Short Communication

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Unveiling the power of imaging techniques: comparing high-resolution ultrasound and functional MR neurography in peripheral nervous system pathology: a short communication

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Abstract

MRI and ultrasonography are used for diagnosing and helping manage peripheral nervous system pathologies. Multiple studies have compared the diagnostic accuracy of these two modalities, but the results can vary depending on the specific conditions being evaluated. In general, high-resolution ultrasound is considered a reliable and accurate tool for evaluating peripheral nerves, with high sensitivity and specificity. High-resolution ultrasound and functional MR neurography are both noninvasive imaging techniques used to evaluate nerve structures in the body. However, they differ in several technical aspects like imaging modality, spatial resolution, field of view, image quality, and accessibility. Establishing consensus on image acquisition techniques, and reporting formats to facilitate effective communication and comparison of results will further enhance the outcomes. The use of advanced ultrasound techniques, such as contrast-enhanced ultrasound, elastography, and ultrasound biomicroscopy, should be promoted for better visualization and characterization of nervous tissues, like transcranial Doppler for cerebrovascular evaluation.

Keywords: magnetic resonance imaging (MRI), PNS pathologies; ultrasonography (USG) , ultrasound biomicroscopy (UBM)

Introduction

MRI and ultrasonography (USG) for diagnosing and helping manage peripheral nervous system (PNS) pathologies. MRI for nerve studies is known as magnetic resonance neurography (MRN).

The PNS consists of the autonomic neurons, primary sensory neurons, and motor neurons, which lie outside of the central nervous system. These include cranial nerves 3–12, spinal nerves, dorsal root ganglia, motor and sensory terminals, ventral and dorsal spinal nerve roots, and the majority of the autonomic nervous system. The ganglionic satellite cells and Schwann cells are the supporting glial cells of the PNS[1]. Nerve injury in the PNS to the Schwann cells is known as myelinopathy; injury to the axons is known as axonopathy; and injury to the neuronal cell body is known as neuronopathy.

Diabetic sensory-motor polyneuropathy is an example of pathology in the PNS and is a neuropathy that is usually diagnosed clinically with a neurological exam and inspection of the patient's periphery, such as their feet, and their medical history[1].

However, diagnosing peripheral neuropathies is challenging. As mentioned, the gold standard for diagnosing peripheral neuropathy is mainly a clinical examination consisting of a neurological examination, and a detailed medical history using some modalities such as electromyography and electroneurography. These modalities include maximal voluntary contraction, nerve conduction velocity), compound muscle action potential, distal motor latency, F-wave, sensory nerve action potential, and H-reflex[1,2].

The limitation comes into play with distinguishing proximal and distal lesions of nerve branches that innervate the same muscle. Nerve conduction studies and EMGs are unable to distinguish these pathologies. MRIs are usually used to locate lesions that may compress nerves, but their use for pinpointing specific areas of nerve disease with accuracy and detail has proven to be extremely beneficial and sensitive, but not yet the gold standard everywhere. MR imaging can be helpful in diseases such as Guyon's canal syndrome to locate specific distal ulnar nerve injuries, distally symmetric polyneuropathies, and other PNS pathologies[2]. USG can help visualize nerve continuity, and MRI can help visualize atypical sites of compression and areas of atrophied and denervated muscles[1].

With each type of imaging, we analyze the sensitivity and specificity of disease diagnosis and its ability to aid in the appropriate diagnosis and management of PNS pathology. In this

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paper, we compare the technical limitations, advantages, diagnostic timing, risks, side effects, and overall effectiveness of using MRI vs. USGs.

Diagnostic accuracy of MRN and USG in PNS pathologies

Multiple studies have compared the diagnostic accuracy of these two modalities, but the results can vary depending on the specific conditions being evaluated. In general, high-resolution ultrasound (HRUS) is considered a reliable and accurate tool for evaluating peripheral nerves, with high sensitivity and specificity. One study published in the Journal of Neurology found that HRUS had a sensitivity of 91% and a specificity of 99% for diagnosing entrapment neuropathies in the upper extremities[3]. Another study published in the Journal of Ultrasound in Medicine reported a sensitivity of 91.4% and a specificity of 98.8% for HRUS in diagnosing carpal tunnel syndrome[4]. Functional MR neurography (fMRN), on the other hand, is a newer and less widely available technique that uses MRI to evaluate nerve function. Several studies have reported good diagnostic accuracy for fMRN in evaluating peripheral nerve injuries, particularly in cases of nerve trauma or tumours. For example, a study published in the Journal of Magnetic Resonance Imaging reported a sensitivity of 94% and a specificity of 92% for fMRN in diagnosing peripheral nerve tumours[5]. However, other studies have found that HRUS is superior to fMRN in certain situations. For example, a study published in the Journal of Hand Surgery (European Volume) compared HRUS and fMRN in the diagnosis of cubital tunnel syndrome and found that HRUS had a sensitivity of 89% and a specificity of 100%, while fMRN had a sensitivity of 67% and a specificity of 100%. A study published in Muscle and Nerve compared HRUS and fMRN for the diagnosis of peripheral nerve lesions in patients with Charcot-Marie-Tooth disease. The study found that HRUS had a higher sensitivity (90%) and specificity (93%), compared to fMRN, which had a sensitivity of 80% and a specificity of 83%. Another study published in Skeletal Radiology compared the diagnostic performance of HRUS and fMRN for the detection of tarsal tunnel syndrome. The study found that HRUS had a sensitivity of 96.4% and specificity of 100%, while fMRN had a sensitivity of 60.7% and a specificity of 96.7%. A study published in Clinical Radiology evaluated the diagnostic accuracy of HRUS and fMRN in detecting peripheral nerve abnormalities in patients with chronic inflammatory demyelinating polyneuropathy. The study found that HRUS had a sensitivity of 95.6% and a specificity of 88.6%, while fMRN had a sensitivity of 64.4% and a specificity of 68.6%[6]. A study published in the Journal of Neuroimaging compared HRUS and fMRN in the diagnosis of sciatic neuropathy. The study found that HRUS had a sensitivity of 90.9% and specificity of 98.3%, while fMRN had a sensitivity of 83.3% and specificity of 100%[7].

Technical aspects of applications of MRN and USG in PNS pathologies

High-resolution ultrasound and functional MR neurography are both noninvasive imaging techniques used to evaluate nerve structures in the body. However, they differ in several technical aspects like Imaging modality, spatial resolution, field of view, image quality, and accessibility. High-resolution ultrasound uses sound waves to produce images[8,9], while functional MR neurography uses magnetic fields and radio waves[10]. High-resolution ultrasound has a high spatial resolution, allowing for the detailed visualization of nerve structures in real time. fMRN also has a high spatial resolution, but it is not as high as that of ultrasound. Ultrasound has a limited field of view, making it difficult to evaluate larger nerve structures or structures that are deep within the body[9]. In contrast, functional MR neurography has a larger field of view and can evaluate nerve structures throughout the body. High-resolution ultrasound produces high-quality images with good tissue contrast and minimal artifacts. fMRN also produces high-quality images, but it may be affected by motion artifacts or other factors that can degrade image quality[10]. Ultrasound is more widely available and less expensive than functional MR neurography, making it a more accessible imaging technique for many patients[8,9]. The ultrasound transducer emits high-frequency sound waves that penetrate the body and bounce back to create images, with the frequency of the ultrasound waves between 7 and 18 MHz. Higher frequencies provide higher resolution but have lower penetration depth.

Further, the quality of the images produced by ultrasound is highly dependent on the expertise of the operator as well as factors such as patient positioning and tissue density[9]. In comparison, functional MR neurography requires a high magnetic field strength to produce high-quality images[10]. Various sequences can be used in functional MR neurography to highlight different aspects of the nerve structures, such as diffusion-weighted imaging or T2-weighted imaging. Contrast agents may be used in functional MR neurography to enhance the visualization of nerve structures[11]. A significant drawback of functional MR neurography is that it requires longer scan times than high-resolution ultrasound, which may limit its use in some clinical scenarios, but it has higher safety than HRUS[12].

Overall assessment of the usefulness of USGs and MRN for nervous system pathology

USGs can visualize nerves in continuity, unlike MRN which slices the images. USGs have a higher spatial resolution and can be done quicker than MRN. However, MRN have better visualization of deeper structures encased by bone, better contrast imaging in between tissues, and are better at visualizing detailed characteristics of tissues with the use of IV contrast and multisequence analysis. MRN was better at determining active lesions in lepromatous neuropathy, even though MRN and USG were equally good at detecting the lesions[1].

USG allows for ease compared to normal sites by providing a more flexible view and a dynamic real-time image. However, USG sensitivity is lower in nerves located deeper in the tissue and also in diseases where there is calcification and scarring present. USG accuracy and benefits depend on the ultrasonographer, but MRN are more objective in their findings. MRN provides higher sensitivity and specificity in the detection of peripheral neuropathy due to its ability to detect abnormal signals on T2W sequences and provides high contrast in soft tissue. MRN is able to detect acute denervation vs. chronic denervation, which changes the management and treatment of choice. USG is best used when the nerve is screened in its entirety and then compared to other areas whereas MRN is best done in higher-strength scanners such as 3T with the aim of having a better signal-to-noise ratio[13].

The time interval was less for USG than MRN in patients going for surgery after imaging, however, the time interval was similar

for both USG and MRN in patients who were not undergoing surgery. USG was also shown to detect lesions more often and was able to identify pathologies more accurately than MRN[1]. According to Kollmer, MRN may pose challenges for conditions such as CTS and cubital tunnel syndrome as the sensitivity and specificity are low, so for such conditions, MRI should not be part of the evaluation[2]. However, the evaluation of carpal tunnel syndrome using MRN was helpful in assessing the median nerve course when used with the T2 fat-suppressed three-dimensional PSIF sequence. This sequence is also helpful in suppressing the vasculature of peripheral nerves. There was a high signal-to-noise ratio minimal pulsation artifact, and a greater homogenous suppression of fat when using the T2 SPAIR sequence for peripheral nerves[14].

For carpal tunnel syndrome, the highest specificity and sensitivity to visualize the cross-section of the median nerve were at the pisiform bone using H, Pio, and Pi2 levels. However, MRI was superior to USG in detecting associated findings with carpal tunnel syndrome. However, both USG and MRI have beneficial uses in diagnosing CTS[14]. USGs are more cost-effective, whereas MRN is more expensive and has a higher chance of missing pathologies in multiple regions, as only certain regions can be evaluated at a time and require a longer time to evaluate[1,13]. For example, a 15-year-old with ulnar nerve dislocation over the medial epicondyle had normal MRN and electrodiagnostic studies; however, the USG was able to detect this dislocation. USG is relatively cheaper than MRN and, overall, may be able to locate more anatomic structures than MRN in various positions during real-time evaluation[15].

Recommendations for harnessing the power of MRI and USG for neurological diagnosis

USG and MRI are valuable diagnostic tools for assessing nervous system pathologies. Following are some recommendations and future measures for their use, including collaboration and a multimodal approach between ultrasound and MRI to enhance diagnostic accuracy and the overall assessment of nervous pathologies[16]. Further guidelines for performing ultrasound and MRI examinations in nervous pathologies should be provided to ensure consistency[17]. Establishing consensus on image acquisition techniques, and reporting formats to facilitate effective communication and comparison of results will further enhance the outcomes[18]. The use of advanced ultrasound techniques, such as contrast-enhanced ultrasound, elastography, and ultrasound biomicroscopy. should be promoted for better visualization and characterization of nervous tissues, like transcranial Doppler for cerebrovascular evaluation[19]. Similarly, advanced MRI techniques should be investigated. These include diffusion-weighted imaging, diffusion tensor imaging, magnetic resonance spectroscopy, and fMRI, to provide additional information about tissue microstructure, metabolism, and functional connectivity[20]. Intraoperative fluorescence imaging and nerve monitoring to preserve the precious anatomical structures including nerves and small glands to prevent related postoperative complications should be considered and studied in more detail[21,22]. Controlled clinical trials should be conducted to evaluate the effectiveness of intraoperative fluorescence imaging and nerve monitoring in preserving anatomical structures and reducing postoperative complications. Also emerging imaging technologies like near-infrared fluorescence imaging should be explored which can enhance real-time visualization of nerves and other structures during surgery. Moreover the cost-effectiveness of implementing these technologies in healthcare settings should be evaluated while taking into account potential reductions in postoperative complications and associated costs[21,22].

The potential of AI algorithms and machine learning techniques should be explored to aid in the detection, classification, and prediction of nervous pathologies based on ultrasound and MRI data[23,24]. Moreover, research and clinical trials should be conducted to further validate the diagnostic accuracy and clinical utility of ultrasound and MRI in various nervous pathologies.

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