapy remains elusive.

High-resolution imaging methods have entered the field, showing essential complementary information about peripheral neuropathies, including morphologic structure, location, and relationship to surrounding tissue (6,7). High-resolution nerve US (HRUS) is an inexpensive and dynamic modality with high spatial resolution, especially for superficially located nerves. Treatment of patients with peripheral neuropathies of different etiologies has been shown to improve substantially when HRUS was used (8,9). Diagnostic accuracy, however, is highly operator-dependent and limited in deep and abnormal tissues (6,7).

Alternatively, MR neurography (MRN) offers excellent soft-tissue contrast enhancement for both deep and superficial nerves and additionally provides information about surrounding structures, including adjacent muscles (10). Complex patterns of nerve lesions can be depicted easily (11). Furthermore, MRN studies are reproducible (12), and tissue properties can be depicted with different sequences and administration of intravenous contrast agent (10). Additionally, functional MRI sequences including diffusion or perfusion MRI may further improve diagnostic performance (13,14). Thus, MRN can improve the diagnostic pathway in numerous peripheral nerve disorders (6). However, given its time- and cost-intensive nature, MRN should be used wisely.

The exact roles of HRUS and MRN in the diagnostic work-up of peripheral neuropathies remain unclear due to a lack of systematic comparative studies. Current estimates of diagnostic accuracy are primarily based on retrospective studies with small and heterogeneous patient cohorts (15–18). This study aimed to evaluate the diagnostic performance of HRUS and MRN in peripheral neuropathies in the upper extremity.

Materials and Methods

Study Design and Participants

This prospective, observational, single-center cohort study was approved by the institutional review board, and written informed consent was obtained from all participants. The study was designed and performed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (known as

Abbreviations

HRUS = high-resolution nerve US, MRN = MR neurography

Summary

MR neurography demonstrated higher accuracy and sensitivity compared with high-resolution nerve US in diagnosis of peripheral neuropathies in the upper extremity, particularly for proximal lesions and multinerve involvement.

Key Results

- In this prospective study of 800 participants with suspected peripheral neuropathy in the upper extremity, MR neurography (MRN) exhibited higher accuracy and sensitivity compared with high-resolution nerve US (HRUS) (85.4% [683 of 800] vs 70.6% [565 of 800] [$P < .001$] and 91.6% [554 of 605] vs 68.6% [415 of 605], $P < .001$, respectively).
- HRUS showed higher specificity than MRN (76.4% [149 of 195] vs 66.2% [129 of 195], $P < .001$).

STROBE) guidelines (19), and prediction model reporting followed the Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis (known as TRIPOD) guidelines (20).

Consecutive participants who were clinically suspected of having neuropathy in the upper extremity, referred for diagnostic HRUS and MRN, were enrolled at an academic medical center from November 2015 to February 2022. The inclusion criterion was all participants undergoing both HRUS and MRN for clinically suspected neuropathy in the upper extremity. The exclusion criterion was nondiagnostic image quality, defined as insufficient assessment of symptomatic nerves.

Demographic and clinical parameters included for statistical analysis were age, sex, side of neuropathy, motor and sensory deficits, pain, prior surgery possibly related to neuropathy, nerve conduction studies, and electromyography. Motor deficits were categorized as absent (strength grade, 5 of 5), mild (strength grade, 4 of 5), moderate (strength grade, 2–3 of 5), severe (strength grade, 0–1 of 5) or as present but of unknown severity if the exact grade of paresis could not be determined unambiguously. If several muscles were affected at different severity, the most severe grade was used for analysis.

The final diagnosis, serving as the diagnostic reference standard, was based on the compound results of clinical, electrophysiologic, imaging, and (if applicable) surgical and histopathologic findings (in 29 of 800 participants [3.6%]), retrieved from the clinical records.

Image Acquisition and Analysis

For each participant, HRUS and MRN studies were performed, and the findings were reported independently by two neuroradiologists with at least 2 years of experience in neuromuscular imaging, with full access to clinical information including electrodiagnostics, without anonymization. In cases of disagreement, a senior expert in neuromuscular imaging (with at least 5 years of specific experience) was included as a third reader to achieve a consensus. Upper extremity HRUS was performed, and the findings were reported by one of the two neuroradiologist readers using an 18-MHz linear array transducer (Siemens Acuson S2000; Siemens Healthineers) on the same day, prior to the MRN study. The major nerves in question were systematically covered in at least one arm and extended to both arms when necessary. This also included distal branches at the wrist and extending proximally to the supraclavicular plexus as far as technically feasible.

MRN examinations were performed using a 3-T MRI scanner (Magnetom Skyra, Verio, or Trio; Siemens Healthineers). In most cases, a large-coverage MRN approach (approximately 50 minutes; Table S1) was used for comprehensive evaluation along the longitudinal course of peripheral nerves. The brachial plexus was examined in the supine position. Nerve branches distal to the axilla were examined in the prone position with the extended arm in an eight-channel phased-array or 15-channel transmit-receive knee coil (Siemens Healthineers). The longitudinal axis of the arm was aligned at an angle of 10° or smaller relative to the B_0 direction to reduce artificial T2-weighted signal changes due to the so-called magic angle effect.

Assessment of nerve abnormalities was composed of a number of findings, including signal abnormality such as hyperintense areas on T2-weighted images, enlargement of fascicles and cross-sectional areas, continuity, and relationship to adjacent tissues including compression or contrast enhancement when applicable. The region of nerve lesions was categorized as spinal; supraclavicular; infraclavicular; branches directly emerging from the brachial plexus; and median, ulnar, or radial nerves along the upper arm, elbow, forelimb, and wrist. To assess the influence of lesion extent, involvement of two nerve regions or fewer was compared with involvement of more than two regions. Moreover, nerve lesion pattern type was categorized as either proximal location (defined as the course of nerves of the brachial plexus and its branches up to the axilla), distal location (defined as the course of nerves beyond the axilla), or both. Additionally, mononeuropathy (defined as involvement of a single nerve root, trunk, fascicle, or peripheral nerve) was separated from involvement of more than one nerve, referred to as lesion characteristics. Muscle findings such as denervation edema or atrophy were routinely covered and considered in the MRN and HRUS radiologic reports. For subgroup analyses, etiologic categories were defined as either inflammation, trauma, compression, spinal, tumor, or other. The category "other" was composed of rare conditions including neurodegeneration ($n = 8$), orthopedic diagnosis ($n = 4$), radiation damage ($n = 4$), primary myopathy ($n = 4$), sarcoidosis ($n = 2$), vascular malformation ($n = 2$), or hereditary nerve disorder ($n = 1$).

Statistical Analysis

Demographic and clinical characteristics were described by means ± SDs or frequencies (numbers and percentages), as appropriate. Sensitivity, specificity, and accuracy of MRN and HRUS imaging diagnoses were calculated in relation to the final diagnosis as an index test. The corresponding rates with exact Clopper-Pearson 95% CIs were reported. Further descriptive statistics were composed of true or false positives and true or false negatives. Differences in sensitivity, specificity, or accuracy between MRN and HRUS were assessed by means of the McNemar test in accordance with Trajman and Luiz (21).

MRN and HRUS results from the written reports were compared and categorized as "both normal" or "congruent" if each modality provided the same information or "discordant" if one modality showed a normal result and the other showed a positive finding. Differences in MRN and HRUS sensitivity and specificity

between categories of demographic and clinical variables were evaluated using univariable χ^2 tests; categories including fewer than 40 participants were not analyzed. Statistical analyses were performed by using statistical software (SPSS Statistics for Macintosh, version 28.0; IBM). $P < .05$ was indicative of statistical significance.

Sample Size

The target sample size of at least 725 participants was calculated on the basis of an expected prevalence of 90% for MRN and 85% for HRUS (power, 0.8; $\alpha = .05$), considering current data regarding the diagnostic performance of HRUS and MRN (15–18).

Results

Participant Characteristics

From a total of 868 patients referred for nerve HRUS and MRN due to clinically suspected neuropathy in the upper extremity, 800 participants were included from November 2015 to February 2022 (Fig 1). Of these, 431 (53.9%) were male and 369 (46.1%) were female. Mean age was 47.8 years ± 16.5 (SD) (age range, 6–93 years). Sixty-eight participants were excluded due to poor imaging quality.

Descriptive Clinical and Lesion Characteristics

A specific diagnosis was established in 608 of 800 participants (76.0%). The most common etiologies were trauma (289 of

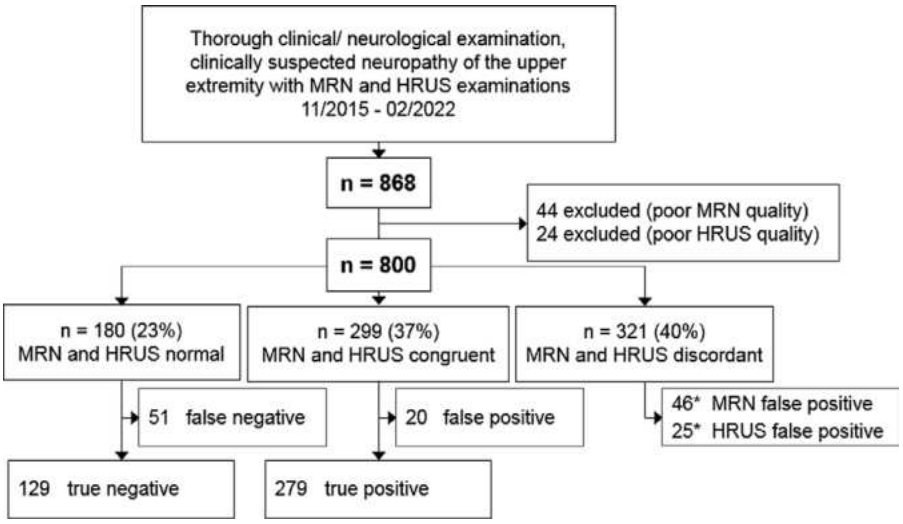

Figure 1: Flow diagram of study participants. Data are numbers of participants with their associated findings. HRUS = high-resolution US, MRN = MR neurography. * = Partly overlapping.

Table 1: Baseline Clinical Characteristics

		Final Diagnosis						
Parameter	All	Trauma	Inflammation	Compression	Spine	Tumor	Other	Idiopathic
Total	800 (100)	289 (36)	119 (15)	115 (14)	29 (4)	28 (4)	28 (4)	192 (24)
Demography								
Mean age (y)	47.8 ± 16.5	45.4 ± 16.9	51.3 ± 14.7	48.0 ± 16.6	57.9 ± 9.4	49.3 ± 18.8	52.9 ± 16.8	46.4 ± 16.4
Male	431 (54)	163 (56)	72 (61)	48 (42)	22 (76)	11 (39)	17 (61)	98 (51)
Female	369 (46)	126 (44)	47 (39)	67 (58)	7 (24)	17 (61)	11 (39)	94 (49)
Affected side								
Right	428 (54)	145 (50)	67 (56)	61 (53)	11 (38)	15 (54)	19 (68)	110 (57)
Left	372 (46)	144 (50)	52 (44)	54 (47)	18 (62)	13 (46)	9 (32)	82 (43)
Motor deficits								
No deficit	257 (32)	85 (29)	15 (13)	56 (49)	9 (31)	9 (32)	7 (25)	76 (40)
Mild	94 (12)	19 (7)	13 (11)	17 (15)	5 (17)	2 (7)	5 (18)	33 (17)
Moderate	63 (8)	18 (6)	18 (15)	10 (9)	2 (7)	2 (7)	2 (7)	11 (6)
Severe	180 (23)	94 (33)	33 (28)	5 (4)	6 (21)	10 (36)	7 (25)	25 (13)
Yes, but unknown severity	203 (25)	72 (25)	39 (33)	27 (24)	7 (24)	4 (14)	7 (25)	47 (24)
Sensory deficits								
No	228 (29)	47 (16)	57 (48)	18 (16)	9 (31)	9 (47)	17 (61)	65 (34)
Yes	496 (62)	202 (70)	49 (41)	95 (83)	17 (59)	6 (32)	9 (32)	114 (59)
Pain								
No	343 (43)	86 (30)	76 (64)	44 (38)	16 (55)	15 (54)	14 (50)	92 (48)
Yes	377 (47)	149 (51)	37 (31)	67 (58)	12 (41)	10 (36)	13 (46)	88 (46)
Prior surgery								
No	467 (58)	87 (30)	96 (81)	73 (64)	19 (65)	17 (61)	23 (82)	152 (79)
Yes	333 (42)	202 (70)	23 (19)	42 (36)	10 (35)	11 (39)	5 (18)	40 (21)
Electrophysiologic examination								
Normal	136 (17)	37 (13)	21 (18)	20 (17)	2 (7)	3 (11)	4 (14)	49 (26)
Abnormal	339 (42)	109 (37)	60 (50)	58 (50)	17 (59)	7 (25)	13 (47)	75 (39)

Note.—Unless otherwise indicated, data are numbers of participants, and data in parentheses are percentages. Mean data are ± SDs. Major clinical and demographic parameters of the 800 participants included in the study (rows) are shown per diagnostic category (columns).

Table 2: Baseline Nerve Lesion Characteristics

Characteristic	All	Final Diagnosis						
		Trauma	Inflammation	Compression	Spine	Tumor	Other	Idiopathic
Total	800 (100)	289 (36)	119 (15)	115 (14)	29 (4)	28 (4)	28 (4)	192 (24)
Region								
Spinal	59 (7)	6 (2)	3 (3)	4 (4)	29 (100)	2 (7)	4 (14)	11 (6)
Supraclavicular	126 (16)	32 (11)	29 (24)	20 (17)	13 (45)	12 (43)	9 (32)	11 (6)
Infraclavicular	101 (13)	36 (13)	30 (25)	1 (1)	8 (28)	13 (46)	8 (29)	5 (3)
Plexus nerves	48 (6)	26 (9)	5 (4)	0 (0)	5 (17)	1 (4)	1 (4)	10 (5)
Upper arm	244 (31)	71 (25)	105 (88)	5 (4)	9 (31)	9 (32)	16 (57)	29 (15)
Elbow	291 (36)	105 (36)	78 (66)	55 (48)	8 (28)	5 (18)	12 (43)	28 (15)
Forearm	185 (23)	65 (23)	71 (60)	8 (7)	2 (7)	7 (25)	12 (43)	20 (10)
Wrist	119 (15)	64 (22)	3 (3)	41 (36)	0 (0)	2 (7)	2 (7)	7 (4)
Lesion characteristics								
Mononeuropathy	493 (62)	213 (74)	34 (32)	95 (83)	7 (24)	18 (64)	8 (29)	104 (54)
>1 nerve	243 (30)	69 (24)	73 (68)	18 (16)	22 (76)	10 (36)	17 (61)	36 (19)
Lesion pattern								
Proximal only	50 (6)	7 (2)	2 (2)	19 (17)	15 (52)	3 (11)	1 (4)	3 (2)
Peripheral only	492 (62)	240 (83)	85 (71)	89 (77)	0 (0)	16 (57)	16 (57)	45 (23)
Proximal and peripheral	104 (13)	25 (9)	28 (24)	4 (4)	14 (48)	9 (32)	8 (29)	17 (9)
Lesion extent								
1–2 regions	487 (61)	242 (84)	31 (26)	110 (96)	16 (55)	24 (86)	13 (46)	51 (27)
>2 regions	159 (20)	30 (10)	84 (71)	2 (2)	13 (45)	4 (14)	12 (43)	14 (7)

Note.—Data are numbers of participants, and data in parentheses are percentages.

800; 36.1%), inflammation (119 of 800; 14.9%), and peripheral compression (115 of 800; 14.4%). Pathologic findings involving the spine (29 of 800; 3.6%), peripheral nerve tumors (28 of 800; 3.5%), and other diseases (28 of 800; 3.5%) were rare in this cohort. In 192 of 800 participants (24.0%), the final diagnosis remained idiopathic despite a thorough diagnostic work-up.

Motor deficits were present in 540 of 800 participants (67.5%), sensory deficits were reported by 496 of 800 participants (62.0%), and 377 of 800 participants reported pain (47.1%). Reports from electrophysiologic examinations were available for 475 participants (59.4%); 339 of these reports were abnormal. Mononeuropathy (493 of 800; 61.6%) was more frequent than involvement of more than one nerve. Proximal nerve regions were involved in 154 participants (19%). Nerve lesions extended to more than two regions in 159 cases (20%), especially in inflammatory neuropathy (71%). A detailed overview of descriptive characteristics is presented in Tables 1 and 2. Intercorrelation between variables was negligible (Cramer $V < 0.6$ each).

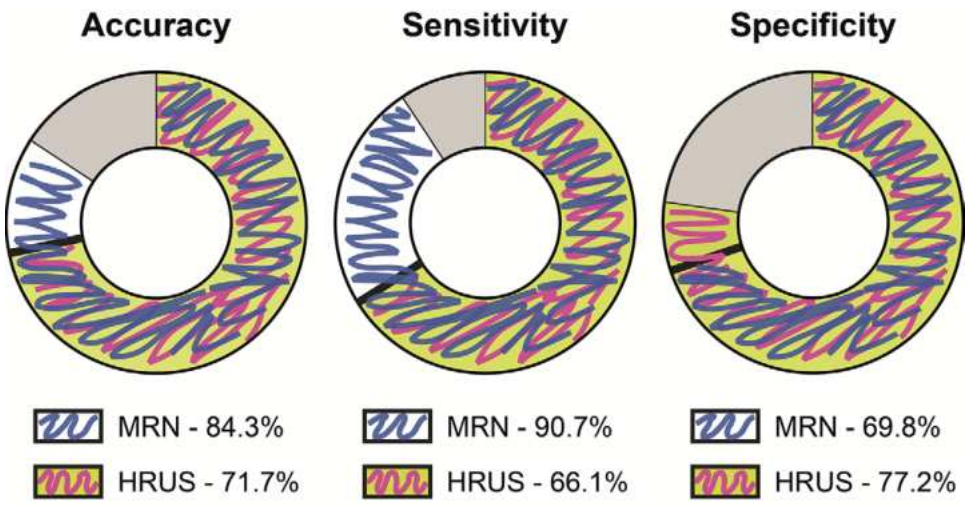

Figure 2: Illustration of the three basic diagnostic indexes: overall accuracy, sensitivity, and specificity, not taking into consideration the etiologic subgroups of tumor and spine ($n = 743$). HRUS = high-resolution nerve US, MRN = MR neurography.

Accuracy, Sensitivity, and Specificity of HRUS and MRN

MRN demonstrated higher accuracy than HRUS across the whole study sample, achieving 85.4% (95% CI: 82.7, 87.8) versus 70.6% (95% CI: 67.3, 73.8), respectively. Accuracy of MRN was also higher than that of HRUS in the subgroups of spinal diagnosis: traumatic, inflammatory, and compressive neuropathies ($P = .02$, $P < .001$, $P = .001$, and $P < .001$, respectively). HRUS achieved an overall sensitivity of 68.7% (95% CI: 64.8, 72.2) and a specificity of 76.4% (95% CI: 69.9, 81.8). MRN achieved an overall sensitivity of 91.6% (95% CI: 89.1, 93.7) and a specificity of 66.2% (95% CI: 59.1, 72.8; Fig 2). Compared with MRN, HRUS showed higher specificity across all participants ($P < .001$; Fig 3) and in the subgroup of inflammation ($P = .03$; Table 3). MRN demonstrated higher sensitivity than HRUS across all participants and in the subgroups of traumatic,

inflammatory, and peripheral compressive neuropathy, as well as neuropathy of other etiology (McNemar test, $P < .001$ each; Fig 4). The same diagnosis was determined at MRN and HRUS in 299 of 800 participants (37.4%), and normal results were found at MRN and HRUS in 180 of 800 participants (22.5%; Table S2).

Determinants of MRN Sensitivity and Specificity

Univariable analysis showed that MRN sensitivity was higher in participants in whom more than one nerve was involved (94.6% vs 92.3%; $P < .001$), proximal nerve involvement (97.8% vs 93.7%; $P < .001$), lesion extent of more than two regions (99.3% vs 93.5%; $P = .006$), or abnormal findings at electrophysiologic examination (95.1% vs 82.6%; $P < .001$) (Table 4). However, specificity was higher in cases of normal findings at electrophysiologic examination (85.7% vs 51.3%; $P < .001$), no prior surgery (71.4% vs 46.3%; $P = .003$), and female participants (76.8% vs 56.0%; $P = .002$).

Determinants of HRUS Sensitivity and Specificity

Conversely, univariable analysis for HRUS found a higher sensitivity in

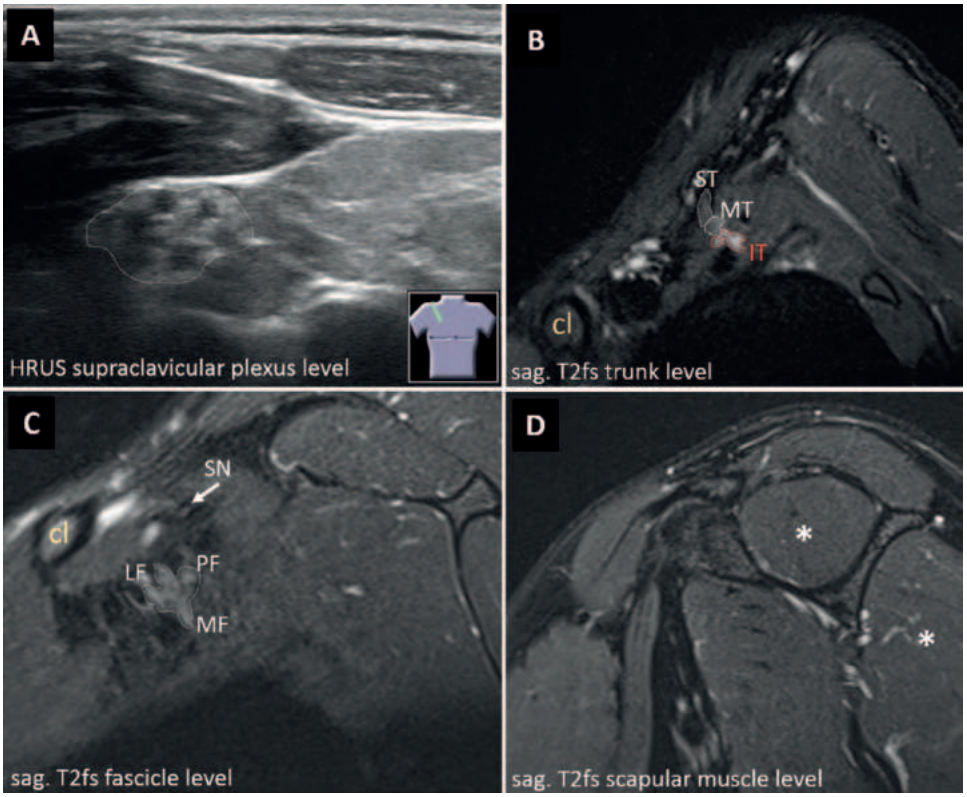

Figure 3: High-resolution nerve US (HRUS) images **(A, C)** show superior specificity to MR neurography (MRN) images **(B, D)**. A 24-year-old male participant presenting with recurrent and exacerbating pain in his right shoulder with a difficulty to elevate (Medical Research Council grade 4+) his arm following a sports-related injury 1 year prior to imaging to rule out suspected plexus neuritis. At electrophysiologic examination, only a borderline spontaneous activity pattern of the infraspinatus muscle was reported. **(A)** HRUS image shows the supraclavicular plexus (dotted white line), which was normal without alterations in nerve echogenicity or diameter suspicious for peripheral neuropathy. **(B)** MRN images in the proximal brachial plexus show a T2-weighted signal increase at the conjunction of the inferior trunk (IT, red dotted line) next to the unremarkable superior trunk (ST) and middle trunk (MT). However, there were no related clinical or electrophysiologic findings. **(C)** Sagittal (sag.) T2-weighted fat-saturated (T2fs) HRUS image shows normal distal, infraclavicular plexus segments with the lateral fascicle (LF), medial fascicle (MF), posterior fascicle (PF), and suprascapular nerve (SN). **(D)** MRN image shows no signs of muscular denervation of the supraspinatus or infraspinatus muscles (*). Therefore, a plexus neuritis or another nerve-related etiologic cause was ruled out. An artificial signal increase, often caused by the so-called magic angle artifact, can lead to false-positive findings at MRN and must be considered when interpreting findings at MRN. cl = clavicle.

Table 3: Sensitivity and Specificity according to Diagnostic Category

	MRN		HRUS			
Parameter	Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)	*P* Value, Sensitivity	*P* Value, Specificity
All	91.6 (554/605) [89.1, 93.7]	66.2 (129/195) [59.1, 72.8]	68.6 (415/605) [64.8, 72.2]	76.4 (149/195) [69.9, 81.8]	<.001	<.001
Trauma	85.8 (248/289) [81.3, 89.6]	97.1 (435/448) [95.1, 98.5]	67.1 (194/289) [61.4, 72.5]	98.7 (371/376) [96.9, 99.6]	<.001*	>.99*
Inflammation	97.5 (116/119) [92.8, 99.5]	95.3 (567/595) [93.3, 96.9]	77.3 (92/119) [68.7, 84.5]	97.9 (473/483) [96.2, 99.0]	<.001*	.03*
Compression	95.6 (110/115) [90.0, 98.6]	97.3 (574/590) [95.6, 98.4]	75.4 (86/114) [66.8, 82.4]	97.6 (479/491) [95.8, 98.6]	<.001*	>.99*
Spine	100.0 (29/29) [88.4, 100.0]	97.0 (654/674) [95.5, 98.2]	31.0 (9/29) [15.3, 50.8]	100.0 (557/557) [99.3, 100.0]	NA	NA
Tumor	100.0 (28/28) [87.7, 100.0]	98.9 (655/662) [97.8, 99.6]	85.7 (24/28) [67.3, 96.0]	99.8 (541/542) [99.0, 100.0]	NA	>0.99*
Other	92.3 (24/26) [74.9, 99.1]	99.0 (659/666) [97.9, 99.6]	42.9 (12/28) [24.5, 62.8]	100.0 (553/553) [99.3, 100.0]	<.001*	NA

Note.—Data in brackets are 95% CIs, and data in parentheses are numerators/denominators. *P* values were calculated using the McNemar test. HRUS = high-resolution nerve US, MRN = MR neurography, NA = not applicable.

* Fisher exact test was applied.

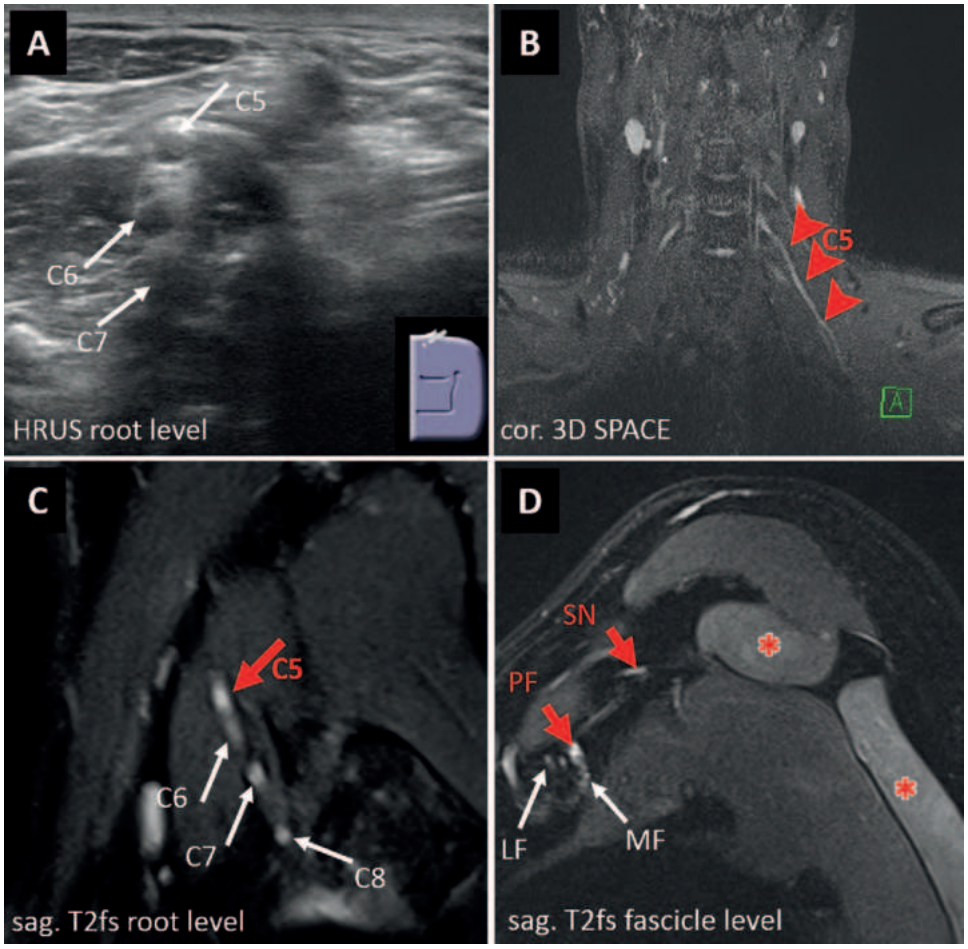

Figure 4: High-resolution nerve US (HRUS; **A**) sensitivity is inferior to that of MR neurography (MRN; **B–D**). A 41-year-old male participant presented with weakness to elevate (Medical Research Council grade 2) and hypesthesia of his upper left arm following a motor vehicle crash that occurred 1 month before he underwent imaging. Results of an electrophysiologic examination suggested an upper plexus injury with denervation activity in the participant's supraspinatus and infraspinatus and deltoid muscles. **(A)** HRUS image shows a normal appearance without suspicious changes in echogenicity or nerve enlargement in the supraclavicular plexus elements, including the extraforaminal nerve roots. **(B)** MRN image shows a mild elongation of the C5 nerve root, and the C5 root (arrowheads) showed a signal intensity increase and a slight enlargement at **(C)** T2-weighted fat-saturated (T2fs) imaging (red arrow on **C**), contrasting with the normal-appearing roots C6 through C8 (white arrows on **C**) of the brachial plexus. **(D)** In the infraclavicular plexus segment, the pathologic T2-weighted signal intensity increase was continued into the axillary nerve portion of the posterior fascicle (PF) and into the suprascapular nerve (SN; red arrows on **D**). Image shows a diffuse T2-weighted hyperintense denervation edema within the supraspinatus and infraspinatus muscles (*). The image shows normal signal intensity (white arrows on **D**) in the lateral fascicle (LF) and medial fascicle (MF). cor. = coronal, sag. = sagittal, SPACE = Sampling Perfection with Application optimized Contrasts using different flip angle Evolution, T2fs = fat-saturated T2-weighted sequence, 3D = three-dimensional.

participants with peripheral nerve involvement (77.2% vs 31.9%; $P < .001$), lesion extent of more than two regions (78.5% vs 69.2%; $P = .03$), prior surgery (76.5% vs 61.3%; $P < .001$), presence of sensory deficits (72.7% vs 61.1%; $P = .02$), and abnormal findings at electrophysiologic examination (72.9% vs 59.8%; $P = .02$). However, specificity was higher in participants with normal electrophysiologic examination findings (91.8% vs 61.0%; $P < .001$), female participants (86.2% vs 68.0%; $P = .003$), and in participants who had not undergone a prior surgical procedure (81.2% vs 60.0%; $P = .005$) (Table 4).

Discussion

In practice, morphologic information provided by advanced nerve imaging techniques is seen as valuable in diagnosing peripheral nerve disorders; however, there is limited clinical evidence regarding diagnostic performance. This prospective, observational study investigated the diagnostic performance of high-resolution nerve US (HRUS) and MR neurography (MRN) in 800 participants suspected of having peripheral nerve disease in the upper extremity. MRN demonstrated higher accuracy and sensitivity than HRUS (accuracy, 85.4% vs 70.6%; and sensitivity, 91.6% vs 68.7%, respectively), whereas specificity was higher in HRUS than in MRN (76.4% vs 66.2%, respectively).

Previous studies on the sensitivity and specificity of HRUS and MRN have been based on smaller cohorts. Zaidman et al (15) reported higher sensitivity and accuracy for HRUS compared with MRI (93% vs 67% and 90% vs 70%, respectively) with equivalent specificity (86%). However, these findings are not directly comparable due to differences in MRI protocols and equipment (15). Recent studies (16) show higher sensitivity and accuracy for MRI compared with HRUS (95.3% vs 81.3%), and these results are similar to the results presented in our study. Likewise, in a recent prospective study (18) including 131 participants with mono-neuropathy of the upper or lower extremity, MRN achieved higher sensitivity and accuracy than HRUS (95% vs 87% and 94% vs 80%, respectively). Taken together, the improving sensitivity and accuracy of MRN observed over time likely reflect the rapid technologic advances and its increasing diagnostic potential.

HRUS strengths include cost benefit and the ability to perform dynamic, bilateral examinations of superficial peripheral nerves with excellent spatial resolution (22). HRUS showed high diagnostic accuracy in specific neuropathies, such as carpal tunnel syndrome (23) or common peroneal neuropathy (24). In line with this common notion and previous results, distal localization of nerve damage was associated with higher sensitivity and specificity. In a previous prospective study (8) of 130 participants with clinical and electrophysiologic signs of peripheral neuropathy, HRUS was shown to modify the diagnostic or therapeutic pathway in 42.3% and confirmed the suspected diagnosis in 40%, mainly by advocating for the surgical indication or localizing the site of lesion. Today, sonographic evaluation is commonly based on cross-sectional area and echogenicity of nerves (25). More advanced techniques including

ultrahigh resolution (eg, 22–24 MHz), elastography, or assessment of intraneural blood flow may provide even more tissue-specific information in the future (25).

This study had several limitations. First, the study was performed at a single academic medical center with strong expertise in neuromuscular imaging, which may have limited the generalizability of the results. Likewise, access to MRN and HRUS at high diagnostic quality may vary across different regions of the world, thereby influencing the practical choice of the ideal imaging strategy. Second, the reference standard for calculation of accuracy measures was based on the compound results of all diagnostic information available, which we think represents the most suitable approach to define the ground truth in the diagnostic challenge of peripheral neuropathies. However, this may leave some uncertainties because invasive diagnostic tests including biopsies were generally not available and must be considered an important limitation. Third, although performed and reported separately, HRUS consistently preceded MRN,

Table 4: Differences in MRN and HRUS Sensitivity and Specificity between Categories of Demographic and Clinical Variables

	MRN				HRUS			
Variable	Sensitivity (%)	*P* Value, Sensitivity	Specificity (%)	*P* Value, Specificity	Sensitivity (%)	*P* Value, Sensitivity	Specificity (%)	*P* Value, Specificity
Sex		.39		.002		.89		.003
Male	92.4 (306/331) [89.1, 94.8]	…	56.0 (56/100) [46.2, 65.3]	…	68.9 (228/331) [63.7, 73.6]	…	68.0 (68/100) [58.3, 76.3]	…
Female	90.5 (248/274) [86.5, 93.4]	…	76.8 (73/95) [67.4, 84.2]	…	68.4 (188/275) [62.7, 73.6]	…	86.2 (81/94) [77.8, 91.7]	…
Side		.51		.16		.72		.50
Right	90.9 (288/317) [87.2, 93.6]	…	70.3 (78/111) [61.2, 78.0]	…	69.3 (219/316) [64.0, 74.1]	…	78.6 (88/112) [70.1, 85.2]	…
Left	92.4 (266/288) [88.7, 94.9]	…	60.7 (51/84) [50.0, 70.5]	…	67.9 (197/290) [62.4, 73.0]	…	74.4 (61/82) [64.0, 82.6]	…
Motor deficit		.043	NA			.62	NA	
No deficit	87.8 (159/181) [82.3, 91.8]	…	…		66.9 (121/181) [59.7, 73.3]	…	…	
Mild	88.3 (53/60) [77.8, 94.2]	…	…		65.0 (39/60) [52.4, 75.8]	…	…	
Moderate	96.2 (50/52) [87.0, 99.3]	…	…		69.2 (36/52) [55.7, 80.1]	…	…	
Severe	96.8 (149/154) [92.6, 98.6]	…	…		72.9 (113/155) [65.4, 79.3]	…	…	
Yes, but unknown severity	90.3 (140/155) [84.7, 94.1]	…	…		67.1 (104/155) [59.4, 74.0]	…	…	
Sensory deficits		.50		.32		.02		.78
No deficit	91.9 (148/161) [86.7, 95.2]	…	59.7 (40/67) [47.7, 70.6]	…	61.1 (99/162) [53.4, 68.3]	…	75.8 (50/66) [64.2, 84.5]	…
Sensory deficit	90.8 (346/381) [87.5, 93.3]	…	70.4 (81/115) [61.5, 78.0]	…	72.7 (277/381) [68.0, 76.9]	…	76.5 (88/115) [68.0, 83.3]	…
Pain		.006		.21		.59		.28
No pain	95.2 (239/251) [91.8, 97.2]	…	62.0 (57/92) [51.8, 71.2]	…	69.5 (173/249) [63.5, 74.9]	…	73.4 (69/94) [63.7, 81.3]	…
Pain	87.8 (252/287) [83.5, 91.1]	…	72.2 (65/90) [62.2, 80.4]	…	69.2 (200/289) [63.7, 74.3]	…	81.8 (72/88) [72.5, 88.5]	…
Prior surgery		.29		.003		<.001		.005
No	90.4 (283/313) [86.7, 93.2]	…	71.4 (110/154) [63.8, 78.0]	…	61.3 (192/313) [55.8, 66.6]	…	81.2 (125/154) [74.3, 86.6]	…
Yes	92.8 (271/292) [89.3, 95.3]	…	46.3 (19/41) [32.1, 61.3]	…	76.5 (224/293) [71.3, 81.0]	…	60.0 (24/40) [44.6, 73.7]	…
Electrophysiologic examination findings		<.001		<.001		.02		<.001
Normal	81.6 (71/87) [72.2, 88.4)]	…	85.7 (42/49) [73.3, 92.9]	…	59.8 (52/87) [49.3, 69.5]	…	91.8 (45/49) [80.8, 96.8]	…
Abnormal	95.1 (250/263) [91.7, 97.1]	…	51.3 (37/76) [40.3, 62.2]	…	72.9 (191/262) [67.2, 77.9]	…	61.0 (47/77) [49.9, 71.2]	…
Lesion characteristics		<.001	NA			<.001	NA	

(Table 4 continues)

Table 4 *(continued)*: Differences in MRN and HRUS Sensitivity and Specificity between Categories of Demographic and Clinical Variables

	MRN				HRUS			
Variable	Sensitivity (%)	*P* Value, Sensitivity	Specificity (%)	*P* Value, Specificity	Sensitivity (%)	*P* Value, Sensitivity	Specificity (%)	*P* Value, Specificity
Mono-neuropathy	92.3 (358/388) [89.2, 94.5]	…	…		74.0 (287/388) [69.4, 78.1]	…	…	
More than one nerve	94.6 (194/205) [90.7, 97.0]	…	…		62.3 (129/207) [55.6, 68.6]	…	…	
Lesion pattern		<.001	NA			<.001	NA	
Only proximal	97.8 (89/91) [92.3, 99.6]	…	…		31.9 (29/91) [23.2, 42.0]	…	…	
Only peripheral	93.6 (394/421) [90.8, 95.6]	…	…		77.2 (325/421) [72.9, 81.1]	…	…	
Proximal and peripheral	100 (95/95) [95.3, 100]	…	…		63.2 (60/95) [53.1, 72.2]	…	…	
Lesion extent		.006	NA			.03	NA	
1–2 regions	93.5 (405/433) [90.8, 95.5]	…	…		69.2 (300/433) [64.7, 73.4]	…	…	
>2 regions	99.3 (144/145) [96.2, 100]	…	…		78.5 (113/144) [71.1, 84.4]	…	…	

Note.—Unless otherwise indicated, data in parentheses are numerators/denominators, and data in brackets are 95% CIs. Data were obtained using univariable analysis with χ^2 testing. Sensitivity and specificity values (columns) of MR neurography (MRN) and high-resolution nerve US (HRUS) are shown in relation to individual clinical and lesion-specific subgroups (rows) and are compared within these subgroups by χ^2 testing. $P < .05$ is considered indicative of statistical significance. NA = not applicable because there were fewer than 40 participants.

which may have introduced some bias in the results. The results, however, do not show a strong indication for this because MRN was found to outperform HRUS in most cases. In addition, nondiagnostic image quality was defined as an exclusion criterion, which may have introduced some selection bias. However, this only applied to fewer than 10% of cases. Heterogeneity and a relatively broad subgroup clustering of the overall study population may obscure distinct characteristics of specific cases and individual disorders. These, however, are often not known a priori and concurring differentials also need to be considered. Therefore, a post hoc analysis of such participants could be of limited value for the initial choice of the correct diagnostic imaging option.

In conclusion, for diagnosing peripheral neuropathies in the upper extremity, MR neurography (MRN) achieved higher accuracy and sensitivity, whereas high-resolution nerve US (HRUS) achieved higher specificity. MRN may be the preferred modality when available, particularly for the suspected involvement of proximal nerve segments or multiple nerves. HRUS remains valuable as an adjunct tool or alternative when MRN is not available or feasible for other reasons.

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