Ultrasound imaging of nerves in the neck

Correlation with MRI, EMG, and clinical findings

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Abstract

Objective

We evaluated the performance of ultrasound in the detection of neuropathy of the suprascapular nerve (SSN), long thoracic nerve (LTN), spinal accessory nerve (SAN), and phrenic nerve and compared this performance with MRI.

Methods

A retrospective review of 56 patients who had undergone ultrasound imaging of the SSN, LTN, SAN, and phrenic nerve was performed. Diagnoses made by ultrasound, MRI, EMG reports, and clinical and operative notes were recorded.

Results

Ultrasound was successful in visualizing nerves in the neck in the overwhelming majority of cases. Sonographic findings were typically in agreement with MRI and clinical findings.

Conclusion

Ultrasound is effective in the visualization and diagnostic evaluation of the SSN, LTN, SAN, and phrenic nerve.

Classification of evidence

This study provides Class IV evidence that ultrasound can effectively visualize and diagnose neuropathy of the SSN, LTN, SAN, and phrenic nerve in the neck.

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In the neck, the brachial plexus constitutes a dense and complicated neural network, and damage to these structures can cause substantial motor and sensory impairment.¹ Outside of the brachial plexus proper, dysfunction of the suprascapular nerve (SSN), long thoracic nerve (LTN), spinal accessory nerve (SAN), and phrenic nerve can lead to considerable patient morbidity. These nerves can be affected by trauma^{2–5} or surgical/iatrogenic complications^{6,7} and in thoracic outlet syndrome and Parsonage-Turner syndrome.⁴

The proper treatment course of peripheral neuropathy is determined by a multidisciplinary diagnostic workup. Electrodiagnostic (EDX) testing identifies damaged nerves and quantifies the degree of injury, informing on neurophysiology.⁸ Supplemental imaging characterizes neuroanatomy, further defining the nature and precise site of nerve injury.⁹ The use of MRI is well established in postganglionic neuropathies.^{10,11} MRI is frequently used in the diagnosis and characterization of suprascapular neuropathy^{12–15} and can detect secondary muscle

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changes related to SAN and LTN abnormality. However, these nerves in the neck can be difficult to visualize on MRI because of their small size and the limitations of motion artifact from breathing.^{6,16–18}

Ultrasound of nerves in the neck has traditionally been used to guide nerve blocks.^{19–21} Techniques for sonographic evaluation of nerves in the neck have been documented,^{9,17,21–27} but the diagnostic performance of ultrasound with respect to these nerves remains unclear. The purpose of this study is to evaluate the performance of ultrasound in the visualization and detection of neuropathy of the SSN, LTN, SAN, and phrenic nerve and compare this performance with MRI.

Methods

Standard protocol approvals, registrations, and patient consents

This study received institutional review board approval and waived the requirement for informed consent for this retrospective review.

A search of the radiology imaging system was performed to identify patients who had undergone ultrasound of the SSN, LTN, SAN, or phrenic nerve between January 1, 2016, and September 19, 2018. The ultrasound studies that met these inclusion criteria but were solely performed for interventional purposes were excluded from the study, as diagnostic assessment of the target nerve was not performed. A retrospective review of the patients' medical records was performed, including medical imaging, EDX reports, and clinician notes. From the ultrasound and MRI reports, note was made if the nerve was a) visualized and b) characterized as normal or abnormal (from direct visualization or secondary imaging characteristics). Specific limitations to nerve visualization encountered during imaging were recorded. The final clinical diagnoses were determined using EDX reports, clinical notes, and operative reports, if available.

The proportion of nerves visualized by ultrasound and MRI is presented with 95% Wilson confidence intervals. Agreement between ultrasound and MRI diagnoses was estimated using unweighted Gwet agreement coefficient (AC_1).²⁸ Binary logistic regression models estimated the concordance (c-index) between ultrasound and MRI with clinical diagnosis.²⁹ To estimate the variability of the c-index, 95% cluster bootstrapped confidence intervals were computed from 1000 resamples.

Nondiagnostic or inconclusive imaging results were treated as normal cases. A sensitivity analysis was conducted to evaluate the discriminatory performance of ultrasound and MRI when nondiagnostic cases were considered abnormal. Analyses were performed using SAS v9.4 (SAS Institute Inc., Cary, NC).

Classification of evidence

This study of diagnostic accuracy provides Class IV evidence that ultrasound can effectively visualize and diagnose neuropathy of the SSN, LTN, SAN, and phrenic nerve in the neck.

Data availability

Anonymized data will be shared by request from any qualified investigator.

Results

Patient/case demographics

Within the search period, 55 patients presented at our institution for diagnostic evaluation of the SSN, LTN, SAN, or phrenic nerve using ultrasound. Six patients underwent ultrasound examination that commented on 2 or more nerves, resulting in 61 total cases in the present study. All ultrasound examinations were performed using 15–18 MHz transducers on LOGIQ E9 ultrasound systems (GE Healthcare, Waukesha, WI), and nerve ultrasound examinations were performed on bilateral extremities. All ultrasound examinations were scanned and reported by a single radiologist expert in nerve ultrasound. All MRI studies were reported by a single radiologist expert in magnetic resonance (MR) neurography. Both radiologists had over 8 years of experience in tertiary care nerve imaging.

Patients' mean age was 44 years (SD = 16; range = 17–74 years), and the majority were men (67%). The majority of cases examined the SSN (56%), followed by the LTN (25%), SAN (16%), and phrenic nerve (3%). Forty-five cases (74%) were evaluated by EDX. Eleven cases (18%) were surgically evaluated. Most cases received an abnormal clinical diagnosis (69%), including transection, neuroma, PTS, and idiopathic neuritis.

Nerve visualization: ultrasound vs MRI

Of the 61 cases, 60 (98%) successfully visualized the target nerve using ultrasound (table 1). In 1 case, the LTN could not be visualized using ultrasound because of poor tissue contrast. There were 57 corresponding MRI examinations that commented on 1 or more of these nerves, 47 (82%) of which successfully visualized the target nerve (table 1). Cases of nonvisualization on MRI included the LTN (5), SAN (4), SSN (1), and phrenic nerve (1). On MRI, 8 nerves were deemed too small to visualize (2 SAN, 5 LTN, and 1 phrenic nerve), 2 nerves were obscured by metallic artifact (SSN and SAN), 1 nerve was obscured by scarring (SAN), and 3 nerves could not be visualized because of motion artifact (2 SAN and 1 LTN). Of note, there was 1 case in which focal SSN constriction was only detected on MRI in a location deep to the distal clavicle, obscured by osseous shadowing on

Table 1 Visualization of the target nerve with ultrasound and MRI

Nerve	Ultrasound cases visualized	Proportion (95% CI)	MRI cases visualized	Proportion (95% CI)
Overall	60/61	98% (91–100)	47/57	81% (69–89)
LTN	14/15	93% (70–99)	10/15	67% (42–85)
Phrenic	2/2	100% (34–100)	0/1	0%
SAN	10/10	100% (72–100)	5/9	56% (27–81)
SSN	34/34	100% (90–100)	31/32	97% (84–99)

Abbreviations: CI = confidence interval; LTN = long thoracic nerve; SAN = spinal accessory nerve; SSN = suprascapular nerve. The proportion (95% Wilson confidence intervals) of cases with successful visualization of the target nerve using each modality.

ultrasound. In this case, the visualized portions of the SSN on ultrasound demonstrated segmental swelling, and the nerve was characterized as abnormal on both ultrasound and MRI.

Imaging agreement: Ultrasound vs MRI

When the target nerve was assessed by both ultrasound and MRI, the ultrasound and MRI diagnoses tended to match, with agreement between ultrasound and MRI on the presence of an abnormality in 57 cases (84%; table 2) (figure 1). Reasons for discordance between ultrasound and MRI included pathology described only on ultrasound and not on MRI (2 LTN and 1 SSN), with ultrasound reporting neuritis due to abnormal nerve size (compared with the contralateral side [figure 2]). The strength of agreement between ultrasound and MRI was almost perfect for the SAN ($AC_1 = 1.00$, $SE = 0.11$) and SSN ($AC_1 = 0.92$, $SE = 0.07$) and substantial for the LTN ($AC_1 = 0.43$, $SE = 0.20$). Agreement could not be calculated for the phrenic nerve cases because MRI resolution at the time of this writing was unable to visualize the phrenic nerve or secondary characteristics of phrenic neuropathy.

Imaging agreement with final clinical diagnosis

When the target nerve was characterized with ultrasound, there was excellent overall concordance between ultrasound and clinical diagnosis for the presence of an abnormality ($c = 0.94$;

table 3). There was also excellent concordance between ultrasound and clinical diagnosis for SSN ($c = 1.00$) and good concordance for the LTN ($c = 0.79$). Discordance between ultrasound and final clinical diagnosis was seen in 2 LTN cases in which “nerve swelling/neuritis” was described on ultrasound (2 LTN), but the EMG was normal. MRI was normal in 1 case, and nonvisualization of the nerve and muscle precluded MRI diagnosis in the other case.

When the target nerve was characterized with MRI, there was excellent overall concordance between MRI and clinical diagnosis ($c = 0.92$; table 3). There was also excellent concordance between MRI and clinical diagnosis for the SSN ($c = 0.95$) and good concordance for the LTN ($c = 0.81$). In 3 MRI LTN cases, 4 SAN cases, and 2 LTN cases, the nerve itself was not visualized on MRI, but as secondary muscle denervation changes were present, the MRI diagnosed neuropathy in agreement with clinical findings (figure 3). Reasons for discordance between MRI and final clinical diagnosis included residual denervation (i.e., positive waves and fibrillation potentials) described only in recovering nerves by EMG (2 LTN and 2 SSN).

Note that concordance statistics were not computed for the SAN because of identical responses for all SAN diagnoses (ultrasound and MRI). Both ultrasound and MRI correctly diagnosed SAN abnormality in 100% of cases in this study. The small number of phrenic nerve cases also precluded concordance analysis. However, ultrasound correctly diagnosed phrenic nerve abnormality in both imaged cases (both related to traction injury at the neck). As previously mentioned, MRI was unable to visualize the phrenic nerve or secondary characteristics of phrenic neuropathy.

In 1 ultrasound examination and 4 MRI examinations in this cohort, the presence or absence of neuropathy was not reported, as the nerve was not visualized (ultrasound and MRI) and/or no secondary signs of neuropathy were appreciated (MRI). For the purposes of concordance analysis, these examinations were designated as normal.

Table 2 Agreement between ultrasound and MRI

Nerve	No. of nerves diagnosed by ultrasound and MRI	Ultrasound and MRI agreement	
		Gwet AC_1 (SE)	Percent agreement (SE)
Overall	57	0.79 (0.07)	0.84 (0.06)
LTN	10	0.43 (0.20)	0.60 (0.13)
Phrenic	0		
SAN	6	1.00 (0.11)	1.00 (0.11)
SSN	31	0.92 (0.07)	0.94 (0.06)

Abbreviations: LTN = long thoracic nerve; SAN = spinal accessory nerve; SSN = suprascapular nerve.

Discussion

Our retrospective review demonstrated that ultrasound is highly successful in visualizing nerves in the neck, and sonographic findings were in agreement with MRI, EDXs, and clinical findings in the majority of cases. When the target nerve was visualized by both ultrasound and MRI, the imaging findings were in agreement in most cases. In addition, both ultrasound and MRI diagnoses of neck nerve pathology tended to be in agreement with the final clinical diagnosis.

Currently, MRI is the preferred modality for imaging peripheral neuropathy, as it is well established in effectively characterizing nerve pathology.^{10,11} Our findings confirm the high predictive accuracy of MRI for the diagnosis of neuropathy of the target nerves in the neck. However, MRI is relatively expensive, and its contraindications and limitations are not insignificant. MRI examinations may not be tolerated in patients with claustrophobia,³⁰ and MRI is susceptible to artifact from patient motion and regional metallic hardware. Pertaining to the nerves in the neck, respiratory motion artifact on MR examinations can be considerable, as these nerves are close to airways and the chest wall.³¹ Regional metallic clips may also obscure the nerve on MRI, as can be seen in postsurgical/postbiopsy cases.

Ultrasound presents a fast and relatively inexpensive alternative to MR neurography and is not affected by the limitations typically associated with MRI. Ultrasound has higher

Ultrasound has a high success rate in visualizing and characterizing the nerve, and MRI superbly demonstrates muscle denervation effect, even when subtle.

spatial (but inferior contrast) resolution compared with MRI, offers dynamic imaging capabilities, and allows for easy comparison with the asymptomatic contralateral side.³⁰ Our results showed that ultrasound performed better than MRI in directly visualizing nerves in the neck, and as well as MRI in diagnosing neuropathy of these nerves. In our cohort, MRI detected secondary characteristics of neuropathy in several cases but was unable to directly visualize the nerve and thus incompletely characterized the nerve abnormality. The superior imaging resolution of ultrasound was demonstrated in these findings, as ultrasound was able to directly visualize and characterize abnormality in these small nerves in the neck. For target nerves in the neck, correctly characterizing pathology such as neuroma or nerve laceration is critical, as these lesions likely warrant surgical treatment. In few cases, only ultrasound detected neuropathy in LTN and SSN cases, as nerve abnormality was only detected due to asymmetry with the contralateral, asymptomatic side; contralateral side imaging is much easier to perform using ultrasound.

The majority of cases in this study aimed to visualize the SSN, in keeping with the relatively high frequency of SSN imaging studies in the literature.^{12–15} SSN lesions were successfully visualized in all but 1 case on both ultrasound and MRI, confirming the capability of current medical imaging techniques to image the SSN. A limitation of ultrasound should be highlighted here, as the osseous shadowing from the distal clavicle and scapula obscure segments of the SSN on ultrasound.

Figure 1 Fifty-six-year-old man with right SAN palsy following excisional biopsy

Transverse (A) and longitudinal (B) ultrasound images of the neck reveal a scar-entrapped neuroma of the SAN adjacent to the IJV, deep to the SCM. Axial MRI (C) in the same patient also shows the scar-entrapped neuroma of the SAN adjacent to the IJV, deep to the SCM. Photograph of the patient's neck (D) depicts ultrasound-guided skin localization of the SAN neuroma with respect to the biopsy scar. Electrodiagnostic evaluation confirmed right SAN palsy. IJV = internal jugular vein; SAN = spinal accessory nerve; SCM = sternocleidomastoid muscle.

Figure 2 Forty-five year-old woman with right SSN palsy following traction-type injury to the neck

Transverse ultrasound images of the neck show abnormal thickening of the right SSN deep to the inferior belly of the omohyoid muscle (A) compared with the asymptomatic left side (B). MRI characterized the right SSN as normal in this case. Electrodiagnostic evaluation confirmed right SSN palsy. SSN = suprascapular nerve.

Table 3 Predictive accuracy of ultrasound and MRI

Nerve	No. of cases characterizing neuropathy on ultrasound	Ultrasound and clinical concordance			No. of cases characterizing neuropathy on MRI	MRI and clinical concordance		
		C-index	95% CI			C-index	95% CI	
Overall	61	0.94	0.85	1.00	57	0.92	0.87	0.97
LTN	15	0.79	0.58	1.00	15	0.81	0.63	1.00
SSN	34	1.00	1.00	1.00	32	0.95	0.88	1.00

Abbreviations: CI = confidence interval; LTN = long thoracic nerve; SSN = suprascapular nerve.

Concordance analysis between ultrasound/MRI and the final clinical diagnosis is presented. Concordance statistics were not computed for the spinal accessory nerve due to identical responses for all spinal accessory nerve diagnoses (ultrasound, MRI, and clinical). The small number of phrenic nerve cases also precluded concordance analysis.

However, ultrasound was still able to diagnose SSN abnormality in the neck, as the SSN is well imaged proximal to the focal regions obscured by bone. Few studies have reported visualizing the LTN, SAN, or phrenic nerve using MRI or ultrasound, and even fewer publications have reported being able to detect neuropathies with the use of these imaging modalities.^{6,9,16–18,21,26} In the present study, ultrasound successfully visualized the SAN and phrenic nerve in most cases and was fairly successful in visualizing the LTN. Compared with ultrasound, MRI was less successful in directly visualizing the SAN, LTN, and phrenic nerves in this study, mainly because of their small size and motion artifact. Metallic artifact and regional scarring were also cited as reasons for nerve nonvisualization on MRI (figure 3).

Our retrospective analysis shows that ultrasound diagnostic characterization of the target nerve tended to match the clinical diagnosis just as often as the MRI diagnosis. These results suggest that ultrasound may provide a useful imaging alternative for the nerves in the neck when MRI is unavailable or unsuccessful. In the authors' clinical practice, ultrasound and MRI serve as complementary modalities in the diagnosis of neuropathy. Ultrasound has a high success rate in visualizing and characterizing the nerve, and MRI superbly demonstrates muscle denervation effect, even when subtle. The high level of concordance between modalities coupled with the superb diagnostic accuracy they provide grants clinicians an increased level of confidence that neuropathy is present or absent. Given that neuropathy affecting the suprascapular,

Figure 3 Sixty-three-year-old man with right shoulder weakness and scapular winging following cervical lymph node biopsy

Transverse ultrasound image (A) shows subcutaneous scar tissue overlying a prominent lymph node (asterisk) at the posterior triangle and the SAN emerging from the sternocleidomastoid muscle in this location (arrows). Focal fusiform thickening (calipers) along the course of the SAN is consistent with a neuroma. A metallic biopsy clip (block arrow) is deep to the scar and adjacent to the SAN. Axial proton density MRI (B) in the same region showed dense scarring (dashed oval) adjacent to SCM and lymph nodes (asterisks). Susceptibility artifacts from metallic clips (block arrows) obscure the course of the SAN and the neuroma detected on ultrasound examination is not seen. However, coronal fat-saturated, fluid-sensitive MRI (C) was able to detect denervation edema in the right trapezius muscle (white asterisks), and the MRI diagnosis of SAN neuropathy was made. Electrodiagnostic evaluation confirmed right SAN palsy. SAN = spinal accessory nerve; SCM = sternocleidomastoid muscle.

spinal accessory, long thoracic or phrenic nerve may result in substantial patient morbidity, diagnostic confidence is critical to providing appropriate and timely management. Note that in our study, MR examination was able to provide a correct diagnosis of neuropathy in several LTN and SAN cases despite nonvisualization of the nerve itself, as the secondary signs of muscle denervation were evident. The ability to detect secondary signs of muscle denervation earlier and with greater sensitivity is an advantage of MRI over ultrasound in the diagnosis of neuropathy. For both ultrasound and MRI, concordance with the final clinical diagnosis was lowest for the LTN. Known difficulties in clinical and EDX evaluation of this nerve³² may partly account for this degree of discordance.

Compared with MRI, ultrasound is highly operator dependent; the skill level of the imager can play a substantial role in the reported findings.³⁰ In addition, nerves in the neck can be difficult to image on ultrasound when the subject has a short neck or hairy skin, preventing an adequate acoustic window on sonography. Despite these limitations, this study demonstrated that ultrasound was able to effectively visualize nerves in the neck and accurately characterized neuropathy. Although this study reports on findings in a relatively small population, the number of cases is still higher than what has been reported in the current literature. In addition, it should be noted that although ultrasound was successful in imaging 100% of the phrenic nerve cases, there were only 2 cases in this cohort. Although the majority of the cases reviewed were evaluated by both ultrasound and MRI, the imaging agreement could not be assessed in the few cases that did not undergo MRI. Intra-observer and interobserver variability could not be calculated in this study, as nerve visualization and imaging diagnoses were determined via retrospective review of imaging reports. Another noteworthy limitation of this retrospective study is that it was not blinded, and, as in clinical practice, EDX, ultrasound, and EMG findings can inform each other. Also, the reviewed cases were referred for imaging in instances where clinicians thought it would be useful, and the authors acknowledge this bias. These limitations can only be resolved with a prospective, blinded study. Nonetheless, the efficacy of ultrasound as an imaging adjunct to the clinical evaluation of the SSN, LTN, SAN and phrenic nerve is well demonstrated in this study and indicates potential for more widespread clinical use of ultrasound in the assessment of neuropathy in the neck.

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Disclosure

The authors report no disclosures relevant to the manuscript. Full disclosure form information provided by the authors is available with the full text of this article at Neurology.org/cp at the end of disclosure paragraph.

TAKE-HOME POINTS

- Ultrasound can effectively visualize and diagnose neuropathy of the SSN, LTN, SAN, and phrenic nerve in the neck.
- Ultrasound demonstrated a higher rate of nerve visualization in the neck compared with MRI.
- Ultrasound of nerves in the neck demonstrated similar or greater concordance with the final clinical diagnosis compared with MRI.

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Appendix Authors

Name	Location	Contribution
Emily Casaletto, BS	Hospital for Special Surgery, New York	Major role in the acquisition of data and drafted the manuscript for intellectual content
Bin Lin, ScM	Hospital for Special Surgery, New York	Analyzed the data; interpreted the data; and drafted the manuscript for intellectual content
Scott W. Wolfe, MD	Hospital for Special Surgery, New York	Revised the manuscript for intellectual content
Steve K. Lee, MD	Hospital for Special Surgery, New York	Revised the manuscript for intellectual content
Darryl B. Sneag, MD	Hospital for Special Surgery, New York	Revised the manuscript for intellectual content
Joseph Feinberg, MD	Hospital for Special Surgery, New York	Revised the manuscript for intellectual content
O. Kenechi Nwawka, MD	Hospital for Special Surgery, New York	Designed and conceptualized the study; analyzed the data; interpreted the data; and drafted and revised the manuscript for intellectual content

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