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Musculoskeletal Ultrasound: From Diagnosis to Rehabilitation

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Ultrasonographic imaging has become an increasingly valuable modality across nearly all medical specialties. Its integration into routine clinical practice often as an extension of the physical examination underscores its substantial diagnostic and practical utility. In the field of physical medicine and rehabilitation, musculoskeletal ultrasonography (US) has gained particular prominence because it enables real-time, dynamic, and cost-effective evaluation of the neuromusculoskeletal system. Beyond diagnostic purposes, US is widely used for interventional procedures, monitoring disease progression, and guiding rehabilitation strategies, thereby establishing it as a cornerstone of contemporary physiatric practice.[1]

The diagnostic utility of US in musculoskeletal disorders is extensive and well established. In addition to its recognized role in the diagnosis and monitoring of various rheumatological diseases, US is routinely employed in the evaluation of a broad spectrum of musculoskeletal conditions.

Owing to its capacity for high-resolution, real-time, and dynamic imaging, US has become an essential tool for the assessment of acute and chronic tendon pathologies. It enhances diagnostic accuracy by identifying tendon thickening, hypoechogenicity, calcifications, partial or complete tears, and peritendinous abnormalities. Furthermore, US supports treatment planning, facilitates effective monitoring of tendon healing, allows modification of standard therapeutic protocols, and informs clinical decision-making throughout the rehabilitation process.[2]

Distinctive ultrasonographic features of postoperative tendons provide valuable insights into tendon healing status, repair integrity, and the presence of complications such as rerupture, suture gapping, or adhesions. By enabling both static and dynamic real-time assessment, US offers more precise and functionally relevant information than physical examination alone or other imaging modalities.[3]

Peripheral nerve imaging represents another important application of US. This modality enables detailed evaluation of nerve morphology, continuity, echotexture, and adjacent anatomical structures. In entrapment syndromes, US allows precise visualization of focal nerve enlargement, disruption of the normal fascicular pattern, and altered echogenicity, while also clarifying the underlying cause, such as space-occupying lesions, anatomical variations, or anomalous structures. Focal nerve enlargement most commonly occurs just proximal to the compression site and is often associated with increased intraneural vascularity, likely resulting from inflammation and edema.[2]

In traumatic nerve injuries, US can identify nerve discontinuity, fibrosis, perineural edema, neuroma formation, and other structural abnormalities.[4] Beyond focal entrapments and injuries, neuromuscular US is valuable in evaluating generalized peripheral neuropathies. Diffuse or segmental nerve enlargement, a hallmark of demyelinating neuropathies (e.g., Charcot–Marie–Tooth disease type 1A, chronic inflammatory demyelinating polyneuropathy), can be detected at multiple points along the nerve course and may complement electrodiagnostic findings. Axonal neuropathies typically exhibit milder enlargement with increased echogenicity and may show denervation-related muscle atrophy in chronic stages.[5]

US is also highly effective for detecting peripheral nerve tumors in patients with neurological deficits.[6] Benign lesions, such as schwannomas and neurofibromas, generally appear as well-defined hypoechoic masses with preserved fascicular architecture, whereas malignant peripheral nerve sheath tumors often present as irregularly shaped lesions with heterogeneous echotexture and increased vascularity.[7]

Beyond peripheral nerve imaging, US is increasingly employed to assess muscle involvement in various neuromuscular disorders.[8] In Duchenne, Becker, and limb-girdle muscular dystrophies, US typically demonstrates diffuse, symmetric, and homogeneously increased muscle echogenicity with loss of normal architecture, reflecting underlying structural changes such as fibrosis and fatty replacement.[9] Early stages may exhibit variable pseudohypertrophy, followed by progressive muscle atrophy as fatty infiltration and fibrosis advance.

Ultrasonographic features of inflammatory myopathies, including polymyositis and dermatomyositis, reflect both active inflammation and secondary structural changes. During the acute phase, US

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often reveals increased muscle thickness, reduced echogenicity due to edema, disrupted muscle architecture, and blurred fascial planes. In chronic or inadequately treated disease, muscles exhibit progressively increased echogenicity from fatty infiltration and fibrosis, often accompanied by atrophy. Unlike muscular dystrophies, inflammatory myopathies may show heterogeneous or patchy involvement, sometimes with asymmetric distribution. Power Doppler imaging can demonstrate increased intramuscular vascularity.[10]

In motor neuron diseases, such as amyotrophic lateral sclerosis (ALS) and spinal muscular atrophy (SMA), US frequently shows increased muscle echogenicity corresponding to fibro-fatty replacement secondary to chronic denervation. In ALS, echogenicity is often patchy, heterogeneous, and asymmetric, with regionally uneven atrophy, whereas SMA generally demonstrates a more symmetric pattern of echogenicity and atrophy. Notably, muscle US has been reported to be more sensitive than electromyography (EMG) in detecting spontaneous fasciculations, providing a higher detection frequency in ALS diagnosis.[11] Peripheral nerve US may also reveal reduced cross-sectional areas of motor nerves, reflecting motor axon loss.[12] The characteristic ultrasonographic features of neuromuscular and peripheral nerve disorders are summarized in Table 1.

Owing to these capabilities, US has become a valuable adjunct to electrodiagnostic studies. It is frequently employed to support diagnosis by visualizing structural alterations in nerves and muscles and to guide needle placement in muscles that are difficult to access during EMG, thereby enhancing diagnostic accuracy and procedural safety.[8]

US guidance also significantly improves the safety and efficacy of musculoskeletal injections. By providing real-time visualization of anatomical structures including nerves, vessels, tendons, and joints—US enables precise needle placement and accurate administration of therapeutic agents. Compared with landmark-based techniques, US-guided injections reduce complication rates, minimize the risk of iatrogenic injury, and improve clinical outcomes.[13] Moreover, real-time tissue visualization allows procedural adjustments during injection, enabling clinicians to modify their approach as needed, which enhances patient satisfaction and procedural confidence.

TABLE 1. Ultrasonographic Features of Neuromuscular and Peripheral Nerve Disorders.

Disease/condition	Ultrasonographic findings
Entrapment neuropathies	Focal nerve enlargement and hypoechogenicity proximal to the entrapment site Nerve flattening at the entrapment site Increased intraneural vascularity
Traumatic nerve injuries	Nerve discontinuity Fibrosis Perineural edema, or neuroma formation
Hereditary neuropathies (e.g., CMT1A)	Diffuse nerve enlargement
Acquired inflammatory polyneuropathies (e.g., CIDP)	Multifocal nerve enlargement outside of compression sites
Benign peripheral nerve sheath tumors (e.g., schwannoma, neurofibroma)	Well-defined margins Hypoechoic mass Preserved fascicular continuity Mild vascularity
Malignant peripheral nerve sheath tumors	Irregular margins Heterogeneously hypoechoic mass Increased and chaotic vascularity
Muscular dystrophies (e.g., Duchenne, Becker, limb-girdle)	Pseudohypertrophy (in early stages) Muscle atrophy (in later stages) Diffuse, symmetric and homogeneously increased muscle echogenicity Loss of normal muscle architecture
Inflammatory myopathies (e.g., polymyositis, dermatomyositis)	Edema-related hypoechogenicity (in the acute phase) Progressive increase in echogenicity (in the chronic phase) accompanied by muscle atrophy Heterogeneous and patchy involvement Increased vascularity
Motor neuron diseases (e.g., ALS, SMA)	Increased muscle echogenicity Muscle atrophy Fasciculations (commonly in ALS) Reduced cross-sectional area of motor nerves (mostly in ALS)

ALS, amyotrophic lateral sclerosis; SMA, spinal muscular atrophy; CMT1A, Charcot–Marie–Tooth disease type 1A; CIDP, chronic inflammatory demyelinating polyneuropathy.

In recent years, artificial intelligence (AI) has emerged as an important tool in enhancing the acquisition and interpretation of high-quality US images, supporting healthcare professionals in achieving more objective and precise analyses.[14] AI algorithms, particularly those based on machine learning and deep learning, have demonstrated considerable potential in automating image segmentation, feature extraction, and pattern recognition in US imaging.[15] These technologies are expected to expand further, offering substantial benefits to clinicians and healthcare systems, including improved diagnostic accuracy, increased workflow efficiency, and reduced costs.

In conclusion, US has become a cornerstone of physiatric practice, providing real-time, dynamic, and cost-effective assessment of a wide range of neuromusculoskeletal conditions. Its use enhances clinical accuracy and procedural safety in diagnosis, interventional procedures, and rehabilitation strategies. The integration of AI further augments objectivity, standardization, and efficiency, solidifying US as a vital, reliable, and indispensable tool in contemporary musculoskeletal practice.

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