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Musculoskeletal Ultrasound in Physical Medicine and Rehabilitation

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Abstract This review article discusses the current role of ultrasound in the modern physiatric practice, both as a complementary diagnostic tool and as a modality for intervention guidance. Indications, limitations, techniques, guidelines for utilization, new training and credentialing initiatives, and potential for future research are discussed. Indications include the role of diagnostic ultrasound and ultrasound-guided interventions in the different areas of physical medicine and rehabilitation (PM&R) including musculoskeletal, pain, neuromuscular medicine/electrodiagnosis, pediatrics, and central nervous system rehabilitation. Guidelines for utilization including recently published articles pertaining to the role of ultrasound in diagnosis of musculoskeletal conditions are reviewed. Training and credentialing are reviewed, specifically the introduction and evolution of ultrasound training in PM&R residency programs as well as recently introduced practitioner certification and practice accreditation processes. Potential for research is discussed including the need for further evaluation of cost-effectiveness, accuracy and efficacy of these techniques when compared to current standards of practice.

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Introduction

The use of ultrasound within the field of physical medicine and rehabilitation (PM&R) is revolutionizing how physiatrists diagnose and treat many musculoskeletal conditions. In the past, physiatrists relied on a fundamental understanding of anatomy, physical examination maneuvers and often costly imaging techniques to diagnose and confirm acute and chronic musculoskeletal conditions. With the recent advances in technology, ultrasound units have become more portable, affordable, and accessible, allowing this modality to become a mainstay in the day-to-day management of their patients. For the first time, physiatrists are able to instantaneously confirm physical exam findings in the office and view tissues of interest both statically and dynamically. Additionally, ultrasound has proved to be a useful tool to assist with the real-time visualization of target and surrounding structures during interventional procedures and electrodiagnostic testing.

Musculoskeletal ultrasound (MSK US) refers to the use of high-resolution sonography for the visualization of joints and soft-tissue structures. While there have been many exciting advancements with respect to ultrasound in PM&R, there is concern regarding overutilization. Use of MSK US has increased considerably during the past decade among all specialities, and with this has come increasing pressure by payers to curb use [1, 2]. A recent survey of international physiatrists found that more than 50 % of respondents were using MSK US daily in their practice and 90 % believed MSK US should be performed by

physiatrists to diagnose and treat a wide range of musculoskeletal conditions [3].

In order to support ultrasound's continued use as a clinical tool, it must be shown to be safe and cost effective, and to improve clinical outcomes in well-designed research studies. The purpose of this paper is to review the latest advances of ultrasound and present the most recent literature published regarding the indications, clinical applications, clinical efficacy, and cost effectiveness of ultrasound as applicable to a practicing physiatrist.

Indications for Diagnostic Musculoskeletal Ultrasound

In order to better define the role of diagnostic MSK US in clinical practice, a group of 16 MSK radiologists convened to develop guidelines for the appropriate application of sonography in the diagnosis of MSK disorders. These guidelines were intended to produce a comprehensive, evidence-based framework for the utilization of MSK US based on expert review of more than 550 published articles. They utilized clinical consensus based on their clinical experience and reviewed and graded the available literature to support these recommendations. They concluded that MSK US could be considered a first-line imaging modality for 72 clinical indications in the six commonly described anatomical areas of (1) hand/wrist, (2) elbow, (3) shoulder, (4) hip, (5) knee and (6) foot/ankle (Table 1) [4••]. These guidelines, along with previous recommendations from the European League Against Rheumatism (EULAR), European Society of Skeletal Radiology (ESSR), and American Institute of Ultrasound in Medicine (AIUM) serve as a framework for proper utilization of ultrasound in clinical PM&R practice [5•].

Indications and Specifications for Ultrasound Guided Procedures

Ultrasound has become an indispensable tool for image guidance of interventional procedures within the MSK system. Unfortunately, there are no accepted standard techniques for performing ultrasound guided procedures. The AIUM, supported by several recent reviews, has attempted to outline recommendations for the performance of ultrasound guided interventions [6••, 7•]. Davidson and Jayaraman [8] recently reviewed the indications and level of evidence for ultrasound guided interventions and different injectates. While the details of every ultrasound guided injection is beyond the scope of this paper, Table 2 provides a list of commonly performed ultrasound guided injections with references for selected techniques.

Table 1 Summary of clinical indications for use of diagnostic musculoskeletal ultrasound by anatomic region [4••]

Upper extremity
Shoulder: 106 articles were reviewed. Level A evidence for evaluation of full and partial thickness rotator cuff tears. Clinical indications based on consensus opinion include bursitis, partial and full thickness rotator cuff tears, calcific tendinitis, long head of biceps rupture and dislocation, and septic arthritis. Ultrasound was not indicated for evaluation of adhesive capsulitis, glenohumeral joint instability, Parsonage–Turner syndrome, or thoracic outlet syndrome
Elbow: 69 articles were reviewed. Level A evidence for evaluation of lateral epicondylitis. Clinical indications based on consensus opinion included lateral/medial epicondylitis, synovitis, septic arthritis, triceps tendon injury, snapping triceps syndrome, olecranon bursitis, radial nerve compression, pronator syndrome, and ulnar nerve disorders. Ultrasound was not indicated for evaluation of lateral collateral ligament, lateral condyle and supracondylar fractures, or radial head subluxation
Hand/wrist: 83 articles were reviewed. No level A evidence was reported. Clinical indications based on consensus opinion included evaluation of tenosynovitis, mass, joint synovitis, pulley injuries, central slip injury, trigger finger, ganglion cysts, jersey finger, FCU/ECU pathology, hammer hand, carpal tunnel syndrome, Guyon's canal, and Wartenberg syndrome. Ultrasound was not indicated for evaluation of fractures of hamate or capitate, evaluation of triangular fibrocartilage complex, or Kienböck's disease
Lower extremity
Hip: 57 articles were reviewed. Level A evidence was obtained for fluid detection, extra-articular causes of snapping hip, synovitis and effusions. Clinical indications based on expert consensus include sports hernias, Morel–Lavallee lesions, and high-grade muscle injuries. Ultrasound was not indicated for evaluation of intra-articular snapping hip, osteoarthritis, labral tears, low-grade muscle injuries, psoas tendon problems, trochanteric pain, or sciatic pain
Knee: 197 papers were reviewed. Level A evidence with a favorable consensus expert opinion included evaluation of patellar and quadriceps tendinopathy, Osgood–Schlatter, Sinding–Larsen, periarticular bursitis and ganglions, and visualization of nerves. Clinical indications based on consensus opinion include pes anserine tendinobursitis. Ultrasound was not indicated for evaluation of osteochondritis dissecans, plica syndrome, cruciate and meniscal tears, fractures, posterolateral corner lesions, intra-articular ganglion, or Hoffa's fat pad syndrome
Ankle: 55 papers were reviewed. Clinical indications based on Level A evidence and/or consensus expert opinion include evaluation of tendon tears, effusions, peroneal dislocation, calcific tendinitis, retrocalcaneal bursitis, anterior talofibular ligament, calcaneofibular ligament, plantar fasciitis, ganglion cysts, nerve entrapments, and Morton neuroma. Ultrasound was not indicated for evaluation of the posterior talofibular ligament, intra-articular disease, cartilage lesions, or assessment of fractures

Although there are few absolute indications for the performance of ultrasound-guided interventional procedures, studies have clearly demonstrated that needle placement is more accurate with image guidance,

Table 2 Examples of ultrasound guided interventions by anatomic region with key references for each procedure [7•]

Upper extremity
Shoulder
Subacromial-subdeltoid bursa injection [79]
Acromioclavicular joint [80]
Glenohumeral joint [81]
Biceps tendon sheath [13]
Aspiration/lavage of calcific tendinitis [68]
Elbow
Medial and lateral epicondyle [82]
Elbow joint [83]
Hand/wrist
Carpal tunnel [84]
De Quervain's tenosynovitis [85]
Carpometacarpal and trapeziometacarpal joint [86]
Trigger finger [87]
Scaphotrapeziotrapezoid joint [88]
Distal radioulnar joint [89]
Lower extremity
Hip
Iliopsoas tendon and bursa [90]
Intra-articular hip joint [91]
Piriformis injection [92]
Knee
Intra-articular knee [93]
Baker's cyst aspiration [94]
Pes anserine bursa [95]
Foot/ankle
Subtalar/tibiotalar/sinus tarsi [96]
Retrocalcaneal bursa [97]
Plantar fascia [98]
Metatarsophalangeal joint/sesamoid disorders [99]
Interdigital neuroma [100]

specifically ultrasound, when compared to anatomical landmark or unguided techniques at a variety of anatomical locations [8–13]. The data are conflicting whether this translates into improved clinical efficacy [9, 14–16].

Cost-effectiveness has also become an essential part of the equation when assessing the clinical utility of procedures and tests. In the 2011 CPT codes, ultrasound guidance for needle placement (76942) added approximately $200 (varies based on geographic location) to the cost of a procedure. Although the literature is limited, there is some evidence suggesting that guided procedures are a more cost effective treatment strategy. Researchers evaluated ultrasound versus blind injections in patients with inflammatory and non-inflammatory arthritis and found a reduction of $7–17 per patient per year with the use of ultrasound and even bigger reduction in costs of $64–224 per patient per year in a subgroup identified as "responders" [17–19].

Ultrasound Applications in Physical Medicine and Rehabilitation

PM&R is a broad field representing several distinct clinical areas that have been organized by the American Academy of Physical Medicine and Rehabilitation (AAPM&R) into five member councils including: (1) Central Nervous System Rehabilitation, (2) Musculoskeletal Medicine, (3) Medical Rehabilitation, (4) Pain Medicine/Neuromuscular Medicine, and (5) Pediatric Rehabilitation/Developmental Disabilities. Using this organization, the current state and recent advancements in MSK ultrasound will be discussed.

Musculoskeletal Medicine

As noted above, ultrasound is a first-line imaging modality for many musculoskeletal complaints as it allows for dynamic evaluation, sonopalpation of potentially painful structures and real-time visualization for interventional procedures (injections, aspirations, and advanced procedures). Ultrasound's ability to allow for both static and dynamic assessment provides an inherent advantage over other imaging modalities when applied diagnostically in the evaluation of impingement syndromes, rotator cuff and biceps tendon pathology, tendon dislocations, snapping hips, and entrapments syndromes [20–22]. These characteristics make ultrasound an ideal clinical companion for assessment and treatment of musculoskeletal complaints as outlined in a recent retrospective case review of >1,100 patients that found the use of ultrasound in an outpatient musculoskeletal clinic reduced the need for repeat clinical appointments, improved clinical outcomes and increased patient satisfaction [23].

Ultrasound has also gained wide acceptance and utilization within the field of sports medicine. The portability of the newer ultrasound units allows for immediate assessment of injuries making it an ideal tool in ski clinics, on the sidelines, and in the training room [24, 25•, 26]. The real time visualization that ultrasound allows has paved the way for bioregenerative medicine techniques such as platelet rich plasma and stem cell injections, needle tenotomy and focused aspiration of degenerative tissues. Platelet-rich plasma injections have shown promise in the healing of muscle, ligament, and tendon injuries in animal models and human evidence continues to grow [27]. A recent article by Nguyen et al. [28] comprehensively reviewed PRP in sports medicine, specifically tendinopathy. The emergence of these new treatments, combined with the needle tenotomy techniques, have been made possible by the ability to visualize the degenerative tendon, perform percutaneous needling of the tendon and accurately place the injectate into the desired area. While

ongoing studies are needed to assess clinical efficacy, the role of ultrasound in the emerging field of bioregenerative medicine appears crucial.

Medical Rehabilitation

Medically complex patients develop common musculoskeletal complaints such as shoulder pain or entrapment neuropathies, and the use of ultrasound in this patient population does not differ much from that of athletes as described above. However, one area of particular interest within the field of medical rehabilitation is the use of ultrasound in the amputee population. Evaluation of residual limb fluid collections, sources of residual limb and phantom pain, and interventional guidance for the treatment of neuromas have all been described [29–31].

Ultrasound allows for the rapid identification of adventitial bursae and neuromas at the distal residual limb. It has also been shown to be effective guiding neurolysis in the treatment of phantom and residual limb pain [32]. Gruber et al. [33] described their clinical experience with 82 subjects and found ultrasound guided neurolysis was both safe and clinically effective. While no studies exist comparing ultrasound guided versus unguided phenol injections, there is certainly concern regarding imprecise injection of phenol given possible adverse local and systemic effects that would seem to warrant the use of image guidance. An alternative to phenol includes the use of a cryoprobe under ultrasound although this has not been well studied [31].

Pain Medicine/Neuromuscular Medicine

Pain Medicine

As indicated by the robust body of evidence (>1,500 articles since 1994), anesthesiologists have embraced the use ultrasound in regional anesthesia. The evidence clearly supports its role in increased efficacy and safety in the performance of peripheral blockades. However, the role of ultrasound in pain medicine is still being defined [34]. A recent review by Narouze [35•] noted a dearth of quality research pertaining to ultrasound-guided pain procedures in which to develop evidence based guidelines.

Ultrasound-guided interventional pain procedures have been described for cervical, thoracic, and lumbar facets [36–38]. Galiano et al. [39] has shown that ultrasound-guided lumbar facet injections were both safe and effective with decreased procedure time and no ionizing radiation exposure for the patient or practitioner and Yun et al. [40] demonstrated that the efficacy of ultrasound-guided lumbar facet injections was equal to that of fluoroscopic injections for pain control and return to activities of daily living. Ultrasound-guided transforaminal epidural steroid injections have been more difficult because of the lack of penetrance of bony structures and lack of contrast to confirm absence of vascular uptake. A technique of selective nerve root block has been described and found to be feasible and safe but accuracy was noted to be poor compared to fluoroscopy [41]. This is in contrast to a study by Jee et al. [42] who evaluated the efficacy of ultrasound-guided selective nerve root block with transforaminal epidural steroid injection and found no difference in outcomes.

Another application that has been studied includes ultrasound for the placement of injections into the epidural space. In 2008, the National Institute of Clinical Health and Excellence published guidelines outlining ultrasound's role in the facilitation of epidural catheter placement, specifically in children and pregnant women. Although limitations were noted, including poor visualization of the epidural space and lack of contrast used to confirm needle placement, it was determined that an epidural catheter could be safely placed with the assistance of ultrasound guidance. Additionally, a feasibility study of ultrasound-guided epidural steroid injection was done that showed successful placement in 28/29 attempts [43]. Additional studies have utilized ultrasound as an adjunct for measurement prior to epidural injections [44, 45].

Other applications that have been described include ultrasound-guided cervical selective nerve root injection, third occipital nerve block, cervical and lumbar medial branch blocks, and cervical sympathetic blocks [35•]. Although recent evidence is promising regarding implementation of ultrasound in pain medicine, clearly, more research is needed to better define the role, particularly in spinal interventions.

Neuromuscular Medicine

Ultrasound has been increasingly utilized as an adjunctive tool in the diagnosis of neuromuscular disease. Like many other emerging areas of ultrasound in medicine, physiatrists' combination of advanced anatomical knowledge, training in electrodiagnostics, and comfort with sonography make them ideal to lead the advancement of ultrasound in neuromuscular medicine.

Ultrasound allows for high-resolution, real-time imaging of neurovascular structures and has been applied to the performance of nerve conduction studies (NCS) and needle electromyography (EMG). Ultrasound is also being increasingly used as a primary imaging study to assist in the diagnosis of various neuromuscular diseases and entrapment neuropathies. It has been shown to provide accurate measurements of muscles and nerves and detect fasciculation and fibrillations to assist in the diagnosis of

amyotrophic lateral sclerosis, hereditary neuropathy with liability to pressure palsies, and acute inflammatory demyelinating polyneuropathy among others [46–48]. While image guidance is not needed for most routine studies, ultrasound has allowed for expansion of electrodiagnostic capabilities including visualization of the diaphragm during needle EMG, visualization of deep structures such as cervical roots and brachial plexus, and sonographic mapping of neurovascular structures with a high degree of anatomic variability, such as the lateral femoral cutaneous nerve, sural nerve, and ulnar nerve following transposition [5•, 49, 50]. Ultrasound-guided needle placement has been shown to be more accurate and has been demonstrated to be particularly helpful in obese patients when normal anatomical landmarks used to guide needle placement are not palpable [51, 52].

An area of particular interest is the utilization of ultrasound in the diagnosis of carpal tunnel syndrome (CTS). Over the past 15 years, there have been well over 500 articles investigating sonography in the diagnosis of CTS [53]. While some studies have only gone as far as to say ultrasound should be utilized as an adjunctive tool, a recent review reported that level A evidence exists to support the use of median nerve cross sectional area by ultrasound as an accurate test in the diagnosis of CTS and can be a valuable tool to assess for structural abnormalities including space occupying lesions, persistent median arteries, and/or bifid median nerves [54].

Central Nervous System Rehabilitation

While there has been relatively limited applicability of ultrasound within central nervous system (CNS) rehabilitation, one area of significant interest has been in the management of spasticity. With the introduction of neurotoxins, specifically botulinum toxin, physiatrists have had an invaluable tool in assisting patients with functionally limiting or painful spasticity following stroke, traumatic brain injury, spinal cord injury, or multiple sclerosis. Accuracy rates of palpation-guided injections vary depending on the targeted muscle, but range from 22 to 88 % [55]. Ultrasound guidance has been shown to be equal or superior to electrical stimulation and EMG guidance in terms of accuracy of injection of neurotoxins [55]. Ultrasound has clear advantages over the other two methods of localization, specifically allowing for direct visualization of the target, placement of injectate, and not requiring patient cooperation to localize.

As with other ultrasound-guided injections, diagnostic information can be obtained during scanning including visualization and avoidance of vessels and nerves, as well as minimizing the volume of injectate so as not to overload the target causing "spillage" into surrounding non-target muscles [55]. Ultrasound has also been reported to increase speed of injection compared to electrical stimulation and be less painful with better patient tolerability [55]. Additionally, and most importantly, a study by Py et al. [56] demonstrated that ultrasound-guided injections of neurotoxin showed better functional improvement in children with cerebral palsy compared to manual technique.

Other uses of ultrasound within CNS rehabilitation include neurotoxin injections for cervical dystonia, primary dystonia, and piriformis syndrome, as well as being an effective means to assess shoulder pathology in wheelchair users with spinal cord injury and early arthritic changes in patients with hemiparesis following stroke [57–59].

Pediatric Rehabilitation/Developmental Disabilities

More recent advances in ultrasound technology, as well as sonographer experience, have opened the door for many new clinical applications in the pediatric population including evaluation of immature bone; ligament, tendon and apophyseal injuries; nerve injuries; infectious and inflammatory processes; and foreign bodies. The lack of ionizing radiation and improved patient tolerability without sedation are particular advantages in the pediatric population [60•, 61•].

Ultrasound is uniquely useful in assessing the anatomy of the immature bone, especially the cartilaginous epiphyses of non-ossified bone. Ultrasound can also help make the diagnosis of an occult fracture in immature bone including transphyseal fractures in nonossified epiphyses and torus fractures, which can sometimes be missed on radiographs [60•, 61•]. In the adolescent population, ultrasound can be helpful in identifying an abnormal connection between tarsal bones or dynamic immobility of the tarsal bones as seen in tarsal coalition [60•]. Ultrasound can also be used in assessment of club foot to assess the severity of the deformity for surgical planning and to quantitatively monitor correction [61•].

In addition to bone, ultrasound is also ideal for evaluation of ligament, tendon and apophyseal injuries. Dynamic assessment of ligaments and tendons provides valuable information regarding functional stability and continuity that static imaging cannot provide. Ultrasound is also useful in the evaluation of apophyseal injuries (commonly seen in the adolescent athlete) and can provide descriptive information regarding anatomic variants such as absent tendons (or muscles), supernumerary bellies, or anomalous origin and insertions [61•].

In addition to structural abnormalities, ultrasound can be helpful in the diagnosis of infectious/inflammatory processes such as septic arthritis, acute hematogenous osteomyelitis and inflammatory arthropathy [60•]. While ultrasound cannot make the diagnosis of infection, early

abnormalities in the soft tissues overlying the bone may be seen as early as 2 days after the onset of symptoms. Most importantly, ultrasound can be used to guide a needle for aspiration of fluid to confirm the diagnosis and help determine appropriate antimicrobial therapy [60•, 61•]. The use of ultrasound-guided needle placement allows the practitioner to avoid contamination of non-infected spaces such as a bursa or tendon sheath [61•]. In the setting of an inflammatory arthropathy, such as juvenile idiopathic arthritis, ultrasound can be used to detect early erosions before they appear on radiographs and allow a practitioner to assess multiple joints during one examination. Doppler can provide a measure of disease activity by assessing the microvascularity of the inflamed synovium with higher sensitivity than sedimentation rate and CRP [61•]. The extent of synovial vascularity and pannus are indicative of disease activity and can be used to monitor response to treatment [60•, 61•].

Lastly, soft-tissue foreign bodies are common in children and delayed diagnosis can lead to cellulitis or abscess [60•]. Material such as wood, plastic and glass may be difficult to visualize on radiographs but typically appear echogenic on ultrasound and can be surrounded by a hypoechoic area of granulation tissue [60•]. Ultrasound can be used to localize foreign bodies for removal, thus minimizing the size of a surgical incision and the duration of the procedure [60•].

Training and Credentialing

The use of ultrasound is highly user-dependent and requires considerable practice and experience to develop the skills necessary to utilize this modality successfully. It has a distinct learning curve that has been described as long and flat [5•]. As previously mentioned, a recent survey of physiatrists found that more than 50 % of survey respondents were using musculoskeletal ultrasound in their daily practice, and 92 % felt that ultrasound was a valuable clinical tool within PM&R. However, a significant portion of this same group reported that a lack of education was a limiting factor to implementing ultrasound into practice, and only 40 % of this surveyed group reported to having obtained formal education or training [3]. Until recently, there were no formal training guidelines or resources for the interested learner, and many of the early pioneers of ultrasound utilized self-guided learning and peer-to-peer tutoring, which has been shown to be effective [62, 63]. For the self-guided learner, there are many reviews outlining ultrasound applications of different anatomic regions and Web-based learning modules demonstrating how to perform interventional procedures [6••, 7•, 8, 64–69]. Additionally, there are now many resources available including courses, workshops, and conferences developed by regional, national, and international organizations interested in the promotion of safe and responsible use of ultrasound [AIUM, AAPM&R, American Medical Society for Sports Medicine (AMSSM), amongst others].

As ultrasound becomes more popular and utilization expands, there is an inherent amount of variability in the quality of ultrasound examinations across the wide range of practitioners with their varying levels of experience and expertise. It has been well documented that novice users or those attempting to utilize ultrasound without proper practice and training are less accurate with measurements, take longer to complete tasks, and have more complications [70–72]. Until recently, there were no formal training requirements or credentialing to indicate that someone was skilled in the use of MSK US. The American Registry for Diagnostic Medical Sonography (ARDMS) is an organization that credentials practitioners in different areas of diagnostic medical sonography. In recognition of MSK US's recent growth, and in an attempt to promote the safe and proper utilization of sonography in the management of joint and soft tissue disease, the ARDMS developed the Musculoskeletal Sonography Examination (MSK-E) which, if passed, designates the practitioner with the "Registered in Musculoskeletal Sonography" credential. The MSK-E was offered for the first time starting in September 2012. To be eligible to sit for the MSK-E, one must be a licensed practitioner in a health-related field and practice in an area of medicine that is enhanced, or directly related to, the use of MSK sonography. This will include sonographers, radiologists, rheumatologists, sports medicine practitioners, orthopedic surgeons, chiropractors, podiatrists, and physiatrists. An additional pre-requisite includes the performance and/or interpretation of 150 MSK US studies within the preceding 36 months. While no longer required, a minimum of 30 ARDMS-approved continuing medical education (CME) credit hours related to MSK US are highly recommended.

Other organizations are also recognizing the need for formalizing and standardizing the utilization of ultrasound. The American Association of Neuromuscular and Electrodiagnostic Medicine (AANEM) has published recommendations for the incorporation of ultrasound as a complementary tool in the diagnosis of neuromuscular disease [73••] and the AIUM has recently developed practice parameters for credentialing the use of ultrasound in a medical practice.

The AIUM ultrasound practice accreditation recognizes clinical practices that meet or exceed standards for the performance and interpretation of diagnostic ultrasound examinations in a peer review process in an attempt to establish minimal standards for quality. In order to be credentialed, a practice must demonstrate competency in

several core areas including training and education, documentation and recording, protocols and procedures, equipment, and quality. This is done through a process which requires submission of licenses, CME activity, maintenance records, protocols, and 4 representative case studies that have been performed within the past 12 months. Although not a strict requirement at this time, there has been discussion that insurance companies may require practice accreditation as part of criteria for future reimbursement [2].

United States medical training programs have also begun to recognize the integral role ultrasound plays in the daily practice of physiatrists. Finnoff et al. [74•] described the experience of implementing an MSK US course into the Mayo Clinic PM&R residency curriculum. The authors reported that residents were overwhelmingly satisfied with the didactic sessions and that participation positively impacted their perception of the quality of their medical education. They noted that the single greatest limiting factor to implementing such a course was trained faculty to help facilitate the course [74•]. Finnoff et al. [75•] also proposed a detailed pathway for implementation of a musculoskeletal ultrasound curriculum for sports medicine fellows based on existing AIUM guidelines consisting of four components: didactic instructional sessions, didactic practice sessions, experience with clinical mentorship, and ongoing education.

Future Research

The continued advancement and successful incorporation of ultrasound into PM&R is dependent upon the rigor and quality of future scientific research. Further evaluation of validity, reliability, and cost effectiveness are certainly needed to demonstrate the value added by ultrasound to clinical care. Advancements in technology are leading to innovative uses for ultrasound in all areas of medicine. Contrast-enhanced sonography is emerging as a diagnostic tool for the evaluation of tendons with the potential to allow vascular mapping of microcirculatory changes within inflamed and/or degenerative tendons [76]. Sonoelastography assesses functional differentiation of tissues based on stiffness with emerging evidence that structurally "normal" tissue demonstrates functional changes that might represent "presymptomatic damage" and real time three-dimensional imaging is allowing for the development of advanced interventional procedures [77, 78]. Current research is defining the potential role of these advanced interventional procedures and bioregenerative medicine techniques in the treatment of tendinopathy including ultrasound-guided percutaneous tenotomies, aspiration of degenerative tendons with pulsed ultrasound, and injection of biologic agents such as platelet-rich plasma and stem cells [8, 28]. As technology advances, further research will be needed to identify underlying pathophysiology of nerve dysfunction and ongoing studies will be required to continue to define the role of ultrasound in the diagnosis of neuromuscular disease and further develop accepted diagnostic criteria and standardization of normal values [5•].

Conclusion

Ultrasound provides high-resolution imaging of joints, tendons, ligaments, muscles, and nerves, and has multiple applications across the broad field of PM&R. While utilization of this modality increases throughout PM&R, ongoing research must continue to address appropriate clinical applications and cost effectiveness. Importantly, recent establishment of certification and accreditation has the potential to improve quality, but many questions remain regarding optimal training. Physiatrists are well-positioned to take the lead on many of these advancements to help establish musculoskeletal ultrasound as a first line modality and standard of care.

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References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

1. Sharpe RE, et al. Dramatically increased musculoskeletal ultrasound utilization from 2000 to 2009, especially by podiatrists in private offices. J Am Coll Radiol. 2012;9(2):141–6.
2. Nazarian LN, Alexander AA. Denying payments for musculoskeletal ultrasound: how did we get here? J Am Coll Radiol. 2010;7(8):553–6.
3. Ozcakar L, et al. Musculoskeletal sonography in physical and rehabilitation medicine: results of the first worldwide survey study. Arch Phys Med Rehabil. 2010;91(2):326–31.
4. •• Klauser AS, et al. Clinical indications for musculoskeletal ultrasound: a Delphi-based consensus paper of the European Society of Musculoskeletal Radiology. Eur Radiol. 2012;22(5):1140–8. *Provides a comprehensive, evidence based framework for the development of guidelines regarding the clinical utilization of musculoskeletal ultrasound.*
5. • Boon AJ, Smith J, Harper CM. Ultrasound applications in electrodiagnosis. PM R. 2012;4(1):37–49. *Reviews the current utilization of diagnostic ultrasound in the diagnosis of neuromuscular disease.*
6. •• American College of Radiology, et al. AIUM practice guideline for the performance of a musculoskeletal ultrasound

examination. J Ultrasound Med. 2012;31(9):1473–88. *Provides guidelines for the performance of musculoskeletal ultrasound by anatomic region including specifications and minimum criteria for a comprehensive examination.*

7. • Lento PH, Strakowski JA. The use of ultrasound in guiding musculoskeletal interventional procedures. Phys Med Rehabil Clin N Am. 2010;21(3):559–83. *Reviews ultrasound-guided injection principles and techniques including advantages, disadvantages, and efficacy of ultrasound guided procedures.*
8. Davidson J, Jayaraman S. Guided interventions in musculoskeletal ultrasound: what's the evidence? Clin Radiol. 2011;66(2):140–52.
9. Gilliland CA, Salazar LD, Borchers JR. Ultrasound versus anatomic guidance for intra-articular and periarticular injection: a systematic review. Phys Sportsmed. 2011;39(3):121–31.
10. Berkoff DJ, Miller LE, Block JE. Clinical utility of ultrasound guidance for intra-articular knee injections: a review. Clin Interv Aging. 2012;7:89–95.
11. Muir JJ, et al. The accuracy of ultrasound-guided and palpation-guided peroneal tendon sheath injections. Am J Phys Med Rehabil. 2011;90(7):564–71.
12. Curtiss HM, et al. Accuracy of ultrasound-guided and palpation-guided knee injections by an experienced and less-experienced injector using a superolateral approach: a cadaveric study. PM R. 2011;3(6):507–15.
13. Hashiuchi T, et al. Accuracy of the biceps tendon sheath injection: ultrasound-guided or unguided injection? A randomized controlled trial. J Shoulder Elbow Surg. 2011;20(7):1069–73.
14. Elkousy H, et al. Retrospective comparison of freehand and ultrasound-guided shoulder steroid injections. Orthopedics. 2011;34(4). doi:10.3928/01477447-20110228-11.
15. Dogu B, et al. Blind or ultrasound-guided corticosteroid injections and short-term response in subacromial impingement syndrome: a randomized, double-blind, prospective study. Am J Phys Med Rehabil. 2012;91(8):658–65.
16. Soh E, et al. Image-guided versus blind corticosteroid injections in adults with shoulder pain: a systematic review. BMC Musculoskelet Disord. 2011;12:137.
17. Sibbitt WL Jr, et al. A randomized controlled trial evaluating the cost-effectiveness of sonographic guidance for intra-articular injection of the osteoarthritic knee. J Clin Rheumatol. 2011;17(8):409–15.
18. Chavez-Chiang NR, et al. The outcomes and cost-effectiveness of intraarticular injection of the rheumatoid knee. Rheumatol Int. 2012;32(2):513–8.
19. Sibbitt WL Jr, et al. A randomized controlled trial of the cost-effectiveness of ultrasound-guided intraarticular injection of inflammatory arthritis. J Rheumatol. 2011;38(2):252–63.
20. Petranova T, et al. Ultrasound of the shoulder. Med Ultrason. 2012;14(2):133–40.
21. Ozcakar L, et al. Musculoskeletal ultrasonography in physical and rehabilitation medicine. J Rehabil Med. 2012;44(4):310–8.
22. Radunovic G, et al. Ultrasound assessment of the elbow. Med Ultrason. 2012;14(2):141–6.
23. Sivan M, et al. A one-stop approach to the management of soft tissue and degenerative musculoskeletal conditions using clinic-based ultrasonography. Musculoskeletal Care. 2011;9(2):63–8.
24. Evans CS, Harris NS. Ultrasound and ski resort clinics: mapping out the potential benefits. Wilderness Environ Med. 2012;23(3):239–47.
25. • Yim ES, Corrado G. Ultrasound in sports medicine: relevance of emerging techniques to clinical care of athletes. Sports Med. 2012;42(8):665–80. *Analyzes recently published research regarding the use of ultrasound in athletes and reviews emerging techniques of ultrasound in the clinical management of the injured athlete.*
26. Nowak MR, et al. Snowboarding injuries: a review of the literature and an analysis of the potential use of portable ultrasound for mountainside diagnostics. Curr Rev Musculoskelet Med. 2009;2(1):25–9.
27. Finnoff JT, et al. Treatment of chronic tendinopathy with ultrasound-guided needle tenotomy and platelet-rich plasma injection. PM R. 2011;3(10):900–11.
28. Nguyen RT, Borg-Stein J, McInnis K. Applications of platelet-rich plasma in musculoskeletal and sports medicine: an evidence-based approach. PM R. 2011;3(3):226–50.
29. Goktepe AS, et al. Sonographic evaluation of the sciatic nerve in patients with lower-limb amputations. Muscle Nerve. 2010;41(6):763–6.
30. van Geffen GJ, et al. Pain relief in amputee patients by ultrasound-guided nerve blocks. Eur J Anaesthesiol. 2008;25(5):424–5.
31. Neumann V, O'Connor RJ, Bush D. Cryoprobe treatment: an alternative to phenol injections for painful neuromas after amputation. AJR Am J Roentgenol. 2008;191(6):W313; author reply W314.
32. Lim KB, Kim YS, Kim JA. Sonographically guided alcohol injection in painful stump neuroma. Ann Rehabil Med. 2012;36(3):404–8.
33. Gruber H, et al. Practical experience with sonographically guided phenol instillation of stump neuroma: predictors of effects, success, and outcome. AJR Am J Roentgenol. 2008;190(5):1263–9.
34. Narouze S, Peng PW. Ultrasound-guided interventional procedures in pain medicine: a review of anatomy, sonoanatomy, and procedures. Part II: axial structures. Reg Anesth Pain Med. 2010;35(4):386–96.
35. • Narouze SN. Ultrasound-guided interventional procedures in pain management: evidence-based medicine. Reg Anesth Pain Med. 2010;35(2 Suppl):S55–8. *Reviews the role of ultrasound in pain management and spine interventional procedures.*
36. Galiano K, et al. Ultrasound guidance for facet joint injections in the lumbar spine: a computed tomography-controlled feasibility study. Anesth Analg. 2005;101(2):579–83, table of contents.
37. Galiano K, et al. Ultrasound-guided facet joint injections in the middle to lower cervical spine: a CT-controlled sonoanatomic study. Clin J Pain. 2006;22(6):538–43.
38. Stulc SM, et al. Ultrasound-guided thoracic facet injections: description of a technique. J Ultrasound Med. 2011;30(3):357–62.
39. Galiano K, et al. Ultrasound-guided versus computed tomography-controlled facet joint injections in the lumbar spine: a prospective randomized clinical trial. Reg Anesth Pain Med. 2007;32(4):317–22.
40. Yun DH, et al. Efficacy of ultrasonography-guided injections in patients with facet syndrome of the low lumbar spine. Ann Rehabil Med. 2012;36(1):66–71.
41. Chumnanvej S, Wetchagama N, Kounsongtham V. Accuracy of needle-tip localization by ultrasound guidance lumbar selective nerve root block: a prospective clinical study of 78 lumbar nerve roots block. J Med Assoc Thai. 2011;94(12):1451–6.
42. Jee H, et al. Ultrasound-guided selective nerve root block versus fluoroscopy-guided transforaminal block for the treatment of radicular pain in the lower cervical spine: a randomized, blinded, controlled study. Skeletal Radiol. 2012;42:69–78.
43. Blanchais A, et al. Feasibility and safety of ultrasound-guided caudal epidural glucocorticoid injections. Joint Bone Spine. 2010;77(5):440–4.
44. Rasoulian A, et al. Utility of prepuncture ultrasound for localization of the thoracic epidural space. Can J Anaesth. 2011;58(9):815–23.
45. Najman IE, et al. Caudal epidural anesthesia: an anesthetic technique exclusive for pediatric use? Is it possible to use it in

adults? What is the role of the ultrasound in this context? Revista brasileira de anestesiologia. 2011;61(1):95–109.
46. Cartwright MS, et al. Peripheral nerve and muscle ultrasound in amyotrophic lateral sclerosis. Muscle Nerve. 2011;44(3): 346–51.
47. Hooper DR, et al. Sonographic features in hereditary neuropathy with liability to pressure palsies. Muscle Nerve. 2011;44(6):862–7.
48. Almeida V, et al. Nerve ultrasound follow-up in a child with Guillain–Barre syndrome. Muscle Nerve. 2012;46(2):270–5.
49. Aravindakannan T, Wilder-Smith EP. High-resolution ultrasonography in the assessment of meralgia paresthetica. Muscle Nerve. 2012;45(3):434–5.
50. Scheidegger O, et al. Reproducibility of sensory nerve conduction studies of the sural nerve using ultrasound-guided needle positioning. Muscle Nerve. 2011;44(6):873–6.
51. Boon AJ, et al. Accuracy of electromyography needle placement in cadavers: non-guided vs. ultrasound guided. Muscle Nerve. 2011;44(1):45–9.
52. Boon AJ, et al. Utility of ultrasound-guided surface electrode placement in lateral femoral cutaneous nerve conduction studies. Muscle Nerve. 2011;44(4):525–30.
53. Roll SC, Case-Smith J, Evans KD. Diagnostic accuracy of ultrasonography vs. electromyography in carpal tunnel syndrome: a systematic review of literature. Ultrasound Med Biol. 2011;37(10):1539–53.
54. French C, et al. Evidence-based guideline: neuromuscular ultrasound for the diagnosis of carpal tunnel syndrome. Muscle Nerve. 2012;46(2):287–93.
55. Alter KE. High-frequency ultrasound guidance for neurotoxin injections. Phys Med Rehabil Clin N Am. 2010;21(3):607–30.
56. Py AG, et al. Evaluation of the effectiveness of botulinum toxin injections in the lower limb muscles of children with cerebral palsy. Preliminary prospective study of the advantages of ultrasound guidance. Ann Phys Rehabil Med. 2009;52(3):215–23.
57. Finnoff JT, Hurdle MF, Smith J. Accuracy of ultrasound-guided versus fluoroscopically guided contrast-controlled piriformis injections: a cadaveric study. J Ultrasound Med. 2008;27(8): 1157–63.
58. Lee IH, et al. Initial experience with imaging-guided intramuscular botulinum toxin injection in patients with idiopathic cervical dystonia. AJR Am J Roentgenol. 2009;192(4):996–1001.
59. Brose SW, et al. Shoulder ultrasound abnormalities, physical examination findings, and pain in manual wheelchair users with spinal cord injury. Arch Phys Med Rehabil. 2008;89(11):2086–93.
60. • Karmazyn B. Ultrasound of pediatric musculoskeletal disease: from head to toe. Semin Ultrasound CT MR. 2011;32(2):142–50 *Reviews the role of ultrasound in the investigation of child and adolescent musculoskeletal disorders.*
61. • Martinoli C, et al. Paediatric musculoskeletal US beyond the hip joint. Pediatric Radiol. 2011;41(Suppl 1):S113–24. *Reviews the role of ultrasound in the investigation of child and adolescent musculoskeletal disorders.*
62. Kissin EY, et al. Self-directed learning of basic musculoskeletal ultrasound among rheumatologists in the United States. Arthritis Care Res. 2010;62(2):155–60.
63. Knobe M, et al. Peer teaching: a randomised controlled trial using student–teachers to teach musculoskeletal ultrasound. Med Educ. 2010;44(2):148–55.
64. Rogers CJ, Cianca J. Musculoskeletal ultrasound of the ankle and foot. Phys Med Rehabil Clin N Am. 2010;21(3):549–57.
65. Brandon CJ, et al. Groin pain beyond the hip: how anatomy predisposes to injury as visualized by musculoskeletal ultrasound and MRI. AJR Am J Roentgenol. 2011;197(5):1190–7.
66. Allison SJ. Musculoskeletal ultrasound: evaluation of the finger. AJR Am J Roentgenol. 2011;196(3):W308.
67. Tamborrini G, et al. Web-based learning in musculoskeletal ultrasound. Z Rheumatol. 2011;70(2):154–9.
68. Lee KS, Rosas HG. Musculoskeletal ultrasound: how to treat calcific tendinitis of the rotator cuff by ultrasound-guided single-needle lavage technique. AJR Am J Roentgenol. 2010;195(3): 638.
69. Daftari AP, et al. Bovine shoulder and hip models to teach ultrasound-guided injections. Am J Phys Med Rehabil. 2011; 90(9):746–55.
70. Iagnocco A, et al. The interobserver reliability of ultrasound in knee osteoarthritis. Rheumatology. 2012;51(11):2013–9.
71. Ozcakar L, et al. Precision of novice sonographers concerning median nerve and achilles tendon measurements. Am J Phys Med Rehabil. 2011;43:681–3.
72. Orebaugh SL, et al. Interscalene block using ultrasound guidance: impact of experience on resident performance. Acta Anaesthesiol Scand. 2009;53(10):1268–74.
73. •• Walker FO, et al. Qualifications for practitioners of neuromuscular ultrasound: position statement of the American Association of Neuromuscular and Electrodiagnostic Medicine. Muscle Nerve. 2010;42(3):442–4. *Outlines indications for neuromuscular ultrasound and recommended proficiencies for practitioners utilizing ultrasound in the diagnosis of neuromuscular disease.*
74. • Finnoff JT, et al. A musculoskeletal ultrasound course for physical medicine and rehabilitation residents. Am J Phys Med. 2010;89(1):56–69. *Provides a detailed description for the implementation of a musculoskeletal ultrasound course in a Physical Medicine and Rehabilitation residency programs.*
75. • Finnoff J, Lavallee ME, Smith J. Musculoskeletal ultrasound education for sports medicine fellows: a suggested/potential curriculum by the American Medical Society for Sports Medicine. Brit J Sports Med. 2010;44(16):1144–8. *Provides a framework for the implementation of musculoskeletal ultrasound training during sports medicine fellowship.*
76. Chang KV, et al. Use of contrast-enhanced ultrasonography in musculoskeletal medicine. Am J Phys Med. 2012;91(5):449–57.
77. Wells PN, Liang HD. Medical ultrasound: imaging of soft tissue strain and elasticity. J R Soc Interface. 2011;8(64):1521–49.
78. Yu H, et al. A 3D freehand ultrasound system for multi-view reconstructions from sparse 2D scanning planes. Biomed Eng Online. 2011;10:7.
79. Chiang YP, Feng CF, Lew HL. Ultrasound-guided examination and injection of the shoulder. Am J Phys Med Rehabil. 2011;90(7):616–7.
80. Peck E, et al. Accuracy of ultrasound-guided versus palpation-guided acromioclavicular joint injections: a cadaveric study. PM R. 2010;2(9):817–21.
81. Zwar RB, Read JW, Noakes JB. Sonographically guided glenohumeral joint injection. AJR Am J Roentgenol. 2004;183(1):48–50.
82. McShane JM, Shah VN, Nazarian LN. Sonographically guided percutaneous needle tenotomy for treatment of common extensor tendinosis in the elbow: is a corticosteroid necessary? J Ultrasound Med. 2008;27(8):1137–44.
83. Lee KS, Rosas HG, Craig JG. Musculoskeletal ultrasound: elbow imaging and procedures. Semin Musculoskelet Radiol. 2010;14(4):449–60.
84. Smith J, et al. Sonographically guided carpal tunnel injections: the ulnar approach. J Ultrasound Med. 2008;27(10):1485–90.
85. McDermott JD, et al. Ultrasound-guided injections for de Quervain's tenosynovitis. Clin Orthop Relat Res. 2012;470(7): 1925–31.
86. Umphrey GL, et al. Ultrasound-guided intra-articular injection of the trapeziometacarpal joint: description of technique. Arch Phys Med Rehabil. 2008;89(1):153–6.

87. Lee DH, et al. Sonographically guided tendon sheath injections are more accurate than blind injections: implications for trigger finger treatment. J Ultrasound Med. 2011;30(2):197–203.
88. Smith J, et al. Accuracy of sonographically guided and palpation guided scaphotrapeziotrapezoid joint injections. J Ultrasound Med. 2011;30(11):1509–15.
89. Smith J, et al. Sonographically guided distal radioulnar joint injection: technique and validation in a cadaveric model. J Ultrasound Med. 2011;30(11):1587–92.
90. Blankenbaker DG, De Smet AA, Keene JS. Sonography of the iliopsoas tendon and injection of the iliopsoas bursa for diagnosis and management of the painful snapping hip. Skeletal Radiol. 2006;35(8):565–71.
91. Smith J, Hurdle MF, Weingarten TN. Accuracy of sonographically guided intra-articular injections in the native adult hip. J Ultrasound Med. 2009;28(3):329–35.
92. Smith J, et al. Ultrasound-guided piriformis injection: technique description and verification. Arch Phys Med Rehabil. 2006;87(12):1664–7.
93. Park Y, et al. Comparison of sonographically guided intra-articular injections at 3 different sites of the knee. J Ultrasound Med. 2011;30(12):1669–76.
94. Wisniewski SJ, Murthy N, Smith J. Ultrasound evaluation of baker cysts: diagnosis and management. PM R. 2012;4(7): 533–7.
95. Finnoff JT, et al. Accuracy of ultrasound-guided versus unguided pes anserinus bursa injections. PM R. 2010;2(8):732–9.
96. Wisniewski SJ, et al. Ultrasound-guided versus nonguided tibiotalar joint and sinus tarsi injections: a cadaveric study. PM R. 2010;2(4):277–81.
97. Chu NK, Lew HL, Chen CP. Ultrasound-guided injection treatment of retrocalcaneal bursitis. Am J Phys Med Rehabil. 2012;91(7):635–7.
98. Yucel I, et al. Comparison of ultrasound-, palpation-, and scintigraphy-guided steroid injections in the treatment of plantar fasciitis. Arch Orthop Trauma Surg. 2009;129(5):695–701.
99. Wempe MK, et al. Feasibility of first metatarsophalangeal joint injections for sesamoid disorders: a cadaveric investigation. PM R. 2012;4(8):556–60.
100. Sofka CM, et al. Ultrasound-guided interdigital neuroma injections: short-term clinical outcomes after a single percutaneous injection—preliminary results. HSS J. 2007;3(1):44–9.