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Perspective Chapter: Recent Advances in Musculo-Skeletal Ultrasound

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Abstract

Medical imaging specialists continue to explore better ways of demonstrating pathology and anatomy of the musculo-skeletal system. The continuous quest is fuelled by the desire to improve diagnostic yield, perform procedures more quickly and accurately, reduce risks to patient or operator, achieve better cost efficiency and utilize less complex methodologies. In many instances, musculoskeletal ultrasound acts as a screening, diagnostic tool but also guide and monitor therapeutic interventions. The paper outlines the use of ultrasound in the imaging of peripheral nerve disorders, traumatic and atraumatic joint disorders, Doppler techniques such as super micro vascular Imaging and sono-elastography. Refinements in probe technology and application of digital and novel proprietary software, have continued to improve the resolution of ultrasound images and with finer details on a scale not previously possible. With increasing experience and standardization of protocols, Musculoskeletal ultrasound will continue to play a great role in the diagnostic work-up and treatment of related disorders.

Keywords: medical imaging, musculoskeletal, ultrasound, nerve imaging

1. Introduction

Medical imaging specialists continue to explore better ways of demonstrating pathology and anatomy of the musculo-skeletal system. The continuous quest is fuelled by the desire to improve diagnostic yield, perform procedures more quickly and accurately, reduce risks to patient or operator, achieve better cost efficiency and utilize less complex methodologies. The use of ultrasound in diagnosis of musculoskeletal disorders follows the same pattern; becoming an important and effective tool for the diagnosis and follow-up management of various disorders affecting the joints and soft tissues [1, 2].

Ultrasound meets the basic criteria for accuracy, safety, affordability and efficiency. The ability to perform studies in real time and thus possible correlation of physico-clinical features of disease entities are even more pertinent reasons to choose ultrasound. Furthermore, it holds a great potential in providing guide to therapy, allowing effective follow-up to be performed. It has also provided learning opportunities for a variety of practitioners in multiple specialties such as radiology, primary care, orthopedic surgery, podiatry and physiotherapy [3].

For physical therapists in particular, ultrasound provides a unique opportunity to have a real-time assessment of musculoskeletal system to identify changes in

function, isolate pain following an injury and provide guide to useful interventions that can improve outcome [3]. In many climes, it can be argued that MRI is the mainstay modality in the evaluation of musculo-skeletal disorders. Its high cost, unavailability especially in developing and resource limited countries and the degree of sophistication required for its operation, remain reasons to explore ultrasound. Even when an MRI is available, diagnostic Ultrasound findings continue to play a complementary role in the diagnostic work-up.

Thankfully, the capabilities of ultrasound appear to have been enhanced by the presence of improved probe technology, better data acquisition and digital image processing techniques. Ultrasound has great potential for the imaging of tendons, nerves, ligaments, muscle tissue and adjoining joints [3–5].

The chapter is dedicated to reviewing various innovations and techniques of Musculo-skeletal ultrasound and promises to be useful to a wide range of readers.

2. The use of high resolution ultra-high frequency transducers

The improved diagnostic yield from ultrasound studies continues to fuel its utilization in the work up of various disease processes. In Particular, high resolution ultrasound is a requirement for musculo-skeletal imaging. To ensure that these requirements are in place, continuous research and development efforts are geared towards rapid advancements in electronics, computing, and transducer technology. Combined with sophisticated signal processing techniques, ultrasound has acquired the degree of spatial and contrast resolution required for musculo-skeletal imaging. The use of high-frequency transducers in the range of 12–18 MHz has become the mainstay in MSK ultrasound. The improved resolution afforded by this, allows evaluation of subtle changes in nerves, tendons, and ligaments [1, 4, 6]. Improvements in the design of ultrasound transducers has resulted in the development of those with very high frequency in the range of 20–70 MHz. This may have spatial resolution in the range of 50–100 μm , which permit detailed anatomy of the extremities. The higher the frequency, the better the spatial resolution and the less the penetrative ability of the resulting sound waves. Fortunately, deep penetration is not a critical requirement for superficial structures, thus ultra-high-frequency transducers are ideal for evaluating superficial musculoskeletal structures. In principle, what we lack in penetration, we gain in detail and spatial resolution. This sort of detail is invaluable when imaging the nerve fascicles by ultrasound [6–8].

3. Tendon/ligament imaging

Tendons are uniquely positioned to connect muscle tissue to bones. This is due to the high collagen content as well as the arrangement of fibers. Generally, the collagen macro-molecules are grouped into fibrils; an arrangement which is both layered and complex in nature. This in turn are bundled into fibers and fascicles surrounded by vascularized connective tissue endotendon. Each tendon is surrounded by a tendon sheath, made of two layers of synovium. Each tendon is uniquely suited to its function, and explains why the orientation of the fibers change, depending on how much tension it's expected to bear. Sometimes, the collagen is majorly aligned along the long axis of the tendon, as seen in the patella. In other tendons, particularly those with origins from more than one muscle such as the Achilles tendon and quadriceps tendon, the fibers run as discrete bundles. Although, healthy tendon bundles exhibit good tensile strength, repetitive stress may result in trauma to the tendon and tendinopathy. This is common in athletes,

where acute inflammatory response may result in Paratenonitis or tenosynovitis. In contrast, ligaments are important in connecting two bones, and contain more proteoglycan and water, as well as a relatively lower collagen content. Furthermore, the connective tissue structure of ligaments are less uniform and consists of poorly ordered, interlaced and weaving pattern. Injuries to a ligament may cause further restriction of joint movement and therefore is associated with joint derangement. In imaging the ligament, it must be appreciated that the tension of each ligament may be determined by the extent of movement at the adjacent joint. The lesions which result from ligament injury therefore depends on the position of the joint at the time of injury. The imaging of tendons and ligaments represents one of the best applications of musculoskeletal Ultrasound. It is not only accurate, but the timely diagnosis allows early intervention using conservative measures thereby delaying or reducing the likelihood of surgery) [9].

It is also possible to guide minimally invasive interventional treatments, which improves outcome and reduce the potential for post-intervention complications. In addition to all other advantages of ultrasound, the imaging of tendons is attractive due to a relatively high lesion detection rate [10]. The introduction of high-frequency, high resolution transducers, use of Doppler techniques and increasing information in this area, have improved the ability of ultrasound to detect fine textural abnormalities of these structures as well as to identify a variety of pathological conditions [11]. Ultrasound In tendon imaging, can evaluate the presence of dislocations, degenerative changes and tendon tears, longitudinal splits, partial and complete rupture, inflammatory conditions and tendon tumors. It is also invaluable as a tool to monitor healing after surgery and to identify post-surgical complications.

4. Nerve imaging

Imaging of the nervous and peripheral structures remain a challenge with conventional modalities such as X-rays and Computed tomography. Ultrasound provides an alternative and effective technique for imaging tendons and nerves. Its attraction is due to the fact that it is painless, has no known side effects and can actually be done in real-time examination. Non pathologic nerves are seen as continuous bundles of neuronal fascicle, which are separated from surrounding connective tissue [11, 12]. Ultrasound of the Neuro muscular tissues continue to define the diagnostic and treatment pathways for peripheral neuropathy [12]. The use of Standard transducers, will ensure imaging of a small proportion of nerve fascicles. This is seen as series of multiple hypoechoic parallel linear areas separated by echogenic bands, representing the fascicle and epineurium respectively. The latter is the outermost layer of dense irregular connective tissue surrounding a peripheral nerve. It usually surrounds multiple nerve fascicles as well as blood vessels which supply the nerve. When diseased, there are identifiable changes in the structure of the nerve tissues including disruption of the connective tissue, loss of parallel/linear hypoechoic fascicular architecture and swelling/increase in diameter. Compression of the nerve fascicles may occur with presence of cysts, tumors or aneurysmal dilatation of support vessels [11, 12].

A very common application of this technique is the evaluation of the relationships of median nerve anatomy in carpal tunnel syndrome, which may explain the cause of nerve compression or impingement. Sonographic changes include increase in the cross-sectional area of the nerve just proximal to the site of compression, loss of hyperechoic intensities within nerve as well as a reduction in mobility of the structures which it supplies [13, 14]. Ultrasound information supports clinical and

electrophysiological testing for detection of compressing lesions caused by nerve entrapment in a variety of osteo-fibrous tunnels of the limbs and extremities. It is also possible to evaluate Congenital anomalies, nerve tears, and neurogenic tumors. Generally speaking, ultrasound has many advantages which include dynamic assessment, non-invasiveness, absence of pain and low cost of service. It therefore qualifies as both a screening, diagnostic as well as monitoring tool [12]. MRI provides a wider field of view, with 3- dimensional images when evaluating nerve entrapment, and the use of intravenous contrast, can diagnose persistent median artery. It is however more expensive, complex and time consuming. It may also have less diagnostic yield in children and patients with claustrophobia [12–14].

5. Sono-Elastography

Sono elastography has become increasingly useful in the evaluation of musculoskeletal disorder injuries and provides a non-invasive method of obtaining both qualitative and quantitative information of mechanical and structural properties of tissues [15]. When a tissue is subjected to a force within a defined cross-sectional area, it can experience changes in its structure or deformation. The degree of deformation is a function of how stiff the tissue is. The Tissue stiffness is expressed using a physical property called Young's modulus, or modulus of elasticity. Theoretically, Young's modulus is defined as the ratio of stress (the force per cross-sectional area) for a certain material and the strain (i.e. deformation; in this case, tissue deformation). The study of the elastic properties of tissues using ultrasound is called Sono-elastography. It gives both qualitative and quantitative distribution of biological tissue strains and elasticity, and finds application in various clinical settings. There are two major applications Strain or Quasi-static elastography (QSE): This involves physical compression and displacement of tissues by the sonographer, which in turn induces a slow mechanical stress (strain) on tissues [15].

Both quantitative and qualitative assessment and comparison of the resulting stress is performed for tissues at rest and under compression. In order words the degree of stiffness, which is indicated by the range of tissue displacement is estimated. The degree of stiffness is represented quantitatively by a value and qualitatively in a color scale/mosaic that identifies the “softest” and “hardest” tissue areas. Strain sono-elastography provides a color map of tissue elasticity that is superimposed on the real-time greyscale ultrasound image. The stiffer the tissue, the more likelihood of being malignant. Consequently, in the breast, invasive cancers present as areas of higher stiffness compared to benign or normal tissues. A number of scoring systems have been developed to compare the presence, size and distribution of areas of elasticity within the supposed abnormality seen on a gray-scale image. This method appear to be more effective for superficially located structures such as breast and soft tissue masses. Shear wave elastography: This is a new method which combines the radiation force induced in a tissue by an ultrasonic beam and an ultrafast or supersonic imaging sequence which synchronizes the real-time propagation of the resulting shear waves. Typically, Shear waves cause particulate moves recorded with high-frequency imaging (5000 to 30,000 Hz), from which the system calculates color shades or elastograms in real-time (quantitative analysis).

This shear wave velocity enables the production of a two-dimensional map of shear elasticity. The technique is performed using a conventional linear array or special matrix probes. The effectiveness of shear wave elastography stems from the fact that the radiation force is automatically generated by the probe rather than the strain induced by an operator in conventional sono-elastography. Consequently, shear wave elastography is more reproducible than conventional or quasi-static

elastography. Once an area has been mapped out by the cursor as region of interest (ROI), the values representing the mean and maximum stiffness are produced. The region corresponding to areas of stiffness can thus be mapped in a fairly reproducible, and quantitative manner. Benign lesions tend to be soft, while malignant lesions are generally stiffer. Applications include assessment of the degree of hepatic fibrosis and characterization of liver lesions, kidney, breast masses, prostate cancer detection, thyroid lesions and imaging of tendons.

6. Doppler studies

The application of Doppler principles in ultrasound imaging has a long history. Its use in the demonstration of blood vessels and patterns of flow have been copiously reported. Consequently, Doppler studies finds extensive clinical use in assessment of pregnancies, gynecology, cardio-vascular system, neonatology, surgery and small parts. The question of whether flow exists or not in a lesion is an important tool in resolving Dilemmas and recognizing or characterizing disease processes. It must be recognized that the increased use of ultrasound in musculo-skeletal imaging relate to the capability and ease of using real-time Doppler US [15]. The amount of flow in the tissue under investigation can be compared with the normal to make diagnosis easy. Doppler is particularly useful when evaluating tumor masses, inflammatory changes related to the joints, tendinopathies and some forms of neuropathies. It is also important when differentiating a ganglionic lesion from sarcoma, and in synovitis [15, 16]. The need to differentiate between acute synovitis (pannus) and chronic fibrotic synovium, is made possible by the demonstration of increased blood flow in the former. In fact, the presence of increased blood flow which is present in proliferating pannus fairly correlates with active joint destruction and symptom development. Consequently, ultrasound can make valuable judgment about the prognosis of active sinovitis and pathological sequel of aggressive and destructive changes in the joint. The deployment of Superb Microvascular Imaging in current studies has improved the resolution and sensitivity compared to conventional methods such as Power Doppler. It is known that superb microvascular Doppler technology allows the operator to detect low-grade inflammation, which was hitherto impossible with Power Doppler. The consequence of early detection of active inflammation, is the prospect of early intervention and impact on treatment outcomes [17].

7. Ultrafast Doppler ultrasound

There is an increasing interest in studying the function of human brain using neuro-imaging techniques [18]. In particular, ultrasonic waves which are transmitted at extremely high or ultrafast frame rates, have shown promise in detecting blood flow signals in very small vessels such as those that perfuse the brain [18]. This has been experimented in rodents with advantages of high spatial and temporal resolution, improved penetration and ability to detect microvascular changes associated with brain functions [18].

The advantages are further enhanced due to its portability and possibility of bedside use. Over the past one decade, bold attempts at applying the technique in preclinical imaging, creates room for wider possibilities in neonates, during operative surgery, or better still, the development of non-invasive brain machine interfaces [19]. The clinical application of this technique opens a new vista in the understanding of brain hemodynamics, changes following brain insult, and options for preserving neurological function [18, 19].

8. Conclusion

Refinements in technology continue to expand the capabilities and application of medical ultrasound in many clinical frontiers. One of the areas that has received significant acceptance is in its application to musculoskeletal and Neuro vascular disorders. This has further brought together a variety of clinical specialties such as orthopedics, vascular surgery, podiatry and physical therapy and rehabilitation medicine. The improvement in probe technology has allowed the development of ultra-fast high frequencies, with amazing results in spatial resolution, finer details, increased sensitivity and accessibility to obscure locations. The challenges of operator dependence and lack of standardized protocols have gradually been addressed due to increasing experience and applications by imaging experts [20].

Deployment of Doppler techniques such as Super micro vascular imaging, elastography, ultrafast Doppler and skilled maneuvers allow distinctive visualization of tissues such as joint capsular ligaments, tendons retinacula, fasciae and nerves all of which involve tiny mesenchymal structures whose diameters are in fractions of millimeters [11]. One more critical area of application is in the diagnostic evaluation of obscure masses [21]. These are essentially lesions in locations where conventional imaging modalities are less effective due to poor access. Such lesions include the perineum, vulva/labial regions, skin surfaces, abdominal walls and scalp [21]. The result is better diagnosis, improvement in patient navigation, quicker and easier treatment, less hospital stay, lower cost of health care and better prognosis. It is obvious that the future continues to hold better prospect for the ultrasound imaging of musculoskeletal systems.

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