CHAPTER 1

Introduction.

1.0 Foreword.

Within musculoskeletal and sports medicine, imaging modalities have been developed for a number of specific objectives. One use for imaging modalities within musculoskeletal medicine is to highlight pathologies and injuries, to allow clinicians to accurately implement appropriate rehabilitation and management plans.

By accurately imaging anatomical structures clinicians are able to correctly diagnose pathologies and therefore are able to reduce lost time from sport, recreation or work and ultimately reduce the cost of lost revenue and productivity. Physiotherapists with their treatment and rehabilitation skills are utilising imaging modalities more and more, to help plan and implement accurate rehabilitation programmes. It is therefore inevitable that physiotherapists may access and utilise further imaging modalities that they are unable to access at present.

Diagnostic ultrasound is a readily available, nonionizing, low cost imaging modality that can be used for the investigation of musculoskeletal pathology, in both static and dynamic states (Cardinal, Chhem, & Beauregard, 1998). Diagnostic ultrasound provides excellent structural detail of superficial tendons and muscles and can characterise areas of swelling, as fluid or solid. Diagnostic ultrasound imaging may reveal non-specific synovial thickening and diagnose disorders such as infection, inflammatory trauma and rheumatoid arthritis. Foreign and loose bodies are also easily visualised (Breidahl, Newman, Taljanovic, & Alder, 1996; Balint, Kane, & Sturrock, 2001).

The development of pulsed wave Doppler, colour Doppler and power Doppler has enabled clinicians to assess large vessel flow thus adding in the accurate interpretation of the aforementioned conditions.

Vast areas of investigations have also been opened as a result of further advancements in technology in other imaging modalities such as magnetic resonance (MRI) and computerised tomography (CT) scans. Clinicians now have a multitude of options in diagnosing pathologies and abnormalities, within the musculoskeletal arena and sports medicine. Of these options diagnostic ultrasound is an economic alternative to the previously mentioned fixed and highly expensive procedures.

Physiotherapists, traditionally involved in rehabilitation and treatment have an expanding role in the diagnosis and assessment of musculoskeletal and sports injuries and are challenging their "historical boundaries" of primarily rehabilitation, by utilising ultrasound in research and diagnosis. Interest in diagnostic ultrasound's clinical application, within musculoskeletal medicine is increasing, but is not yet widely used in practice. Stokes, Hides, & Nassiri (1997) suggested this is probably due to diagnostic ultrasound's potential applications only emerging and the lack of research required to examine it's validity and reliability in different areas.

A vast amount of literature exists on diagnostic ultrasound's use in musculoskeletal medicine and sports medicine and with recent technological developments and changes in its functional use, diagnostic ultrasound as an imaging tool has opened up multiple options for clinicians and physiotherapists alike.

1.1 Purpose Statement.

The purpose of this paper is firstly to provide some concise background information on the history and development of ultrasound and a brief overview on its physics, its function and instrumentation, with regards to musculoskeletal medicine. More importantly an in-depth review of the current literature on ultrasound's role and use within musculoskeletal medicine will also be presented. This will include all relevant musculoskeletal applications available to date. Diagnostic ultrasound's advantages and disadvantages, it's role within musculoskeletal medicine, it's safely characteristics, it's relationship to physiotherapy and it's comparison against other diagnostic tools will also be discussed. Concluding statements and generalisations will be drawn, as to where ultrasound's future applications may lie within musculoskeletal medicine and more specifically it's relevance to physiotherapy.

1.2 History and Evolution of Diagnostic Ultrasound.

The human ear functions over a frequency range of 15000 to 20000 cycles per second (Hertz). Any sound having a frequency exceeding 20 kilohertz (kHz) that is, greater than that which is audible by humans is termed ultrasound. Medical imaging with diagnostic ultrasound most commonly utilises frequencies ranging from 2 to 12 megahertz. (MHz) (Van Holsbeeck & Introcaso, 2001c).

Historically the medical use of diagnostic ultrasound has developed slowly, primarily due to limitations imposed by equipment. Van Holsbeeck & Introcaso (2001c) suggested that ultrasounds first practical application was made in the unsuccessful search for the wreck of the passenger liner, the Titanic, around 1912. The salvagers used "sound beams" to try and locate the sunken vessel. With the outbreak of World War Two and the subsequent heightened technological advances SONAR (sound navigation and ranging) was developed. Following the war (in the 1950's) medical researchers applied this technology to other medical applications. A-mode scanning was the first practical use of diagnostic ultrasound. A-mode scanning is a type of scanning mode in which the amplitude of the signal is plotted versus the depth of the interface. The strength of the reflected echo is represented by the height of a spike on a monitor. A-mode scanning was utilised for the examination of the eye and echoencephalography.

Stokes et al. (1997) described that in the early 1970's the advent of analog and the subsequent development of digital scan converters made two-dimensional static B-mode gray scale imaging possible. B-mode or brightness mode modulates the brightness of a dot to indicate the amplitude of signal displayed at the location of the interface. Stokes et al. (1997) continued by describing the first use of diagnostic ultrasound in musculoskeletal medicine as the measurement of muscle size. B-mode scanning was utilized to measure the cross-sectional area of muscles and as the ultrasound probe moved over the body surface an image was obtained and stored. Researchers found that tape measure estimates of muscle size significantly underestimated the amount of wasting revealed by ultrasound measurements and B-mode scanning more accurately determined the cross-sectional area of muscles. These compound ultrasound scanners, first used in the 1970's are now considered obsolete and are not feasible for clinical use, as they are large and not portable. While compound scanners could not provide real-time images, their main advantage was that larger muscles could be measured. Van Holsbeeck & Introcaso (2001c) stated that these scanners are occasionally still useful for research, particularly when examining the effects of exercise programmes on the size of muscles.

The development of gray scale imaging through improved technology has improved diagnostic ultrasound's accuracy in clinical application. Gray scale imaging is a B-mode scanning technique that permits the brightness of the B-mode dots to be displayed in various shades of gray to represent different echo amplitudes (Van Holsbeeck & Introcaso, 2001c). Initially Baker's cysts in the knee were examined in a rheumatology setting. As a result imaging techniques to view tissues such as tendons, nerves and muscle were developed.

A better understanding of the design criteria for transducers, coupled with such developments as the miniaturization of electronics, the formation of computer based signal processing and the creation of flexible microprocessor driven instrumentation has contributed to an increase in the clinical applications of diagnostic ultrasound (Alder, 1999).

The heightened technology in the late 1970's and early 1980's has led to the development of real-time gray scale imaging. Real-time scanning is an automated scanning technique in which a rapid series of images are acquired and displayed one after the other to depict motion, enabling further clinical musculoskeletal applications.

Doppler sonography was developed in the mid to late 1980's. This method of scanning indicates the presence or absence of motion and significantly increased the clinical application of diagnostic ultrasound's to a plethora of anatomical structures and pathologies. Finally, technology has been developed to provide the facility to export digital images, which can be analysed using various software on compact packages off sight if necessary.

With the continuing technological evolution and development ultrasound has the potential to be the foremost readily available and assessable diagnostic tool within musculoskeletal medicine.

1.3 Physics and Instrumentation: An Overview.

1.3.1 Diagnostic Ultrasound Principles and Properties.

A detailed review of diagnostic ultrasound's physics and instrumentation is beyond the scope of this paper. An overview of diagnostic ultrasound's principles and properties will be given to provide some relevant background information.

Sound waves and x-ray photons are two commonly utilised forms of clinical energy transmission. Their interactions with matter are quite dissimilar and the way that either sound waves or x-ray interact (with matter) determines how they are utilised within medical imaging. Ultrasound imaging uses energy reflected back to the source to produce an image. This is defined as pulse–echo imaging. A sound wave can be produced in a medium by placing a vibrating source in contact with it which causes particles to vibrate. In ultrasound a piezo electric transducer serves as both the source and detector of sound waves. A piezo electric crystal has unique qualities in that when voltage is applied, the crystal vibrates and produces sound at a specific resonant frequency (Low & Reed, 1990). If a mechanical force is applied to a piezo electric crystal an electrical potential will result. It is these properties that make piezo electric crystals ideal for ultrasound transducers, because the same element serves as both transmitter and receiver of the ultrasound beam. Often lead zirconate titanate replaces piezo electric crystals in modern medical imaging equipment (Van Holsbeeck & Introcaso 2001c).

A sound wave propagates into a medium and is attenuated, scattered and reflected by a variety of substances. The speed of sound is determined by the density and compressibility of a particular substance or structure.

Materials with the greatest density and least compressibility will transmit sound at the highest velocity. Due to the variety of substances and structures within the human body the speed of sound varies widely (see Table 1). The average speed of sound has been found to be 1540 m/sec. (through soft tissue).

Table1: Speed of Sound Through Various Substances.

Transmitting Substance.	***Speed of Sound (m/sec).***
Air	331
Fat	1450
Water	1540
Liver	1549
Blood	1570
Muscle	1585
Cortical Bone	4080

Adapted from (Van Holsbeeck & Introcaso, 2001c).

Reflection is an interaction that results when part of the sound is redirected back into the medium from which it came after striking an acoustic interface. Reflection is the primary interaction used for all types of diagnostic scanning applications. Reflectivity is the intensity of a reflected echo from any interface. Reflectivity is influenced by two factors, acoustic impedance of the two materials and the angle of incidence of the sound beam.

Reflectivity is the greatest at interfaces between materials with dissimilar acoustic impedance. Interfaces between air and soft tissue are highly reflective. This is why ultrasound gel or coupling gel is utilised to ensure contact between the ultrasound transducer and the client's skin. If an air gap exists between the tissue-air interface there is fundamentally no energy available for imaging (Van Holsbeeck & Introcaso, 2001c).

The angle of incidence influences reflection in that the least reflection occurs with the sound beam perpendicular to the reflecting interface (i.e. 90 degrees). As the angle of incidence is decreased the percentage of the sound beam reflected increases.

Zagzebski (2001) suggested as a sound beam passes through a material a portion of it's energy is absorbed by frictional forces. The energy is converted to heat and no longer contributes to the imaging. Temperature of the material, viscosity, relaxation time and the frequency of the sound beam all effect absorption. Clinically, the frequency of the transducer can be modified. The degree of absorption of a sound beam in soft tissue is directly proportional to its frequency.

1.3.2 Instrumentation.

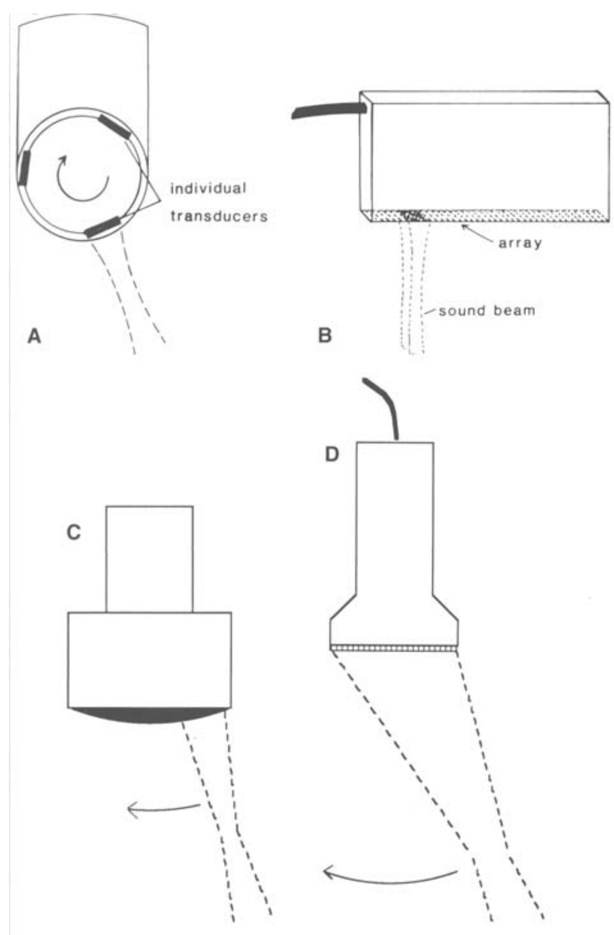
There are three basic requirements for diagnostic ultrasound. Firstly generation of a sound wave, secondly reception of the returning echo and finally the processing of the signal for display. All musculoskeletal ultrasound apparatus have these features. Changes in the reception and in the processing, analysis and display of returning echo signals differentiate one apparatus from another.

A transducer is a device that converts an electrical stimulus through a piezo electric crystal into an ultrasound pulse and the returning echo into an electrical signal. It is an essential and variable component with diagnostic ultrasound. Presently there are four types of real-time transducers or scanners as they are often termed, that are utilised clinically. These transducers automatically sweep ultrasound beams over the imaged region at a rapid rate, to produce an image for the clinician to view. Selection of the transducer depends on the part of the body and type of tissue being imaged (Stokes et al., 1997). There are four types of transducers described by Zagzebski (2001) in his review on ultrasound: A) Sector Transducer, B) Linear Array Transducer, C) Curvilinear Array Transducer, D) Phased Array Transducer (see Figure 1).

A) Sector Transducer. A single transducer or multiple transducers are oscillated within the scan head (transducer assembly), steering the sound beam over the target area. Alternatively, the beam from a stationary transducer may be swept by oscillating an acoustic mirror. Each transducer may be a single element, or an annular array consisting of a central disk surrounded by five to ten annuli.

B) Linear Array Transducer. An array of up to 120 separate rectangular transducer elements placed side by side forms the image. Groups of approximately 15 to 20 elements are activated simultaneously to produce each ultrasound beam, with the beam line centred over the central element in the group. Imaging starts with a group of elements on one end of the array which transmits the first beam line and collects the echo signals. The active element group is shifted (moved by one element), forming a new element group and the pulse–echo process is repeated. The active element group progresses from one end of the array to the other by simple element switching. Beam lines are parallel to one another, and the resultant image format is rectangular.

Figure 1: Diagnostic Ultrasound Transducers.



(Zagzebski, 2001).

C) Curvilinear Array Transducer. These arrays are similar to the linear array however, only the elements are arranged along a convex scanning surface. The method for image formation is exactly the same to that of the linear array scanner. Compared to the linear array, the curved array provides a wider image field at depth, from a narrower scanning window on the client surface.

D) Phased Array Transducer. These consist of an array of 120 very narrow elements arranged side by side. All elements are used for each beam line. The ultrasound beam is “steered” by introducing small time delays between the transmit pulses applied to individual elements. Time delays are also applied among echo signals picked up from individual elements during reception, steering the received directionality as well. An image is formed using perhaps 150 beams steered in different directions (Zagzebski, 2001).

The footprint and the field of view in linear and curve–linear (convex) arrays are often larger than sector transducers and are therefore most commonly used in musculoskeletal imaging. The choice of transducer can often one of personal preference and limited to what is available at a certain medical facility. There are however, valid reasons for transducer selection, based on anatomy and pathology (Stokes et al., 1997).

Most musculoskeletal ultrasound examinations require the use of real-time gray scale imaging. However, the composition, difference in size and varying locations of the musculoskeletal system requires the clinician to have access to a wide variety of transducers and indeed a variety of transducer frequencies (Hashimoto, Kramer, & Wiitala, 1999).

The sonographic investigation of the musculoskeletal system is best performed with 5 and 7 MHz linear array transducers. A 3.5 MHz probe can occasionally be used for imaging deeper structures such as deep muscles the case of larger clients. Extremely small structures such as the superficial ligaments of the wrist are viewed with very high frequencies, i.e. those greater than 10 MHz (Bellah, 2001).

Most of the structures with the musculoskeletal system are linear or elongated oval in shape, so the best transducer shape for imaging the musculoskeletal system is a linear transducer. The linear configuration provides a uniform, wide field of view, which is commonly necessary to image the affected structure as well as its relationship to the structures around it. The superior near field resolution of a linear transducer is also important in imaging superficial structures (Gibbon & Long, 1999).

Besides appropriate transducers a number of other tools are useful to identify and document pathologies and deviations in the musculoskeletal system. If the structure is superficial, a standoff pad may improve the visualization. To document the findings the clinician should have a digital system to store the images of the examination however, film, video or digital archives can still be utilised.

Many examinations of the musculoskeletal system involve stretching and contracting the particular structure. Cine loop replay is a useful method to review the real–time movement. If the abnormality is visible only with movement, for example subluxation of a tendon, then digital storage of real-time clips may be the best way to document the case. Sometimes a pathologic process is best displayed when the affected structure is compared with the opposite structure. In this situation side-by-side images are an effective way to document comparison (split screen).

Hashimoto et al. (1999) suggested that since some structures are very large, wide field of view composite real-time images are useful to provide a global representation of the abnormality. Apart from gray scale imaging, many diagnostic ultrasound machines have duplex, power and/or colour Doppler capabilities. Doppler imaging can rapidly display the vascular anatomy of a region. Colour Doppler may be used in musculoskeletal medicine for identification and confirmation of normal anatomy, such as in sports hernias, where the identification of the blood vessels is helpful.

Furthermore, Doppler information is necessary to differentiate a pathologic cystic structure from a vascular abnormality such as a pseudoaneurysm. Colour Doppler imaging also provides a qualitative method to evaluate vascularity in abnormal structures (Haynes, 1996; Rivett, Sharples, & Milburn, 1999). Increased vascularity in tendons has been associated with pain and inflammation.

1.3.3 Imaging.

Diagnostic ultrasound images are composed of a matrix of picture elements. Gray scale images are produced by the display of echoes returning to the transducer as picture elements and are termed pixels. These pixels vary in brightness in proportion to the intensity of the echo (Van Holsbeeck & Introcaso, 2001c).

Resolution is the ability of the ultrasound apparatus to visualise or display objects or anatomical structures. Within ultrasound imaging there are two types of resolution, axial resolution and horizontal resolution. Axial resolution is the ability to distinguish two objects as being separate when they lie directly over each other, while horizontal resolution is the ability to distinguish two objects as separate when they are located side by side, at the same distance from the transducer. Clinicians who utilise diagnostic ultrasound have a variety of options with their equipment to produce optimal images for identifying pathologies and abnormalities. Clinicians must be familiar with the instrumentation to produce optimal images.

Zagzebski (2001) suggested the following controls of diagnostic ultrasound as significant in producing optimal, clinical images (see Table 2). There are also a number of terms that deal specifically with ultrasound imaging (see Table 3).

Table 2: Ultrasound Controls Utilise in Producing Optimal Clinical Images.

Control.	***Use.***
Depth Setting.	To select to size of the imaged field.
Output Power Control.	To vary the transducer sensitivity.
Transducer Frequency.	To select the dominant ultrasound frequency from the transducer.
Overall Receiver Gain.	To vary the transducer sensitivity.
Time Gain Compensation.	To compensate for attenuation of the ultrasound beam in tissue.
Compression.	To vary the amplitude range of echoes displayed as shades of grey on the image.
Post-Processing.	To change the appearance of echo signals already stored in the memory on the image.
Persistence.	To include the images from several successive sweeps of the transducer with the current image.

Adapted from (Zagzebski, 2001).

Table 3: Imaging Definitions.

Term.	***Definition.***
Echoic.	The area of an ultrasound image that depicts strong echoes created by multiple interfaces.
Echogenic.	An area of anatomy that is more easily visualised on an ultrasound image via strong echoes created by several interfaces.
Hyperechoic.	The area of an ultrasound image that has significantly stronger echoes (brighter).
Hypoechoic.	The area of an ultrasound image that has significantly decreased echoes (darker).

Adapted from (Van Holsbeeck & Introcaso, 2001a).

1.3.4 Doppler Flow Imaging.

The Doppler effect is a phenomenon observed when the relative motion between the sound source and sound receiver causes a change in the observed frequency within the ultrasound examination. The Doppler shift is the frequency shift created between the transmitted frequency and received frequency by an interface moving at velocity. An everyday example of the Doppler shift is the change in siren tone experienced by someone listening to an emergency vehicle. As the siren in an emergency vehicle approaches the siren produces sound of constant frequency, yet the sound appears to increase in pitch. As the vehicle moves past the listener an apparent decrease in pitch is heard, although the siren is still producing the same constant frequency sound. The amount of increase or decrease in the frequency depends on the speed of the motion, the angle between the wave propagation direction and the motion direction and the frequency of the wave emitted by the source. Doppler equations can be derived from these relationships which give velocity characteristics of the moving object (Hough, Moore, & Jones, 2000).

Studies have focused on Doppler ultrasound's increasing application in the diagnosis of abnormalities and pathologies of the musculoskeletal system (Hunerbein et al., 2001; Von Herby & Haussinger, 2001; Winter, Teefey, & Middleton, 2001). Van

Holsbeeck & Introcaso (2001c) suggested that local hyperemia is often associated with focal tendon lesions and a synovial reaction in inflammatory arthropathies. Granulation tissue at sites of healing is also quite vascular. These alterations in tissue vascularity are often observed using Doppler ultrasound imaging.

Within musculoskeletal ultrasound a Doppler shift occurs when reflectors move relative to the transducer. The frequency of echo signals, from moving reflectors, is higher or lower than the frequency transmitted by the transducer. This is determined by whether the motion is moving toward (increasing), or moving away (decreasing), from the transducer (Van Holsbeeck & Introcaso, 2001c).

There are two common ways of presenting flow–related information in musculoskeletal imaging. Firstly via colour flow, or secondly via power Doppler images. Colour flow Doppler images are obtained by estimating and displaying the mean velocity, relative to the ultrasound beam direction of scatters and reflectors in a particular scanned region. Echo signals from moving reflectors are generally displayed so that the colour hue, and brightness indicate the relative velocity. Colour flow image data is then superimposed on B-mode data from stationary structures to obtain a composite image (Zagzebski, 2001).

Colour flow Doppler imaging enables the clinician to view both directional and velocity information which is a distinct advantage. The disadvantages of colour flow are that it is extremely sensitive to the angle of incidence of the sound beam, aliasing can occur and also noise will result in image artefacts (Van Holsbeeck & Introcaso, 2001c).

Power Doppler displays information (in colour) on the amplitude or power of the Doppler signal, rather than the frequency data (as in colour flow Doppler). Zagzebski (2001) suggested that power Doppler has many advantages. It is less angle dependent, no aliasing is experienced and noise results in much less image degradation. Power Doppler is significantly more sensitive to "slow flow". The disadvantage of power Doppler is that direction and velocity information is forfeited (Von Herby & Haussinger, 2001). Van Holsbeeck & Introcaso (2001c) stated that in the musculoskeletal arena directional velocity and information is usually of little value and therefore power Doppler usually proves to be the more valuable technique over colour flow.

1.3.5 Extended Field of View Imaging.

Historically one of the major limitations of diagnostic ultrasound's imaging has been its limited field of view. Advances in computer hardware and software have made possible an extended field of view imaging without the use of specialised equipment. Video image processing hardware systems are able to analyse sequential frames that are acquired from linear array transducers. The direction of motion is determined by dividing each image into a group of blocks of equal size and comparing sequential image frames. Each block is examined to determine a motion vector for that block which is dependent on the degree of change occurring within that block.

The individual motion vectors are then analysed to determine the overall direction of transducer motion. If all vectors are in the same direction and have equal magnitude, then transducer motion must be linear. Transducer motion with a rotational component will yield vectors, which vary in direction and magnitude. This type of imaging proves most valuable when evaluating long muscles, vessels and indeed tendons (Hashimoto et al., 1999). Further technological advancements and instrumentation relevant to the musculoskeletal arena will be discussed later.

1.4 Diagnostic Ultrasound Artefacts – Technological Advantages and Disadvantages.

An ultrasound image is the portrayal of anatomy that is scanned by an ultrasonic beam. Bouffard, Eyler, Introcaso, & Van Holsbeeck (1993) stated that every diagnostic imaging modality is subject to "artefacts" that are particularly unique to that modality. A ultrasound artefact is any structure in an ultrasound image that does not correlate directly with actual tissue. Artefacts assume different forms, including perceived objects in the image that are not actually present, structures that should be represented in the image but are missing and structures whose locations in the image are misregistered. In the majority of modalities, artefacts degrade images and reduce their diagnostic value to clinicians. Ultrasound has a number of artefacts that in fact facilitate its diagnostic value however, like other modalities it also has artefacts which demean its imaging (see Table 4). It is of vital importance that clinicians recognise artefacts so they can be corrected, ignored or be deciphered within context, or indeed utilised to optimise diagnostic accuracy within the musculoskeletal arena.

1.5 Diagnostic Ultrasound – its Current and Prospective Applications.

1.5.1 Current Applications.

Historically the medical and clinical use of diagnostic ultrasound has developed slowly. Technological advances over the past 50 years have developed ultrasound technology to a stage where it has widespread clinical application (Hides, Richardson, & Jull, 1998).

Whilst the major area of application is now diagnostic imaging by experienced sonographers, initially the first report of ultrasound within musculoskeletal medicine, described simply the measurement of muscle size. As technology improved and as operators became more highly skilled, the functional and practical of diagnostic ultrasound use broadened. Wang, Chhem, Cardinal, & Cho (1999) in their review on diagnostic ultrasound divided its current clinical application into two broad groupings of non traumatic pathologies and trauma.

1.5.2 Non Traumatic Pathology.

A localised subcutaneous mass or swelling is a common presentation for a wide variety of different pathologies, often associated with pain, tenderness and inflammation. It may be difficult or impossible to distinguish these clinically. Such a mass may be due to an inflamed bursae or cyst due to inflammation from a muscle or tendon tear, strain or rupture. Malignant soft tissue or bony tumours may also present this way. Abscesses or masses associated with arthritis, rheumatoid nodules or pannus can be depicted and sometimes characterised in the appropriate clinical setting (Wang et al., 1999). Painful and diffuse joint swelling is often seen as arthritis on ultrasound.

Table 4: Artefacts Associated with Diagnostic Ultrasound.

Artefact.	***Description.***
Refraction.	Resulting from the depiction of structures in false locations. Refraction occurs at interfaces between substances that transmit sound waves at different velocities. (E.g. muscle and fat). The sound wave is bent at these interfaces in proportion to the difference in velocity of sound transmission within the two materials and the angle of incidence of the sound beam. Bending of the sound beam results in the depiction of structures deep to the interface in an incorrect location.
Anisotrophic Reflectors.	Anisotrophic substances display different properties depending on the direction of measurement. Tendons, muscles, ligaments and nerves are anisotrpohic reflectors. Tendons are strongly anisotrophic, due to their longitudinally oriented bundles of collagen fibres.
Reverberation.	Anatomical structures which are highly reflective are misinterpreted as calcifications or phantom structures. Reverberation artefacts from air, foreign bodies or skin scars superficial to the tendons being examined may be highly reflective and appear as calcifications.
Client Movement and Electrical Noise.	Client movement and electrical noise (including magnetic fields) are mechanical problems that can alter image quality.
Beam Width Artefact.	An ultrasound beam has a width that varies depending on the design and make up of the transducer head. Therefore ultrasound images a volume of tissue. When an object is smaller than the width of the ultrasound beam echoes depicted at that location are a combination of the echoes from the object and the surrounding tissue.
Shadowing.	At a highly reflective interface almost all of the energy of a sound beam incident, on that interface, will be reflected. A minimal amount of energy will pass deep to this interface and will be available for imaging. The result is a signal void deep to the hyper-reflective object, termed shadowing. Good examples of materials that produce shadowing *in vivo* are bone, air and calcifications. Dirty shadowing is a characteristic exhibited by gas within soft tissues. Refractile shadowing is observed when objects with highly curved surfaces (e.g. long bone) are imaged. Refractile shadowing is a common finding at the ends of torn, retracted tendons – indicating a full thickness tear.
"Comet Tail Artefact".	Foreign objects to the musculoskeletal system such as metal and glass produce characteristic bands on increased echogenicity deep to that object. These bands cross tissue boundaries, including the boundaries of tissues that produce shadowing. This may allow clinicians to accurately diagnose foreign objects.
Enhanced Through–Transmission.	The intensity of echoes returning to the transducer decreases exponentially with increasing depth in the tissues being examined. Superficial echoes may be over 100 times greater in amplitude than those from the deeper tissues. If the discrepancy is uncorrected, the result will be a rapid decline in image definition with increasing depth. Time gain compensation is the primary means of correcting for the discrepancy in the image to be displayed.

Adapted from (Van Holsbeeck & Introcaso, 2001c).

Diagnostic ultrasound has also been used for the assessment of acute and chronic joint infection, rheumatoid arthritis and gout. The findings however, tend to be non specific such as synovial thickening or masses, echogenic debris, bone or cartilage erosions, but are still useful for clinical staging, guiding percutaneous joint aspiration and even synovial biopsy. Acute pain and loss of movement in the absence of trauma may indicate an infection. Diagnostic ultrasound can help determine if there is a joint effusion and if seen, this can be aspirated under diagnostic ultrasound guidance for appropriate culture or other analysis (Hashimoto et al., 1999; Wang et al., 1999).

Non-specific joint pain can be extremely difficult to assess clinically. Some periarticular calcifications due to calcium hydroxyapatite deposition disease can cause severe diffuse joint pain. Plain x-rays remain the mainstay for this diagnosis, but ultrasound also diagnosis this readily and can be used to guide percutaneous aspiration of the calcific material.

A number of studies on vertebrobasilar insufficiency, (VBI) used real-time ultrasound imaging, allowing the researchers to simultaneously visualise the target vessel and ensure accurate sampling of blood flow, at multiple angles and sites (Rivett et al., 1999; Rivett, Milburn, & Chapple, 1999; Haynes, 1996 ; Terenzi & Di Fabio, 1996).

In the infant or child ultrasound has become the first investigation for hip dysplasia. The ability to image the acetabulum and unossified femoral head directly without ionizing radiation or sedating the child and its real-time assessment of joint laxity during stress manoeuvres is a significant advantage (Wang et al., 1999).

1.5.3 Trauma.

In joint trauma x-rays remain crucial and are the norm in the assessment of type, extent, joint involvement, alignment, healing and for progress after treatment. However, there are a number of scenarios, where x-rays alone are insufficient for management and where diagnostic ultrasound could have a significant clinical role to play (Wang et al., 1999).

Chronic repetitive trauma can result in local inflammation, such as enlarged bursae or ganglions, or produce focal injury to tendons, ligaments and muscles, cartilage and even bone, which are frequently occult to or only partially visualised with x-ray. Diagnostic ultrasound can clarify the nature of this inflammation, depict superficial tendon, ligament, or muscle injury, and in some instances demonstrate joint loose bodies and associated bony erosions (Hashimoto et al., 1999).

In acute trauma x-rays may be negative, or show signs of joint pathology, but not the associated soft tissue injuries that frequently occur in either tendon or ligament injuries. In this situation diagnostic ultrasound could be used to determine whether such a lesion is present. Therefore muscle, tendon, bursae, joint and neural structures all can be visualised.

Movement related joint pain is very common and is the usual presenting symptom in tears of tendons and muscle. The dynamic abilities of diagnostic ultrasound are valuable in this situation. The client can reproduce the movements that cause symptoms, thus enabling the depiction of tendon or bursal impingement that usually accompanies the pain and also distinguishing between an impingement and tendon tear (Hashimoto et al., 1999).

Wang et al. (1999) also suggested that children with injuries to nonossified cartilage cannot be diagnosed directly with x-ray. Similarly, growth plate injuries can be missed as well, particularly in neonates. Diagnostic ultrasound can show fractures, displacements of nonossified cartilage and thus could prevent subsequent deformities and growth disturbances. Some soft tissue foreign bodies produce an intense inflammatory reaction and present as a large mass within a joint. Diagnostic ultrasound is an excellent method not only for detection, but more recently even for extraction of non-radiopaque foreign bodies.

The clinician requires a good understanding of the physical principles and properties of diagnostic ultrasound, adequate training and an understanding of the ultrasound appearance of all soft non soft tissue pathology that might be encountered (Wang et al., 1999).

1.5.4 Prospective Applications.

Recent developments in diagnostic ultrasound technology have seen the move from compound to real-time scanning. Advances have been made in the latter technique, which have resulted in a significantly improved image quality. Major advances have also been made in transducer technology which has allowed greater resolution and lead to improved diagnostic accuracy. Not only can the pathology of tissues such as muscles, tendons and ligaments be examined but their internal architecture can now be studied. The higher frequency transducers now available aid this improved definition and allow more superficial structures such as the skin, subcutaneous tissues and joints of the fingers to be seen (Stokes et al., 1997).

Signal processing has progressed with the introduction of advanced computers and digital imaging. Image display has also improved giving high display resolution. Wide frequency bandwidth transducers have the advantage of signal processing that allows the utilisation of high frequency signals at superficial tissues (Stokes et al., 1997; Van Holsbeeck & Introcaso, 2001c).

One of the main advantages of real-time imaging over other techniques is the possibility of dynamic examination of structures as they move under the transducer. The performance of tendons passing through their sheaths is a typical example of where examination during movement is very useful (Stokes et al., 1997). Another example is the information collected from Rivett et al's. (1999) study on vertebrobasilar insufficiency (VBI).

Hides et al. (1998) stated that the physiotherapist can use diagnostic ultrasound to facilitate or provide evidence of the effectiveness of a therapists rehabilitation programme within a clinical setting. Widespread accessibility, non-invasiveness and functional or practical application of diagnostic ultrasound are all advantageous, as is the cost of a ultrasound examination, compared to a MRI or CT.

Hides et al. (1998) have suggested that the use of ultrasound as a biofeedback tool is an application within a physiotherapy rehabilitation setting. Diagnostic ultrasound gives the therapist the ability to visualise the contraction of deep muscles in conjunction with the more superficial overlying muscles.

Doppler ultrasound may provide a valuable tool for non-invasive measurement of longitudinal nerve motion. There are research applications in studies of entrapment syndromes and for verifying aspects of neurodynamic theory and practice. These could specifically include investigations of normal nerve dynamics, comparisons of these characteristics between client and healthy populations and evaluating the effects of therapeutic intervention (Hough et al., 2000).

Hunerbein et al. (2001) investigated the use of three dimensional (3D) ultrasound on bone and soft tissue lesions and suggested that 3D ultrasound could provide previously unobtainable scan planes and realistic 3D views, through new technological developments and operator skill.

Diagnostic ultrasound has a number of future clinical applications within the musculoskeletal arena. Radiologists, sonographers and clinicians will develop and foster ultrasound's functional use through technological advancement and clinical application. Ultrasound's functional use in facilitating the diagnosis of musculoskeletal disorders and using it as a research tool, will ultimately lead to improvements in knowledge, diagnosis and the monitoring of various structures within the musculoskeletal arena.

An increased amount of literature and relevant research could expand the clinical use of ultrasound. This broadening scope for the clinical use of ultrasound has initiated a plethora of applications and benefits for its future practice. This could lead to ultrasound imaging being the principal diagnostic modality within musculoskeletal and sports medicine.

CHAPTER 2.

Literature Review.

2.0 Diagnostic Ultrasound and its Role Within Musculoskeletal Medicine.

There are numerous current and prospective applications of ultrasound within musculoskeletal medicine. The purpose of this section of this paper is to provide a review of the current literature on the role and function of diagnostic ultrasound within sports and musculoskeletal medicine. This will encompass all relevant musculoskeletal applications, including a review of the role, function and use of ultrasound within specific anatomical structures, musculoskeletal pathologies and management, with attention on diagnostic ultrasound's connection with physiotherapy.

2.1 Tendon and Muscle.

2.1.1 Introduction.

Tendon and muscle pathology and injury as a result of sport, work or recreation have been widely reported throughout the literature. There has been a phenomenal growth in medical imaging technology with plain x-ray, CT, MRI and ultrasound contributing to the accurate diagnosis of tendon and muscle pathology. However, muscle and tendon imaging still remain controversial as a result of limited understanding of tendon anatomy, physiology and pathology. The current modalities utilised to diagnose muscle and tendon pathology are providing new clinical information and consequently a fresh perspective on many common muscle and tendon disorders (Read & Peduto, 2000).

Figure 2: Normal Anatomy of the Anterior Tibial Compartment.

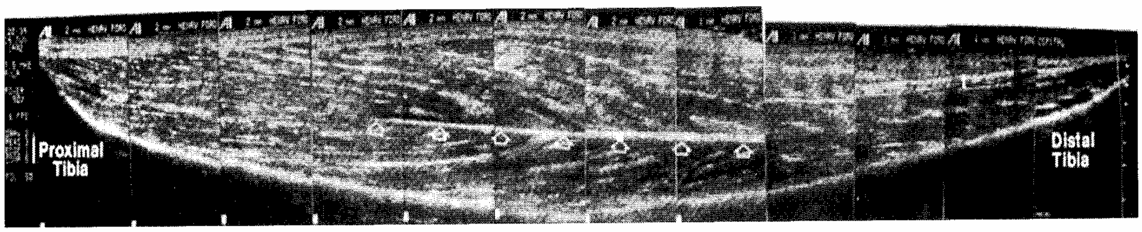


Figure 3–1 ▪ Normal muscular anatomy of the anterior tibial compartment: composite longitudinal image. This image demonstrates the normal muscular anatomy of the anterior tibial compartment in a young athlete. Serial longitudinal images were obtained and then juxtaposed to produce a composite image demonstrating the entire length of the tibialis anterior muscle. This is a circumpennate muscle that functions in dorsiflexion of the foot. Note the feather-like appearance of the muscle created by the convergence of the fibroadipose septa upon the aponeurosis (*open arrows*). Abbreviation: tibialis anterior tendon (*t*).

From (Van Holsbeeck & Introcaso, 2001c).

For a clinician to successfully examine the musculoskeletal system, they must have an understanding of the normal musculoskeletal anatomy and function and have extensive knowledge of the abnormal processes that affect the musculoskeletal system (Read & Peduto, 2000; Hashimoto et al., 1999; Allen & Wilson, 1999). Diagnostic ultrasound is an imaging technique that with recent developments in technology has come to the forefront in diagnosing specifically muscle and tendon pathology and injury (see Figure 2).

The development of real-time ultrasound which, significantly improves signal to noise values and therefore the contrast resolution in the physical ultrasound image, has increased the diagnostic ability of ultrasound imaging significantly. It can quickly and routinely compare the normal side with the abnormal side, improving diagnostic sensitivity for subtle pathologic changes and provide an objective appreciation of diffuse changes such as tendon enlargement or atrophy and also provide a useful control for the interpretation of measurements on the symptomatic side. Real-time ultrasound allows for the assessment of tendon and muscle tissue dynamics, which can be helpful in the differentiation of tendon rupture from tendon adhesion (Read & Peduto, 2000).

Diagnostic ultrasound is an interactive test where the sonographer is in the room with the client examining the affected part with the transducer and directly correlating the site of reported pain or tenderness with its sonographic appearance. This targeted approach can be invaluable in achieving a clinically relevant diagnosis, because imaging modalities detect a high incidence of asymptomatic pathology (Allen & Wilson, 1999; Read & Peduto, 2000; Wang et al., 1999).

Stokes et al. (1997) suggested the imaging of tendon or muscle is the most common use of diagnostic ultrasound within a musculoskeletal setting. Skeletal muscle fibres are grouped into bundles and surrounded by perimysium or fibroadipose septa. Dense connective tissue or epimysium covers the entire muscle and the fascia separates muscles from each other. The muscle bundles are hypoechoic and the fibroadipose septa, epimysium and the fascia are hyperechoic (Hashimoto et al., 1999).

Several types of muscular abnormalities can be detected by sonography. The most common muscle problems result from trauma, as a result of being crushed by external force or being torn apart via distraction. After a compression injury sonography may demonstrate a haematoma. Acutely, these haematomas usually have irregular contours and are hypoechoic compared to muscle. Sometimes the haematoma is ill defined, with an echogenicity similar to that of the surrounding muscle. Sub acutely (after 3-5 days), the fluid will be hypoechoic. Later, there may be an echogenic scar that may be associated with calcification, which is termed myositis ossificans.

Ruptures that result from distraction are classified into 3 grades. Grade I corresponds to a mild elongation (mild) injury. Grade II is a partial tear and is generally associated with a haematoma and Grade III represents a complete tear. In Grade I injuries the muscle exhibits multiple subtle “flame shaped” hypoechoic muscle bundles. Grade II injuries affect greater than 5% of the muscle but less than the whole width of the muscle. Usually hypoechoic haematoma is present. Sometimes there is a “bell clapper” sign, which are fragments of the muscle moving within the haematoma. Since Grade II injuries represent partial tears, some part of the muscle will be intact and exhibit normal contraction. With Grade III injuries the entire muscle is torn. The torn muscle ends are separated by hypoechoic fluid and no voluntary muscular contraction can be detected.

After healing of muscle tears a variety of pathologic entities can develop. These abnormalities include scars, muscle cysts and myositis ossificans. Scars are irregular echogenic sonographic abnormalities that do not change in appearance with muscle contraction. Muscle cysts appear sonographically as well defined anechoic or hypoechoic round or oval structures and may have slightly thickened walls and septations. Myositis ossificans exhibits irregular hyperechogenicity and shadowing (Hashimoto et al., 1999).

Tendons differ from muscles and can be subdivided into two groups, those covered with a synovial sheath and those covered with a dense connective tissue layer. Tendons are composed of collagen and appear hyperechoic. When a tendon is covered with a synovial sheath the hyperechoic tendon is surrounded on transverse scans by a hypoechoic rim that is less than 1–2 mm thick. Tendons with sheaths include the long head of biceps tendon of the shoulder and the tendons of the wrist and ankle. Tendons surrounded by a dense connective tissue layer are hyperechoic and do not have the hypoechoic rim. Tendons without a synovial sheath include the supraspinatus, Achilles, patellar and semimembranous (Allen & Wilson, 1999).

The most common reasons for examining tendons include inflammation, rupture and subluxation or dislocation. In tendonitis, tendons with sheaths exhibit a different sonographic appearance than tendons without sheaths. When a sheath is present tendonitis is associated with fluid within the sheath, thickening of the tendon, and/or hypoechogenicity within the tendon. The abnormal fluid will produce a hypoechoic rim around the tendon that is greater than 2 mm thick. In tendons without sheaths tendonitis produces thickening of the tendon. The thickening may be either global or focal. There may also be irregular hypoechoic areas within the tendon. Findings of tendinitis in tendons without sheaths are more subtle than in tendons with sheaths, so comparison with the contralateral tendon is important (Wang et al., 1999).

The fat pads adjacent to the tendon may exhibit increased echogenicity. Chronic tendonitis may be associated with calcium deposition which is generally in the tendon insertion (Hashimoto et al., 1999). Tendon ruptures have several sonographic appearances. When a sheath is present, partial rupture is associated with hypoechoic clefts within the tendon and fluid in the sheath. When a sheath is not present, a partial tear appears as a hypoechoic defect within the tendon. With complete rupture of a tendon with a sheath, a clinician may sonographically demonstrate a complete hypoechoic cleft through the tendon or a fluid–filled sheath separating, the retracted ends of the torn tendon. In complete rupture of the tendons without sheaths, sonographic findings include absence of the tendon, thinning of the tendon and abnormal positioning of adjacent structures into the space normally occupied by the tendon (Read & Peduto, 2000).

Real-time ultrasound examination of a completely ruptured tendon will demonstrate no normal sliding motion during contraction and relaxation of the associated muscle. This is an important clue when the sonographic findings are subtle. The most commonly ruptured tendons are the rotator cuff, Achilles and patellar tendons. Diagnostic ultrasound can also demonstrate subluxation or dislocation of tendons. If the tendon is not in its normal location in the resting and contracted states then the tendon is dislocated. With subluxation the tendon temporarily moves to an abnormal location. Using real-time ultrasound the clinician can demonstrate the abnormal displacement of the tendon. The most commonly identified dislocated tendons are the hand flexor and extensor tendons, the peroneal tendons in the ankle and the long head of biceps in the shoulder (Hashimoto et al., 1999).

2.1.2 Measurement of Muscle Size.

Since the early use of ultrasound in studies which used compound scanning to measure quadriceps size, imaging has involved either measurement of the cross-sectional area of muscle or measurement of muscle thickness by linear measurements (Stokes et al., 1997). Diagnostic ultrasound allows the generation of measurements of muscle size in cross-section thus providing a method of direct assessment of muscle atrophy and hypertrophy. Clinicians and particularly physiotherapists have traditionally assessed muscle bulk by limb circumference measurements, a crude and often inadequate technique. This technique of limb circumference measurements has the distinct disadvantage in that the tape measure is unable to measure individual muscles (Hides, Richardson, Jull, & Davies, 1995).

These measurements may also seriously underestimate the loss of size of one muscle group. Measurement of the circumference of an extremity has therefore been deemed an unreliable way of determining the degree of muscle atrophy of hypertrophy. Different muscles have been studied with real-time scanning to assess their suitability for measurement and to establish normal reference ranges of size for comparison with patients. Muscles which are more suitable for ultrasound imaging, are those which are small enough to allow their whole cross-sectional area to be measured. This allows the muscle to fit within the field of view and the borders are well defined to allow accurate measurements (Hides et al., 1995; Stokes et al., 1997).

Studies have reported variation between repeated measurements in the investigation of various muscles including the quadriceps, anterior tibial muscle and the multifidus muscle. The results of these studies varied considerably, with inter-operator reliability demonstrated in the measurement of the multifidus and quadriceps. However, reliability was unable to be demonstrated in the examination of the anterior tibial muscle (Stokes et al., 1997; Hides et al., 1995).

With regards to measuring muscle cross-sectional area and size ultrasound has been compared with other imaging modalities to investigate its validity. When compared with MRI there was no difference found between modalities for measurements of multifidus in normal subjects (Hides et al., 1997). It appears that CT and MRI are generally accepted to be more accurate due to better resolution of images, wider fields of view and less dependence on operator expertise.

Real-time ultrasound imaging is used as a direct assessment of hypertrophy and atrophy of muscle. It also has the potential to be used in evaluation of the efficacy of treatment on the musculoskeletal system through its serial measurements of muscle cross-sectional area. The limitations of real-time ultrasound include its inability to measure large muscles in their entirety in cross section and the possible effects of pathology such as fatty infiltration on muscle size. The quality of the ultrasound image is also dependent on the operator (Hides, Richardson, et al., 1995).

In order to assess whether a muscle is atrophied, it must be compared with a "normal range", for that particular muscle, such as the contralateral uninjured side or pre injury measurements for that individual (Stokes et al., 1997). Researchers are establishing a "baseline" of normal muscle size for comparison. Diagnostic ultrasound has a role to play in the relationship between muscle size, force and muscle geometry (Stokes et al., 1997; Hides, Richardson, et al., 1995). The role of ultrasound in these fields could expand with more detailed studies to validate its effectiveness and reliability.

2.1.3 Tendon Pathology (Tendonopathy).

With respect to tendon pathology there are numerus papers exploring ultrasound's role. The following section will look at some key papers and studies which emphasise ultrasound's diversity when investigating tendon pathologies.

Bonaldi et al. (1998) describe a case report using ultrasound to diagnose iliotibial band friction syndrome (ITBFS). ITBFS is the result of repetitive friction of the iliotibial band across the lateral femoral condyle, usually it is diagnosed clinically and is often related to biomechanical deficiencies. The authors presented a case study of a woman with ITBFS. The woman developed increasing pain during a running race at the lateral aspect of her right knee.

An MRI scan was performed 6 hours immediately after she finished the 10 km running race. This showed the ITB tendon over the lateral femoral condyle to be focally thickened, with a poorly defined border. Peritendinous oedema also was demonstrated, all these findings consistent with an acute ITB tendonitis. Bonaldi et al. (1998) then performed a diagnostic ultrasound examination 20 minutes after the MRI examination to assess the reliability of diagnostic ultrasound for evaluating ITBFS.

The diagnostic ultrasound examination also revealed moderate thickening of the ITB adjacent to the lateral femoral condyle, which was associated with a hypoechoic area in the vicinity of the tendon. A flat poorly defined fluid collection was seen along the medial aspect of the ITB proximal to the lateral femoral condyle. The diagnostic ultrasound findings were comparable to those found on MRI examination.

There is no mention in Bonaldi et al. (1998) study as to whether the clinicians who undertook the MRI examination were "blinded" to the probable pathology and prior results. The authors stated that in their report, comparison with MRI demonstrated clearly the utility of ultrasound because of the easy access to this superficial location and an excellent correlation between sonographic imaging and MRI. Tendon thickening, peritendinous oedema and probable bursitis were all demonstrated on both MRI and ultrasound, all suggesting ITBFS.

Bonaldi et al. (1998) concluded that diagnostic ultrasound showed clinically suggestive features of ITBFS, as clearly as MRI and suggested the low cost and ease of accessibility could make ultrasound more advantageous in the diagnosis of ITBFS. The authors stipulated that ultrasound could allow follow up examinations to visualise the "progress" ITBFS is making if the individual is undergoing conservative treatment. This study could be modified by using a statistically significant population.

The plantar fascia like most other superficial tendons is readily demonstrated by diagnostic ultrasound. Numerous studies have suggested ultrasound has proved to be an excellent imaging technique for the assessment of tendon pathology and has the advantage of being non-invasive and relatively inexpensive. Effective treatment of plantar fasciitis requires an accurate diagnosis and differentiation from other causes of heel pain (Alder, 1999; Hashimoto et al., 1999; Read & Peduto, 2000; Gibbon & Long, 1999).

Ultrasound imaging may also be of value in the follow up of these patients and particularly in athletes, in order to time appropriate recommencement of physical activity. The objective of a study by Gibbon & Long (1999) was to assess the plantar fascia using asymptomatic volunteers and compare the appearance of the plantar fascia with inflammatory arthropathies of symptomatic volunteers. An ultrasound examination using an experienced sonographer of the relevant plantar fascia was undertaken, on 297 feet. No comparison to other imaging modalities was made.

The results from this study suggested that the symptomatic plantar fascia demonstrated significant thickening compared with the asymptomatic volunteers. Multiple other heel and foot pathologies were identified including bone spurs, peritendinous oedema, sub calcaneal bone erosion, bursitis and intratendinous calcification.

The vast majority of patients with inferior heel pain have a primary soft tissue problem and therefore it seems logical to use either MRI or diagnostic ultrasound to investigate these patients. The broad field of view and multiplanar capacity of MRI make it an excellent imaging modality for the investigation of heel pain. Compared with MRI, diagnostic ultrasound has the advantage of being quick, inexpensive and widely available. The greater spatial resolution of ultrasound imaging for superficial structures provides advantages over MRI in the assessment of patients with plantar fasciitis (Gibbon & Long, 1999).

Gibbon & Long (1999) found that diagnostic ultrasound imaging is complementary to conventional radiography when examining patients with inferior heel pain assuming primary bony pathology is not clinically suspected. Additionally ultrasound should be considered early in management to provide an objective measurement of patients with plantar fasciitis.

Snapping hip syndrome consists of a painful audible snap in the hip during movement. Clinically it is difficult to diagnose with several possible causes that include "external" and "internal" subcategories. External causes include friction of the iliotibial band or friction of the gluteus maximus muscle against the greater trochanter. An internal cause is the snapping of the iliopsoas tendon over the iliopectineal eminence. The normal iliopsoas tendon glides smoothly during hip rotation. A snapping or abnormal movement of the iliopsoas tendon during hip motion may be demonstrated with bursography or tenography followed by fluoroscopy (Cardinal, Buckalter, Capello, & Duval, 1996).

Cardinal et al. (1996) suggested that these imaging modalities are invasive and infrequently performed. Diagnostic ultrasound in contrast is a non–invasive technique that allows the dynamic evaluation of tendons (see Figure 3). Cardinal et al. (1996) utilised 3 patients in which a dynamic ultrasound of the hip was performed. The patients had symptomatic snapping hips of uncertain diagnosis. Each hip was flexed, abducted, externally rotated and extended and the contralateral hip was also evaluated. Following ultrasound, hip arthrography was performed in all 3 patients along with an MRI.

On ultrasound examination an abnormal jerk of the iliopsoas tendon during hip motion was correlated with the painful audible snap. The motion of the contralateral iliopsoas tendon was smooth and pain free. No intraarticular abnormality was found in two patients on arthrography and MRI and an associated labral tear was suspected following arthrography of the third patient.

Cardinal et al. (1996) suggested that ultrasound can demonstrate non-invasively the abnormal jerky movement of the iliopsoas tendon and establish a correlation with the painful snap. Diagnostic ultrasound also permits comparison with the smooth continuous motion of the iliopsoas tendon on the contralateral asymptomatic side. Once the snapping iliopsoas tendon is demonstrated in the appropriate clinical setting, no additional imaging study may be needed before initiation of treatment. However ultrasound does not allow accurate evaluation of intraarticular pathologic conditions, so x-ray, arthrography, CT or MRI may still be required to accurately diagnose snapping hip in some cases.

Bertolotto, Perrone, Martinoli, Rollandi, & Derchi (1995) evaluated with ultrasound, the appearance of the normal Achilles tendon to establish an anatomical correlation of the gross anatomy. Normal tendons, numbering 30 were examined *in vivo* and 3 *in vitro* with diagnostic ultrasound. The results of Bertolotto et al. (1995) study suggested that two tendinous portions were detected by the presence of an internal acoustic interface, which had different appearances. Scanning of isolated tendons allowed precise location of these interfaces at the boundary between anatomically distinct tendinous portions arising from the soleus and gastrocnemius muscles. Although the normal Achilles tendon is commonly regarded as a uniform structure by diagnostic ultrasound, the use of high-resolution probes allows identification of its constituent portions. The authors suggested that the identification of constituent portions may be useful to avoid misdiagnosis of pathological findings.

The study of Bertolotto et al. (1995) showed that ultrasound is able to identify intratendinous interfaces which correlated with the presence of anatomically distinct tendon portions arising from the soleus and gastrocnemius muscles. Two different diagnostic ultrasound features were visible on sagittal and coronal scans, including intratendinous linear echoes of increased reflectivity and lateral displacement of the distal part of the sector of maximum reflectivity. Furthermore, intratendinous echoes were variable appearing either as a single or a double line also in the same tendon at increasing ultrasound frequencies.

The different diagnostic ultrasound appearance of the intratendinous echoes can possibly be related to the thickness of the gap between the tendinous portions. Knowledge of the different intratendinous structural patterns in normal Achilles tendons can be important in clinical practice since they can mimic the presence of changes in the normal fibrillar echo texture. However, careful ultrasound examination enables proper identification of normal findings (Bertolotto et al., 1995).

In conclusion, the structure of the Achilles tendon, as seen by high-resolution diagnostic ultrasound appears more complex than previously suspected. Further correlative evaluation between imaging methods and dissection studies are required to characterise completely the variants near the calcaneal insertion, where the echo texture is not visible. At present high-resolution ultrasound plays a central role in the clinical evaluation of Achilles tendon diseases (Bertolotto et al., 1995).

Gibbon, Cooper, & Radcliffe (2000) suggested Achilles tendon pathologies such as tendinitis are usually associated with overuse of the tendons, with the aetiology involving many factors, including abnormal biomechanics in the lower limb, poor selection of footwear, over training or lack of ankle flexibility and/or proprioception.

Possible mechanical processes underlying Achilles tendon pathology were studied by Gibbon et al. (2000) who conducted a retrospective study of the sonographically detected abnormalities in patients who had a clinical diagnosis of Achilles tendinitis.

The authors utilised 118 symptomatic heels in 73 patients who had a clinical diagnosis of chronic Achilles heel pain. The heels were examined over a 12 month period by the same experienced sonographer. The distribution of altered tendon architecture and features suggesting retrocalcaneal bursitis or Achilles paratendinitis were evaluated.

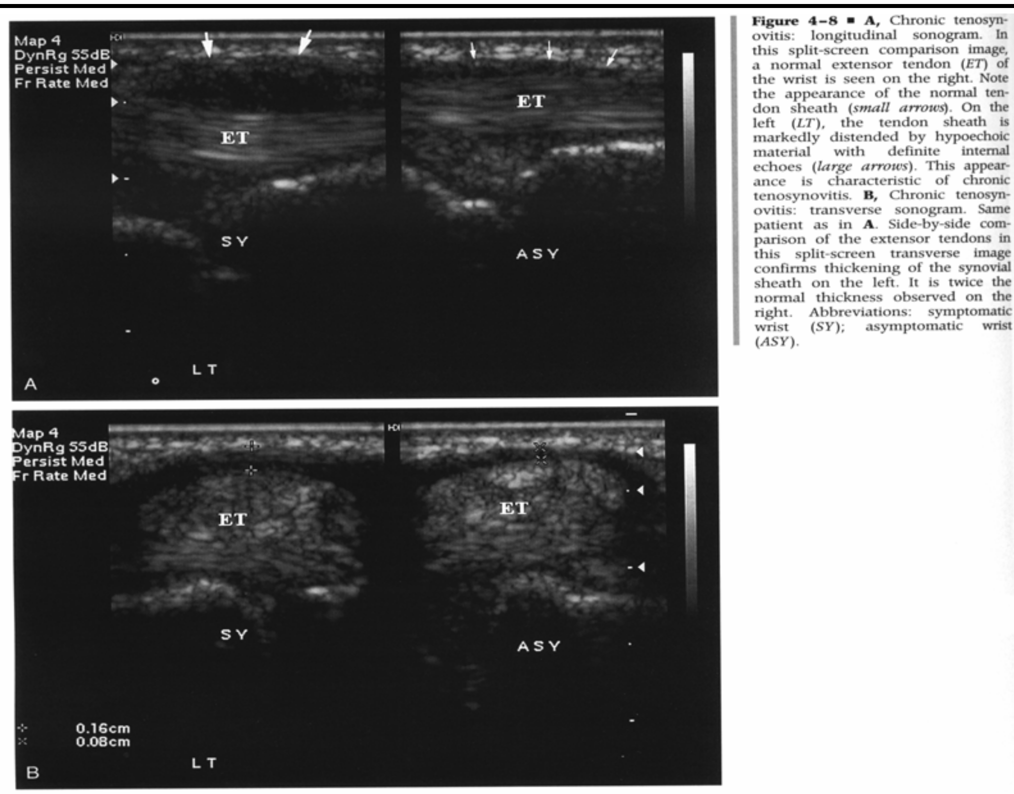
The results demonstrated that 81% had abnormalities confined to the proximal two thirds of the Achilles tendon, 8% had abnormalities in the distal third alone and 11% had abnormalities at both sites. Of the 109 heels with proximal two-third Achilles tendon disease, 91% had medial tendon involvement. Lateral tendon segment changes were seen in 19% of the 118 symptomatic heels. No lateral tendon segment was involved in isolation. Of the 22 heels with distal third abnormalities, 64% had ultrasound evidence of Achilles paratendinitis and 59% had ultrasound evidence of Achilles tendinitis. Diagnostic ultrasound evidence of retrocalcaneal bursitis was found in 18 of the 22 Achilles tendons. In all cases of distal third tendinitis, the deep surface of the tendon was primarily involved. In the heels with both proximal and distal changes, superficial segment involvement of the mid Achilles tendon was present.

In conclusion Gibbon et al. (2000) suggested that ultrasound provides information that helps to diagnose not only the cause of posterior heel pain but also the possible underlying injury mechanisms. A potential criticism of this study is that it is limited by its retrospective nature, potential lack of objectivity of the sonographer and the absence of independent biomechanical assessment. A prospective, blinded study is needed to compare and evaluate the reliability between the sonographic changes and the biomechanical processes in patients with chronic Achilles tendonitis.

2.1.4 Rotator Cuff Calcification.

Calcific tendonitis is a common painful condition of the shoulder due to deposition of hydroxyapatite crystals, which are commonly located in the tendons of the rotator cuff. In the localization of these calcium deposits, fluoroscopy, radiography, CT and MRI have all been used. An accurate diagnosis and following management is critical to the ongoing management of calcific tendinitis. Farin & Jaroma (1995) compared ultrasound findings of rotator cuff calcification to those of plain x-ray films to determine their accuracy in the diagnosis and localization of calcific deposits.

Figure 3: Chronic Tenosynovitis. (Extensor Tendon).



From (Van Holsbeeck & Introcaso, 2001c).

Diagnostic ultrasound findings were correlated with plain x-ray in 951 patients. A multitude of bursal pathologies, calcifications and tendon pathologies were observed. In the assessment of calcifications in the rotator cuff ultrasound showed a sensitivity of 94%, a specificity of 99% and accuracy of 99% when compared to plain x-rays.

Farin & Jaroma (1995) concluded that ultrasound could reliably diagnose all of the large and most of the small and scattered calcifications. Because of the shadow of the acromion, subacromially located calcifications could not be detected with diagnostic ultrasound imaging. Calcific slurry masses in the subacromial bursa were found more reliably with ultrasound than with plain x-ray films. This observation was explained by the thin bursal bulging producing only a minimal density. Diagnostic ultrasound is not limited to standard projections but can depict almost the entire circumference of the humeral head and the surrounding tissues.

As CT scanning was not included in this study, the authors could not determine the absolute sensitivity or the specificity of the ultrasound diagnosis of the rotator cuff calcifications. In practice it seems CT scanning is unable to show or exclude rotator cuff calcifications. Because of direct visualization of calcific deposit in different tendons, the greater and minor tuberosities, the groove and the bursae, the localization of calcifications was easier with diagnostic ultrasound than with plain films. Thus, ultrasound could offer ideal guidance without exposure to hazardous radiation if treatment of rotator cuff calcifications by needle aspiration is considered.

In summary Farin & Jaroma (1995) suggested that rotator cuff calcifications can have different appearances on diagnostic ultrasound and can be detected and localised reliably, but cannot be characterized to a formative or resorptive phase. Because of this and possible pathologic conditions of bone, plain radiographs are an integral part of shoulder sonography and aid in the assessment of both the soft tissues and the underlying bone.

2.1.5 Tendon Pathology (Rupture or Tear).

There are a number of important papers with respect to tendon ruptures or tears. These will be reviewed, highlighting the extensive utilisation of ultrasound within this field.

Ankle tendon tears can be difficult to diagnose clinically, specifically posterior tibial tendon and peroneal tendons. Rupture or tear of these tendons can lead to a range of symptoms, including pain, weakness, instability and both rear and forefoot abnormalities.

Historically the imaging modality of choice in detecting ankle tendon tears has been MRI. With the increasing use of ultrasound in the diagnosis of musculoskeletal abnormalities involving the shoulder, knee and hand, aside from studies assessing the

Achilles tendon, diagnostic ultrasound imaging has been under utilized for imaging ankle tendons.

Waitches, Rockett, Brage, & Sudakoff (1998) investigated the accuracy of ultrasound in diagnosing ankle tendon tears using operative findings and clinical follow up as the "gold standard". Tendons (N=68) were evaluated sonographically. The diagnosis of an intrasubstance tear was made when disruption of uniform tendon architecture by hypoechoic linear or globular clefts were observed. The criteria used to diagnose complete tendon rupture included discontinuity or a gap within the tendon or complete nonvisualization of the tendon. Ultrasound was able to identify all tears correctly with an accuracy of 93%, a sensitivity of 100% and a specificity of 88% in this study. The authors suggest that diagnostic ultrasound confirmation of an acute rupture often is not necessary, as this entity usually is appreciable clinically. Partial intrasubstance tears are more common and more challenging clinically to diagnose. Diagnostic ultrasound can be most helpful to the clinician in this setting to allow for distinction between tear and other disease processes.

A potential criticism of Waitches et al. (1998) study is that it was neither random nor blinded. The results of the diagnostic ultrasound examinations were also made available to the surgeon preoperatively. Despite Waitches et al. (1998) excellent results in accurately diagnosing acute ankle tendon tears, the authors discussed ultrasound as an imaging modality having some limitations. The examination is operator dependent, with a variable learning curve and ultrasound imaging has a limited ability to image deeper tissues and bones round the ankle. If pathologic conditions other than ankle tendons are in question, MRI may be more appropriate. However, the authors concluded that their study's excellent results have suggested diagnostic ultrasound is an accurate and sensitive modality in detecting tears of the peroneal and posterior tibial tendon.

Quadriceps tendon ruptures are either traumatic, idiopathic or caused by a variety of systemic diseases. Clinically tears of the quadriceps tendon should be suspected in patients with pain and oedema proximal to the patellar and with limited extension of the knee (Bianchi, Zwass, Abdelwahab, & Banderali, 1994).

Diagnosis of tendon rupture and differentiation between partial or complete tears are essential to ensure adequate treatment and rehabilitation. Partial tears are usually treated conservatively, while complete tears often require surgery. CT and MRI are the modalities of choice in the evaluation of suspected partial or complete tears, particularly in athletes.

The role of ultrasound in diagnosing traumatic tears of the quadriceps tendon and specifically to determine whether ultrasound could differentiate between complete and partial tears was examined by Bianchi et al. (1994).

Ultrasound was performed on 29 patients with suspected partial or complete quadriceps ruptures. The study used 59 normal knees from 30 patients as a control and of these, 17 showed subcutaneous fluid collections, oedema and knee effusions but no tear of the quadriceps tendon. Treatment of these patients was conservative. The control group's quadriceps tendons all showed normalised tendon appearances consistent with the sonographer's previous experiences with tendon visualisation with diagnostic ultrasound. Ultrasound of 12 of the 29 patients examined, showed a quadriceps tendon tear, in which 4 patients had a complete tear and 8 patients had a partial tear. By establishing the absence of a tear and differentiating partial tears from the complete tears, ultrasound changed the clinical diagnosis and helped define subsequent management of the patient (Bianchi et al., 1994).

Figure 4: Partial Rupture of Biceps Femoris.

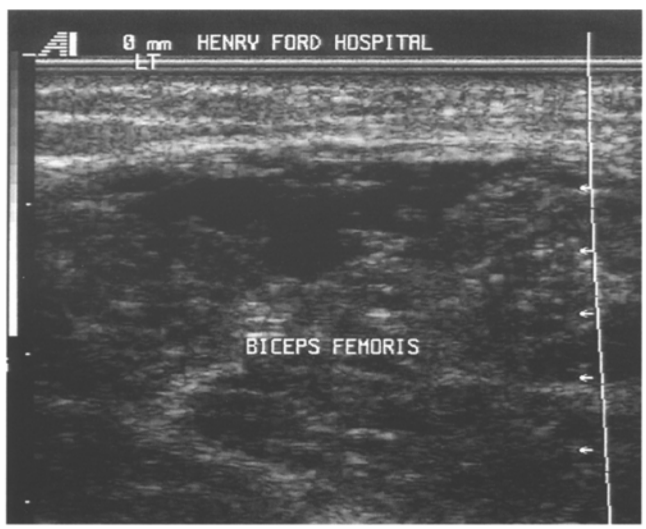


Figure 3–14 ■ Partial rupture of the superficial biceps femoris tendon: transverse sonogram. Three weeks ago, this 27-year-old soccer player sustained an injury to his left leg. A triangular hypoechoic defect is seen in the superficial layer of the biceps femoris muscle. It took several months before this athlete could perform at full strength again. Hamstring injuries are often very resistant to treatment.

From (Van Holsbeeck & Introcaso, 2001c).

The quadriceps tendon injuries were then treated conservatively or with surgery depending on their diagnosis. Follow up sonography post treatment, showed the integrity of the tendon. The presence of a complete or partial tear was confirmed at surgery or by MRI. Bianchi et al. (1994) found that diagnostic ultrasound was helpful for determining the site of the tear and for differentiating partial from complete tears and helpful in determining the appropriate treatment. MRI and CT imaging are presently utilised to evaluate tendon injuries however, Bianchi et al. (1994) suggested their results support the use of diagnostic ultrasound as a useful imaging technique for evaluating suspected ruptures of the quadriceps tendon. Experience is however necessary for sonograms to be acquired and interpreted adequately and accurately.

Identification of acute rotator cuff tears is important, not only because early surgical intervention is indicated, but also because such patients are more likely to benefit from less invasive arthroscopically assisted techniques. Teefey, Middleton, Bauer, Hildebolt, & Yamaguchi (2000) suggested that patients with rotator cuff tissue that is of good quality, freely mobile, minimally retracted and associated with traditional rotator cuff muscles, are better suited for arthroscopic repair and have a better surgical outcome. The aforementioned characteristics are found in patients with acute rotator cuff tears, rather than chronic pathology. Teefey et al. (2000) investigated whether diagnostic ultrasound was sensitive and specific enough to identify the appearance of acute and chronic rotator cuff tears in preoperative patients with a painful shoulder.

The researchers obtained the clinical histories and operative reports of 127 patients with shoulder pain whom had undergone standardized preoperative shoulder diagnostic ultrasound and subsequent arthroscopy. All ultrasound images were reviewed independently by two radiologists who were blinded to the patient's history and operative findings-retrospectively. The operative techniques were performed by a single orthopaedic surgeon with standardised recordings.

The authors were able to accurately determine the location and the appearance of rotator cuff tears and differentiate as to whether the rotator cuff was of an acute or chronic nature. The sonograms of 24 patients with an acute tear and 20 patients, with a chronic tear were reviewed for tear size (width), location and the presence and distribution of fluid. Among these patients, 75% with a mid substance tear location had an acute tear, 64% of patients with a joint or bursal fluid had an acute tear, 80% of patients with a nonvisualized rotator cuff due to a significant tear had a chronic tear and 73% of patients with no ultrasound evidence of bursal or joint fluid had a chronic tear.

The authors suggested a mid substance location at the presence of joint or bursal fluid were more commonly associated with an acute tear. A nonvisualized rotator cuff and the absence of joint and bursal fluid were more commonly observed with a chronic rotator cuff tear. Rotator cuff tears are a common cause of shoulder pain and can result in significant loss of function and strength. Although a majority of patients have chronic pain as a presenting feature, a small percentage of patients without a previous history of shoulder pain have an acute, traumatic cause for their rotator cuff tear. Acute tears are considered an indication for early surgical intervention because a delay in repair may result in attritional changes in the cuff tendon, muscle, or both. These chronic changes may make the repair more difficult technically and the functional outcome less satisfactory (Teefey et al., 2000).

Early repair generally affords the best opportunity for return of shoulder function and strength in addition to pain relief. Although patient history, physical examination and plain radiographs can provide information about the chronicity of a cuff tear, the diagnosis may not always be clear and imaging tests, such as ultrasound may be important in providing additional information (Teefey et al., 2000).

Information gained from ultrasound imaging would be useful to the orthopaedic surgeon not only in treatment planning, but also in advising patients regarding the success of conservative therapy, surgical options and eventual outcome. Teefey et al. (2000) suggested that their retrospective study had several limitations. This included their sample sizes were small and although the comparisons between the sonographic findings in acute and chronic rotator cuff tears in the authors study approached statistical significance, the sample sizes were not large enough to demonstrate a significant relationship. The authors also reported that the clinical and surgical criteria we used to categorize their patients as having acute or chronic rotator cuff tears created two relatively "pure" populations of patients.

Teefey et al. (2000) concluded that differences exist in the ultrasound appearance of acute and chronic rotator cuff tears. The presence of a mid substance tear location or fluid in the joint or bursae suggests an acute tear, whereas the presence of a nonvisualized cuff or absence of joint and bursal fluid suggests a chronic tear. Diagnostic ultrasound could accurately differentiate these aforementioned differences in acute and chronic rotator cuff tears and was specific and sensitive to identify the appearance of acute and chronic rotator cuff tears.

Although the history and the clinical findings of injury to the medial head of gastrocnemius muscle are suggestive, an imaging examination is usually performed to confirm the clinical impression and evaluate the severity and size of the lesion.

Another study by Bianchi, Martinoli, Abdelwahab, Derchi, & Damiani (1998) retrospectively reviewed the ultrasound images of 65 patients with clinically suspected ruptured medial head of the gastrocnemius. Torn muscle fibres, haematoma, inflammation and the reparative process were all visible on diagnostic ultrasound. The sonographers were easily able to differentiate partial or complete tears and able to identify a number of other associated or non-associated pathologies. Follow up ultrasound examination up to one year later was able to visualise hyperechoic areas probably relating to fibrous tissue.

Sonographic examination of the gastrocnemius muscle was easy to perform, was painless and could be completed in 10 to 15 minutes. Based on the completeness of disruption of the normal appearance, Bianchi et al. (1998) were able to differentiate between partial and complete lesions. Clinically, a ruptured gastrocnemius must be differentiated from a ruptured Baker's cyst, deep venous thrombosis and occasionally Achilles tendon rupture. These conditions can be diagnosed accurately with ultrasound.

Bianchi et al. (1998) study has some limitations. Confirmation of ultrasound findings was not obtained by surgery or other imaging modalities. Surgical therapy was not performed because the patient population was mainly composed of amateur sportsmen not engaged in high level or professional activities and because conservative treatment and rest were successful in all patients.

The authors concluded that diagnostic ultrasound proved to be easy to perform, fast and was a safe imaging modality to evaluate patients with clinically suspected torn gastrocnemius muscles. The size of the tears could be appreciated with smaller lesions having the main sonographic diagnostic feature of local disrupted arrangement of the muscle fibres and fibroadipose septa. In larger tears, the presence of a fluid collection separating the injured medial head of the gastrocnemius muscle from the soleus made the diagnosis straightforward. Healing of torn gastrocnemius could be easily evaluated by diagnostic ultrasound. The low cost of ultrasound allowed serial follow-up examinations and optimal monitoring of the reparative processes. Other conditions that can mimic ruptured gastrocnemius, such as a ruptured Baker cyst and Achilles tendon ruptures, have characteristic diagnostic ultrasound features and can easily be differentiated from ruptured gastrocnemius (Bianchi et al., 1998).

2.2 Bursae and Ganglia.

2.2.1 Bursae.

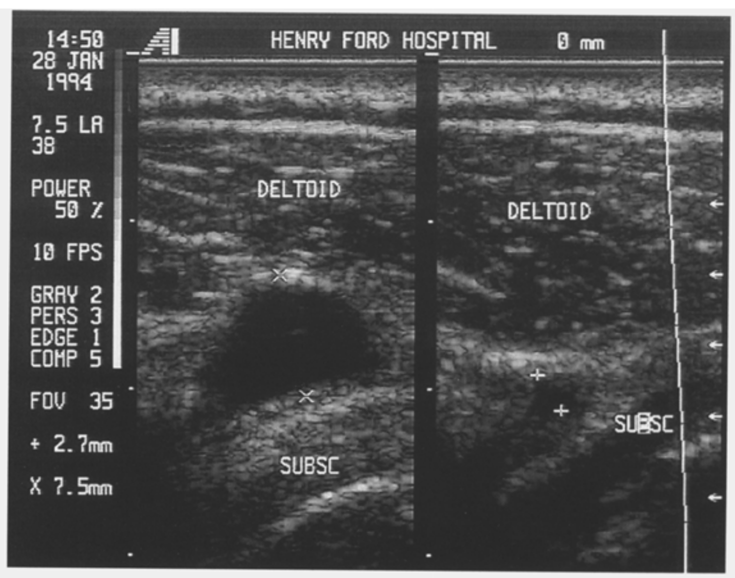
The first report of diagnostic ultrasound imaging being used to examine bursitis was in the early 1970's where it was used to examine Baker's cysts or gastrocnemio-semimembranous bursae. (Stokes et al., 1997). The location of fluid generally identifies the bursa. There are three types of bursae; superficial, deep and acquired adventitial bursa. Superficial bursae are close to the skin surface and bursitis in these structures is generally easy to identify clinically. These bursae include the olecranon, subcutaneous trochanteric, prepatellar, subcutaneous infrapatellar and subcutaneous Achilles tendon bursae. The deep bursae are less accessible for clinical examination and diagnostic ultrasound imaging is particularly useful to identify signs of bursitis in these structures. The deep bursae that have been examined by ultrasound include the subacromial, deep trochanteric, iliopsoas, retrocalcaneal and gastrocnemio-semimembranous bursae. Adventitial bursae result from a variety of pathologic conditions such as amputation or exostosis. For example, a bursa may develop adjacent to the end of an amputated limb. Occasionally, diagnostic ultrasound may be utilised to identify bursitis in this clinical setting (Hashimoto et al., 1999).

A bursa is a potential space, so normally it does not contain a large amount of fluid. Sonographically normal bursae are not visualised, appearing only as thin hypoechoic spaces or sacs in a typical anatomic location. A hyperechoic line surrounds the hypoechoic space and is generally not thicker than 2mm (Wang et al., 1999). Bursitis leads to accumulation of synovial fluid and distension of bursae and the synovial sheath of the surrounding tendons. The causes of bursitis include trauma, haemorrhage, infection, crystal-induced arthritis, or from systemic diseases such as rheumatoid arthritis and gout (Cardinal et al., 1998).

When a bursa is distended it appears as a hypoechoic structure with well defined margins and variable echogenicity contents (see Figure 5). The internal appearance varies according to the pathology. In a simple bursitis there may be just anechoic fluid with or without septa. In chronic bursitis, due to impingement or overuse, more frequently there is just bursal thickening evidenced by a band of moderate echogenicity. Echogenic debris may be present, but it is not usually possible to characterise such bursal fluid without infective synovitis. This may appear thick walled and chronic bursitis may even be moderately echogenic and mimic a solid mass (Wang et al., 1999).

Figure 5: Bursal Effusion in Subacromial Bursa.

Figure 5–15 ▪ Bursal effusion in subacromial-subdeltoid bursa: split-screen dynamic examination. A 74-year-old carpenter presents with pain in the shoulder and with a rotator cuff tear documented by ultrasound. Shoulder motion brings the arm from internal to external rotation. This maneuver shows expansion of the bursal lumen during external rotation (left image) and flattening (right image) of the bursa during internal rotation. This phenomenon is equivalent to fluctuation observed clinically.



From (Van Holsbeeck & Introcaso, 2001a).

2.2.2 Ganglia.

Ganglia are cystic structures surrounded by fibrous tissue without a synovial lining and are filled with mucinous fluid. They most commonly present clinically as masses round the wrist and hand and may produce compressive symptoms. Ultrasound visualises ganglia as anechoic masses, which often have a visible communication with a joint or tendon sheath (Wang et al., 1999). Ganglia are easily visualised with ultrasound, if a clinician requires a diagnostic evaluation. However, the majority of ganglia are diagnosed without difficulty clinically (Wang et al., 1999; Hashimoto et al., 1999). The use of ultrasound guidance in the injection of ganglia is discussed later in this paper.

2.3 Interventional Diagnostic Ultrasound (Ultrasound Guided Techniques).

Diagnostic ultrasound has a number of potential interventional uses within the musculoskeletal arena. Injection, aspiration and the guidance of needle placement within anatomical structures can be facilitated by the use of ultrasound. Soft tissue biopsy needles have been designed to allow maximum visibility in the ultrasound field of view and colour Doppler sonography and vibration technology to detect needle placement have also been developed. Van Holsbeeck & Introcaso (2001b) indicated there is no limit to the size of the lesion that can be visualised, aspirated, sampled or injected. Lately many researchers have published their studies collaborating diagnostic ultrasound’s usefulness within an “interventional” musculoskeletal setting.

2.3.1 Aspiration and Injection.

Intraarticular corticosteroid injections are widely used in clinical practice, but often their effect is variable. Jones et al. (1993) suggested one possible explanation for this variability might be inaccurate injection. A study by Jones et al. (1993) utilised 108 patients with “active” inflamed knees, with stiffness, synovial thickening, local warmth, tenderness and synovial effusion. Each knee was aspirated and injected followed by a single plain x-ray. A successful accurate injection was deemed to be associated with aspiration of synovial fluid. This study's results indicated that only 45% of the patients who were aspirated or injected had a reduction in joint inflammation. An explanation for the failure to aspirate synovial fluid was inaccurate injection through poor technique (Jones et al., 1993). The authors suggested that their study showed that intraarticular injections are often inaccurate and that this has obvious clinical relevance. Indeed inaccurate injection might contribute to the incidence of local tissue damage or atrophy.

Although the doctors who gave the injections had differing rheumatalogical experience, their study was unable to show any effect of experience or seniority. This could imply that current training in injection techniques needs to be refined (Jones et al., 1993). Further controlled studies are needed to determine the reliability of intraarticular corticosteroid injections.

Qvistgaard et al. (2001) have also reported an uncertainty regarding the accurate placement of injections in joints. The exact placement of injections of glucocorticoids is important for the effect of the therapy as well as for avoiding local adverse effects of the medication.

Air is highly echogenic in diagnostic ultrasound and guidance of needle placement in organs by injection of air while scanning has been previously proposed (Qvistgaard et al., 2001). This method has been proposed for the guidance of injection in the hip but its application has not been fully evaluated. A study was undertaken by Qvistgaard et al. (2001) which evaluated a method for ascertaining the correct placement of injections in either hip and knee joints by the use of a small amount of air under the guidance of ultrasound. Injections in the hip and knee were performed, numbering 195 using a ultrasound examination before and during the injection into the joint. On injection if the appropriate bursa was not discernible on ultrasound, the needle was inserted from the lateral aspect of the joint and placed in the joint cavity. With the traditional approach of injection the needle is covered by bone and cannot be detected on the ultrasound screen. By injecting air inside the joint cavity the bursae will move thus making it visible. This placement is dependent on the experience and skill of the doctors performing the manoeuvre.

The authors study's results indicated that both the aspiration of the joint fluid and the subsequent injection are clearly visible on ultrasound, thus assisting the procedure to be as complete as possible, in the joints with significant effusion. When preceded by aspiration of joint fluid, an injection given through the same needle, will in most cases be quite accurate (Qvistgaard et al., 2001). All vessels can be visualised easily by ultrasound and especially Doppler ultrasound. This leaves no doubt as to the nature of non-echoic cavities, which are in all cases were distinguishable from vessels. Qvistgaard et al. (2001) concluded that the procedure may be extensively used for the documentation of the placement of intraarticular therapy of the knee and hip joints.

Balint & Sturrock (2001) found musculoskeletal ultrasound can detect small or deeply located effusions not found on clinical examination. Diagnostic ultrasound has been shown to detect effusions of as little as 1 ml of fluid and can provide information on the pressure, location, structure and extent of palpable effusions in addition to delineating surrounding tissues such as skin, vessels and nerves (Balint & Sturrock, 2001). This allows the safest route of injection to be identified and provides useful information on the depth to which the needle must be inserted and improves the detection and aspiration of joint effusions.

Balint & Sturrock (2001) both imply ultrasound may also detect intraarticular and intrabursal septure or complex multiloculated structures but cannot differentiate between inflammatory or non-inflammatory effusions, septic arthritis or hemarthrosis. Synovial proliferation also appears hypoechoic, though fluid can be confirmed by compression and displacement with transducer pressure.

Using diagnostic ultrasound to guide injections improves accuracy and efficacy, thus decreasing the risk of injecting into the tendon, adipose tissue, muscle, nerve or skin which could result in tissue damage. Ultrasound guidance will also allow more rapid diagnosis and a better appreciation of musculoskeletal anatomy. This could improve the operator's skills in examination and in unguided aspiration and injection (Balint & Sturrock, 2001; Qvistgaard et al., 2001; Van Holsbeeck & Introcaso, 2001b).

Brophey, Cunnane, Fitzgerald, & Gibney (1995) studied the effect of ultrasound guidance for injection of soft tissue lesions round the heel. Heel pain is a frequent complaint among patients with chronic inflammatory arthritis and is caused by a variety of lesions which include arthritis, bursitis, tendonitis, bone erosions, tendon rupture and fasciitis. Pain round the heel is often poorly localised and physical signs equivocal. Therefore an accurate diagnosis is essential in these patients in order to direct appropriate treatment which may include a local injection of corticosteroid. Brophey et al. (1995) used diagnostic ultrasound guidance for injection of soft tissue lesions round the heel. Ten patients with tenosynovitis and bursitis were injected with steroid under guidance of diagnostic ultrasound. Tendons and bursitis were selected for injection, as they were deemed to be appropriate in response to corticosteroid injection. All 19 patients were successfully injected reducing the patient's symptoms of heel pain.

Steroids are often used as treatment for a variety of musculoskeletal disorders such as bursitis and tenosynovitis and those injections are usually given using palpation to guide needle placement. Diagnostic ultrasound imaging helped in the selection of lesions appropriate for injection and enabled precise needle tip placement during injection (Brophey et al., 1995).

Since tendon sheaths round the ankle communicate with the ankle joint, fluid within these sheaths may result from tenosynovitis or from extension of an ankle joint effusion. For the treatment of tenosynovitis, steroid injection between the tendon sheath and tendon substance has been shown to cause tendon necrosis, which many predispose to rupture. Therefore accurate needle placement via ultrasound guidance could significantly decrease this incidence.

In summary ultrasound guided injection seems most useful where an effusion has collected and injection is directed into the bursae or the inflamed tendon sheath. Diagnostic ultrasound guidance may be the technique of choice for injection of a variety of soft tissue lesions round the heel (Brophey et al., 1995).

Ultrasound has been reported to be a very sensitive and specific modality in the diagnosis of ganglia. It has also been shown to be effective in the guidance of the aspiration of fluid collections in relation to ganglions (Cardinal et al., 1998). However, there are conflicting reports as to the efficiency of the injection of ganglia with hydrocortisone which has been advocated in the treatment of ganglia.

Breidahl & Alder (1996) indicated the distribution of corticosteroid in the region of the ganglion which may affect the success of the outcome has not been evaluated. Ten patients underwent diagnostic ultrasound guided injection of a ganglion in the wrist, fingers or talus. All ganglia were injected with corticosteroid and local anaesthetic after aspiration where possible. Confirmation of intralesional injection was obtained by visualising the echogenic bubbles exiting from the needle tip into the ganglion. The injection was confirmed when the ganglion was uniformly echogenic.

The results of Breidahl & Alder (1996) study were impressive. All the ganglia injected either resolved, significantly reduced in size and/ or resolved after a second injection, all within a twelve month period. Only one ganglion did not show significant improvement with steroid injection.

In their discussion the authors have stated that pathologically, ganglia are composed of a cystic space without epithelial lining filled with material that is often gelatinous or mucoid. The wall of the ganglion consists of flattened fibrous elements and areas of myoid connective tissue. The imaging features of ganglia have been well described; they are typically oval or lobulated cystic masses that may contain septations. Ganglia are liable to spontaneous regression.

Breidahl & Alder (1996) suggested that the mechanism by which corticosteroids should provide benefit is unclear. Those that use that corticosteroids for treatment work on the theory that chronic inflammation may play a role in the pathogenesis of ganglia. For whatever reason corticosteroids are effective on ganglions, the use of ultrasound guidance to guide corticosteroid injection has a number of potential advantages. It allows direct visualisation of the needle tip within the ganglion. Furthermore the injection can be observed in real-time, appearing as a stream of echogenic material entering the cyst. The use of ultrasound guidance allows the injection of symptomatic but impalpable ganglia.

The confirmation of intralesional injection has the potential to result in improved efficacy compared with an injection by palpation. When palpation is used, material may be injected into the adjacent soft tissue thus minimising local cutaneous effects. Ultrasound imaging provides a guide to the volume of therapeutic agent to inject. In addition ultrasound guidance may help in avoiding the needle traversing adjacent structures such as vessels, nerves and tendons.

Injecting corticosteroids under the guidance of ultrasound has a role in the management of ganglia. The ganglion is injected safely and reliably and it is relatively cost effective. Breidahl & Alder (1996) have demonstrated the benefit of diagnostic ultrasound guided injection in a small number of patients however, a larger series is required to establish this method as a preferred technique.

2.3.2 Surgical Procedures.

The role of diagnostic ultrasound imaging in guiding surgical musculoskeletal procedures to date is limited. However, sonographers have removed some foreign bodies using ultrasound. In their review of the literature Van Holsbeeck & Introcaso (2001b) found ultrasound useful in removing pieces of gravel or metallic foreign bodies. Removal of pieces of glass is more delicate and requires a combined approach of diagnostic ultrasound and surgery. Wood can be removed, but only when the injury is fresh. Splinters and thorns that have been causing granulation for weeks cannot be removed as one piece and they often disintegrate upon removal.

The percutaneous removal of foreign bodies requires sterile preparation of the transducer, skin cleansing with iodine and alcohol and sterile instruments that can articulate and clasp the foreign body (Van Holsbeeck & Introcaso, 2001b). The authors described surgical musculoskeletal procedures beginning with sonographic localization of the foreign body. The most superficial end of the foreign body is marked with a small dot on the skin with a sterile marker to locate this point. A skin incision is made that will allow the instrument to enter the cutaneous and subcutaneous tissues. The instrument is then guided toward the foreign body using ultrasound guidance. The transducer is removed if and when the foreign body had been firmly clasped. Van Holsbeeck & Introcaso (2001b) suggested that if the skin incision is wide enough to allow extraction without injury the clinician should proceed with removal. Careful rescanning of the surface always follows foreign body removal. Tumour ablation has been performed percutaneuosly as well. An alcohol solution can be used to induce necrosis in posttraumatic neuromas and in Morton's neuromas. Diagnostic ultrasound imaging is the preferred method because of its superior spatial resolution and its ability to show and follow the normal nerve into the mass. This allows sonographers to target nerve lesions with great accuracy and without causing damage to the normal nerve feeding the lesion. Removal of pathological lymph nodes and extraction of recurrent melanoma have been performed for diagnostic purposes.

Using diagnostic ultrasound imaging to provide guidance allows faster and more accurate procedures that save tissue and reduce costs (Bianchi et al., 1998; Van Holsbeeck & Introcaso, 2001b). However, according to Van Holsbeeck & Introcaso (2001b) much more is possible and remains unexplored. Better communication between orthopaedic surgeons and sonographers could soon lead to new percutaneous procedures. The authors anticipate that the following procedures could be done percutaneuosly and with ultrasound guidance with the relevant research; tendon, ligament and capsular release, loose body removal and meniscal and rotator cuff repair. The options for ultrasound image guided musculoskeletal surgical procedures has a huge prospective potential.

In a review of interventional musculoskeletal procedures using ultrasound guidance Sofka, Collins, & Alder (2001) retrospectively examined 195 procedures. Thirty one procedures had MRI correlation within 6 months beforehand. Of the 195 procedures performed, the authors found that 180 were performed most readily using ultrasound guidance because of its good tissue contrast and real-time nature. Diagnostic ultrasound guided interventions included therapeutic injections into tendon sheaths, Morton's neuromas, plantar fascia, wrist ganglia, tarsal tunnel cysts, peritendinous hamstring injections and synovial cyst and muscle biopsies. In all cases aspiration or injection of medication to the site of interest was observed during real-time and post procedure images of the area confirmed the administration of medication or reduction of cyst volume.

Diagnostic ultrasound has the direct advantage of imaging in real-time, enabling the sonographer to observe the needle tip at the target of interest, to observe medication delivery and to confirm localisation of medication at the end of the procedure. Ultrasound is also portable and therefore procedures can be done at bedside as warranted clinically. Furthermore, ultrasound imaging does not involve exposure to ionizing radiation thus expanding its usefulness for children and pregnant women.

Some techniques can be used to improve visibility, such as using roughhead needle tips, injecting small amounts of air, micro bubbles or test amounts of local anaesthesia and using colour Doppler imaging. A single focal zone and low persistence allow improved needle tracking. Both 3-D and tissue harmonic imaging, which are available as part of current ultrasound technology, may further enhance needle identification and localization even more. Documenting exact needle placement in real-time allows for selective injection into tendon sheaths as opposed to direct injection into tendons (Sofka et al., 2001). It has been shown that direct injection into tendons has been associated with tendon degeneration and rupture (Bianchi et al., 1994).

In their review Sofka et al. (2001) summarised these findings, by stating ultrasound has several distinct advantages as an imaging guidance system in performing musculoskeletal procedures. One of the strongest advantages is the ability to show needle placement and subsequent therapeutic injection or diagnostic aspiration in real-time. Although a formal clinical outcome study has yet to be performed, verbal communication with referring clinicians and patients has indicated an overall positive response.

2.4 Foreign and Intraarticular Loose Bodies.

The standard imaging procedure used in diagnosis of foreign bodies has been plain x-rays obtained in two projections. In their review on ultrasound and surgically removed foreign bodies Van Holsbeeck & Introcaso (2001a), suggested that x-rays correctly identified metallic fragments in 100% of cases and glass in 96% of cases, but wood was correctly identified in only 15% of cases. These statistics would be considered excellent except for the fact that the most common foreign bodies in order of frequency are wood, glass and metal fragments.

Plain x-ray still remains the investigation of choice for imaging foreign bodies primarily because of its wide availability, low cost and ease of examination. MRI has been shown to be helpful in detecting complications like abscess formation, intraarticular penetration and indeed in the identification of foreign bodies. A limitation of MRI is difficulty distinguishing low signal intensity foreign bodies from tendons, scar tissue and calcifications. Lack of availability and high cost further limit the usefulness of MRI. CT scanning has a sensitivity 5 to 15 times greater than that of plain x-ray, but is also less sensitive than ultrasound. Additionally, the expense, use of radiation, and limited availability make CT less than optimal in the clinical detection of foreign bodies (Van Holsbeeck & Introcaso, 2001a).

2.4.1 Foreign Bodies.

Ultrasound is being increasingly used in the diagnosis of foreign bodies, particularly for non-radiopaque materials which cannot be visualised with conventional x-ray techniques (Bradley, Kadzombe, Simms, & Eyes, 1992). A study by Bradley et al. (1992) reported a 95% sensitivity for detecting nonradiopaque foreign bodies and a specificity of

89% from the literature they examined. The aim of their study was to assess the feasibility of percutaneous ultrasound guided techniques for the impalpable foreign body which normally would require a difficult surgical procedure.

Bradley et al. (1992) imaged 11 non palpable foreign bodies, (8 radiopaque, 3 non-radiopaque), in a total of 5 patients. The foreign bodies were diagnosed by x-ray and ultrasound. Extraction, whilst scanning in the longitudinal plane of the foreign body was carried out. This was successful with 5 foreign bodies, the remainder required formal surgical exploration.

Bradley et al. (1992) suggested the advantages of this technique are that it does not use any ionizing radiation and it may be used for either non-radiopaque or radiopaque foreign bodies. The avoidance of general anaesthesia shortens the patient's stay in hospital, and a small incision causes less scarring. It is also a cost effective procedure compared with surgical exploration. Scanning and instrument selection require consideration with regard to imaging. The use of ultrasound imaging along with a need for further quantitative studies to assess whether there is a role for imaging in the removal of foreign bodies warrants continued attention.

A study by Jacobson, Powell, Craig, Bouffard, & Van Holsbeeck (1998) evaluated the use of ultrasound for the detection of wooden foreign bodies that were implanted in cadaveric specimens. Penetrating injuries are a common injury and the continued presence of foreign bodies in soft tissue can lead to serious infections and inflammatory complications. Detection and removal are imperative. According to Jacobson et al. (1998) non-radiopaque foreign bodies such as wood remain undetected by x-ray, whereas radiopaque foreign bodies such as glass, metal and stone can easily be identified by x-ray (see Figures 7 and 8). CT scanning and examination by MRI are limited due to its cost, use of radiation, availability and intermediate sensitivity. Ultrasound imaging has therefore been advocated in the detection of non-radiopaque foreign bodies.

Wooden fragments are hyperechoic with acoustic shadowing deep to the object in an acute setting. This makes identification and localization quite simple. However, unlike other types of foreign bodies, wood fragments tend to decompose quite rapidly due to the surrounding inflammatory reaction. Over the course of several days, the wooden fragment will become progressively less echogenic and finally disappear within the inflammatory collection. These disappearing foreign bodies have misled clinicians into searching for sources of septic emboli when an accurate clinical history is not available. Organic materials like splinters, plated wood and thorns are very significant allergens. These foreign materials tend to induce granulomas and local infections. Synovial inflammation will often follow intraarticular penetration or penetration of the foreign body into a tendon sheath or a bursa lumen.

Ten foreign bodies were implanted into a cadaver. Ten incisions were performed without implantation of foreign bodies. Three sonographers independently performed ultrasound examinations to record the presence of a foreign body.

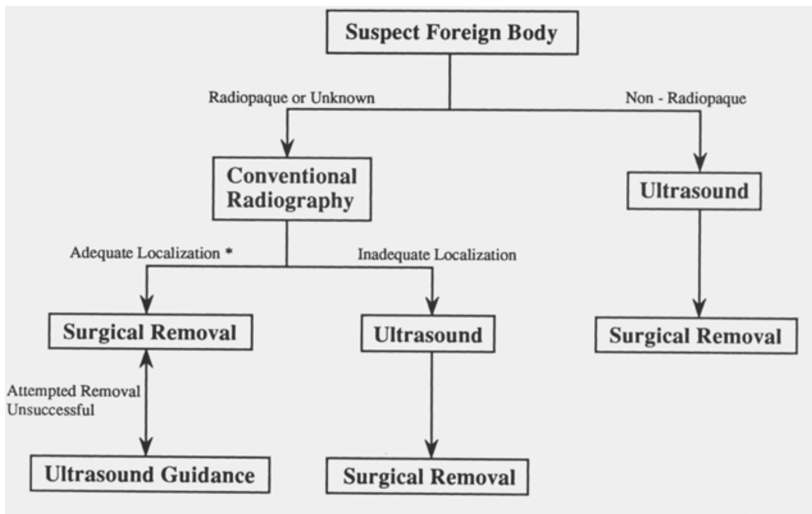
The results of the authors study show a sensitivity of 86.7% and a specificity of 96.7%. The accuracy was 92.3%. The positive predictive value was 98% and the negative predictive value of 83%. This study has shown that ultrasound can be used effectively to locate wooden foreign bodies as small as 2.5 mm in length. Many foreign bodies are undetectable by x-ray and the accuracy and availability of ultrasound make it an excellent modality for the evaluation of non-radiopaque foreign bodies.

A study by Bray, Mahoney, & Campbell (1995) utilised ultrasound imaging in the diagnosis of foreign bodies in the hand. The authors used 15 fresh frozen cadaver hands and divided each hand into 21 standardized sites for potential insertion. Wood, glass and metal were utilised in 2 different sizes. The foreign bodies were randomly assigned to 50% of the available sites. The cadaver hands were scanned by a single radiologist who was unaware of which cadavers contained foreign bodies. In total 166 foreign bodies were inserted, in which 156 were detected by diagnostic ultrasound. Ten sites were falsely analysed as negative, for a sensitivity of 94%. One false positive was reported with 148 true negatives, giving a specificity of 99%.

Bray et al. (1995) described the false negative results due to both operator dependent and independent factors. Operator skill is a major factor in the successful use of diagnostic ultrasound imaging for foreign bodies and depends on the use of slow methodical technique. False negative results could be due to the complicating effects of the echo patterns of surrounding structures, such as tendons, or scar tissue, or soft tissue calcification. Ossified cartilage and haematomas within lacerations may also contribute to false positive results (Bray et al., 1995).

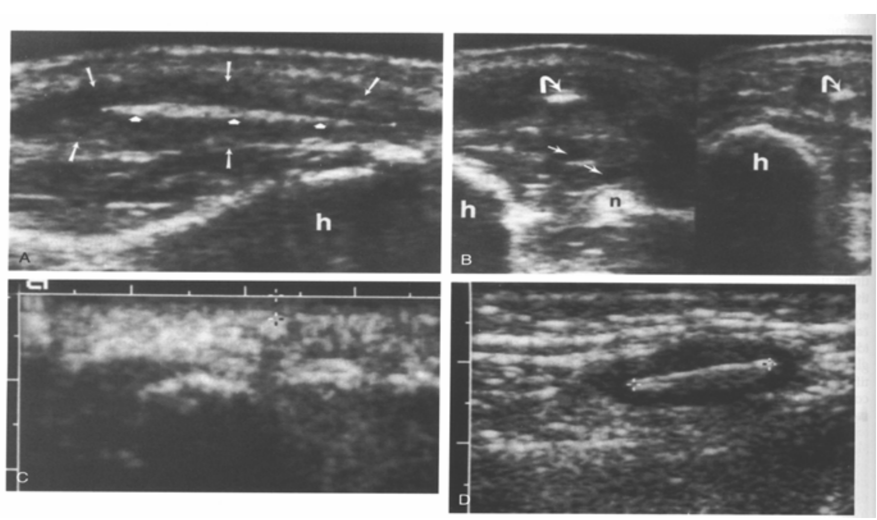
Diagnostic ultrasound is relatively inexpensive and can be promptly arranged if requested for examining a foreign body. Plain x-ray films are still less expensive, more readily available and are used as the initial step in the diagnosis of a foreign body. If the history is clear enough that the suspected foreign body could only be composed of a radiopaque substance such as metal or stone, then x-ray films alone should be sufficient to rule out or confirm foreign body presence. In other cases x-ray films can be obtained first, and if negative, can be followed by ultrasound. The selectively combined use of x-ray and ultrasound examinations should permit efficient diagnosis of all foreign bodies (Bray et al., 1995). This algorithm from Van Holsbeeck & Introcaso (2001a) provides a logical approach to a suspected non-radiopaque foreign body (see Figure 6).

Figure 6: Algorithm for Evaluation of Foreign Bodies.



From (Van Holsbeeck & Introcaso, 2001a).

Figure 7: Wood Splinter in the Elbow.



From (Van Holsbeeck & Introcaso, 2001a).

Figure 8: Glass Fragment in the Thumb.

From (Van Holsbeeck & Introcaso, 2001a).

2.4.2 Intraarticular Loose Bodies.

Intraarticular loose bodies are often chondral, osseous or osteochondral fragments located in the articular cavity. They derive from the internal surfaces of synovial joints including bone surfaces covered by hyaline cartilage and capsule lined by the synovial membrane. Loose bodies that move freely in the joint cavity are predisposed to be entrapped between the articular surfaces causing intermittent joint locking, limitation of motion, pain and intraarticular effusion. On the contrary, fragments stably located either in a synovial recess or in a bursa are usually asymptomatic. Repetitive internal derangement of a joint results in damage to the joint surfaces and leads to chronic symptoms and early osteoarthritis. The diagnosis of loose bodies is essentially based on imaging findings because clinical findings lack specificity. Different imaging modalities are able to confirm the presence of intraarticular fragments, assess their number, size and location and guide a successful early surgical treatment to prevent secondary degenerative changes. Although invasive and expensive, CT scanning and MRI have long been the procedures of choice in the evaluation of loose bodies. Currently, technical refinements of diagnostic ultrasound equipment, with improved spatial and contrast resolution capabilities, have made it possible to evaluate abnormalities of joint structures (Bianchi & Martinoli, 1999).

Osteochondral intraarticular bodies are commonly the result of traumatic, inflammatory and degenerative processes in synovial joints. Detection of intraarticular bodies with conventional x-ray depends on the presence of calcium in the fragment. Purely cartilaginous fragments are relatively radiolucent and will be radiographically occult. On CT scanning, some ossified intraarticular bodies not depicted at conventional x-ray may be seen, but detection of small fragments is still difficult. Small ossified fragments can also be easily overlooked on MRI due to the effects of volume averaging and the low-to-absent signal intensity. In this instance, further imaging has traditionally been performed with CT arthrography, which entails a degree of invasiveness, as well as considerable expense.

Diagnostic ultrasound imaging is becoming increasingly advocated as the modality of choice in patients suspected of having intraarticular bodies. Frankel et al. (1998) performed ultrasound examinations in 280 patients in various joints. Of those 280 patients, 61 underwent arthroscopy or related surgical procedures. The authors found that in 61 patients with surgical correlation, the ultrasound examination findings were positive in 39 and did not show an intraarticular body in 22. Surgical results confirmed 37 of the positive and all of the negative sonograms giving diagnostic ultrasound a sensitivity and specificity of 100% and 95% respectively. The authors concluded that with most orthopaedic complaints, conventional x-ray was the appropriate modality for initial evaluation. However, if x-rays depict ossific opacities in the region of the joint and the importance or exact location relative to the joint space must be further investigated, ultrasound would be indicated. If x-rays are negative, diagnostic ultrasound may be warranted if clinical symptoms such as joint locking are present which strongly suggested of the presence of an intraarticular body.

Bianchi & Martinoli (1999) concluded from their paper that the ability of ultrasound to diagnose intraarticular loose bodies greatly depends on a high degree of suspicion of the clinician, related to the knowledge of radiographic and clinical findings. X-ray is still the modality of choice when a loose body is suspected on clinical grounds. X-rays are panoramic and not expensive. If a calcified image consistent with a loose body is shown on x-ray, diagnostic ultrasound can be performed to prove its intraarticular location and rule out para-articular calcification.

2.4.3 Orthopaedic Implants.

Orthopaedic implants can be considered "foreign bodies" according to Van Holsbeeck & Introcaso (2001a). Diagnostic ultrasound can be valuable in the evaluation of orthopaedic implants used in internal fixation of fractures and also orthopaedic prostheses.

Following successful, uncomplicated surgery orthopaedic implants can occasionally become infected. Surgeons usually aspirate the joint in question if required, after appropriate medications and advice, if there is no marked improvement. The ability of diagnostic ultrasound to locate these fluid collections and guide aspiration makes it a widely used modality.

The loosening of orthopaedic prostheses and the accompanying inflammation as well as soft tissue erosions as a result of loose orthopaedic hardware are other examples where ultrasound imaging may be used to visualise pathologies and aid in diagnosis, appropriate treatment and management (Van Holsbeeck & Introcaso, 2001d).

2.5 Ligaments and Joints.

The relationship between joints and ligaments is symbiotic, with the structures allowing both movement and stability within the body. With the human body being placed under stress and force, through various work, leisure and sporting activities, joints and ligaments are prone to pathology and injury. The investigation of joint and ligament dysfunction is paramount in forming a diagnosis and management plan for adequate treatment and rehabilitation.

Often joint and ligament dysfunction are inter-twined, with both anatomical structures suffering collective dysfunction. X-rays and recently MRI have been utilised to diagnose joint and ligament dysfunction. However, a number of studies support the view that for specific indications, ultrasound imaging is an efficient and inexpensive alterative for the evaluation of joints and ligaments (Fessell et al., 1998; Lee et al., 1996; Murphey, Hashimoto, Buckmiller, Kramer, & Wiitala, 1997). With the increasing use of ultrasound imaging for the evaluation of musculoskeletal injuries, it has been described as a side effect free and cost effective procedure for examination of ligaments and joints.

2.5.1 Joints.

The acromioclavicular (ACJ) is traditionally examined via x-ray with 10kg weights held in each hand when there is a suspected injury or pathology. A study by Kock, Jurgens, Hirche, Hanke, & Schmit-Neuerberg (1996) investigated the reliability and practical diagnostic value of ultrasound imaging to indicate whether surgical ACJ stabilisation was required. The authors compared ultrasound imaging with the current x-ray procedure.

Kock et al. (1996) selected 20 patients with various grades of ACJ dysfunction and measured the width of each ACJ from the most lateral cortex of the clavicle to the most medial cortex of the acromion and compared the two sides and the shortest distance between the acromion and clavicle. Ten kg weights were used, as described previously. This was repeated with ultrasound and subjected to statistical analysis.

The results of Kock et al. (1996) study indicated that the customary x-ray of both shoulder joints while holding weights, could be dispensed with completely and replaced by examination with diagnostic ultrasound imaging. Kock et al. (1996) reported the accuracy of the method in distinguishing between the various grades of ACJ injury is identical to that achieved by x-ray examination. Ultrasound examination for distinguishing between stable and unstable ACJ appears to be a cost effective examination procedure with a low rate of side effects. The diagnostic ultrasound examination technique and the calculation of the degree of instability are easy to learn by sonographers and clinically applicable. However, I feel the exclusion of a fracture of the injured ACJ needs to be analysed with x-ray, thus x-ray may still be required to rule out bony pathology.

2.5.2 Ligaments.

Clinical evaluation is recommended in the orthopaedic literature as the standard diagnostic tool to confirm a ligamentous injury. Tendon and ligaments appear on diagnostic ultrasound as moderately echogenic structures with relatively well defined margins. This appearance may differ however with variations in the orientation of the scan beam. When the beam is perpendicular to the tendon a longitudinally oriented, sometimes fibrillar pattern of echogenicity is noted. However, when the beam is orientated obliquely to the tendon, an artificial hypoechogencity may be noted. A normal ligament appears on ultrasound images as a thin and relatively homogeneous hypoechoic band. The injured ligament appears as a thickened and heterogeneous hypoechoic lesion with the causes of heterogeneity being oedema, haemorrhage and fluid collection (Lee et al., 1996).

In most cases a diagnostic ultrasound examination of ligaments can be performed more rapidly and effectively than comparable MRI and x-ray examination. Patients can be seen in the clinical setting, sent directly for musculoskeletal ultrasound and return to the clinician with a diagnostic report. There are a number of recent reports and papers which outline the use of diagnostic ultrasound for the examination of ligamentous structures.

The detection of an acute anterior cruciate ligament (ACL) lesion using only clinical examination can be difficult and produce ambiguous results. The diagnosis of an ACL rupture is important with regards to ongoing management and surgery. MRI or arthroscopy are routinely carried out should a clinician require further confirmation of the extent of an ACL injury (Schwarz, Friewert, Mayer, & Gerngross, 2001).

A study by Schwarz et al. (2001) utilised 41 patients with acute knee injury. The authors carried out an ultrasound examination in which the ventral translation of the tibia and the measured distance was compared to healthy side. A difference of greater than 1mm in anterior tibia translation was used to diagnose an “ACL lesion”. Diagnosis of an ACL lesion was verified in 33 cases following arthroscopy. Using the diagnostic ultrasound method, the authors found a positive ACL deficiency in 32 cases. With a sensitivity of 97% and specificity at 88%, the authors concluded that ultrasound guided manual clinical testing for ACL injuries is a reliable and accurate indication of the severity of ACL deficiency (Schwarz et al., 2001).

However, this study lacked a significant subject population, statistical analysis and had minimal clarification of the methodology. Potentially further, larger controlled studies are required

The rehabilitation and prognosis for injuries of the medial collateral ligament (MCL) of the knee has also traditionally been determined by clinical examination and diagnostic modalities. MRI is traditionally the imaging modality of choice in the evaluation of sports related injuries in the knee. Diagnostic ultrasound has not been utilised extensively to study this anatomic site however, Lee et al. (1996) suggested that the superficial location of the MCL should make the ligament particularly amenable to evaluation by ultrasound (see Figures 9 and 10).

Lee et al. (1996) studied the usefulness of diagnostic ultrasound in both evaluating the presence and location of the MCL injuries and predicting the prognosis of patients. The study utilised 16 patients with the clinical diagnosis of MCL injury and 20 knee joints in 10 subjects who had no history of injury to the knee. Lee et al. (1996) divided the patients into two groups on the basis of the location of the MCL injuries after diagnostic ultrasound to try and predict prognosis. A thickened and heterogeneously hypoechoic appearance of the MCL was considered injured, while a thin and moderately homogeneous hypoechoic band of the MCL was considered normal or minimally injured. Diagnostic ultrasound imaging results were confirmed by means of clinical examination, radiographic valgus stress views and MRI.

The results of Lee et al. (1996) study found that in 15 of the 16 subjects (94%) a correct diagnosis was made with ultrasound, with 1 diagnosis considered a false–positive. The authors stated that 14 injuries were located at the femoral attachment, 5 injuries at the tibial attachment and 6 patients had associated injuries. (i.e. ACL injuries).

Both ultrasound and MRI have advantages and disadvantages in evaluating MCL injuries. Diagnostic ultrasound imaging has the advantage of a high detectability rate in the diagnosis of MCL injury, can demonstrate the exact location of the MCL injury and aid in treatment planning. The major and significant drawback is that the accuracy of the diagnostic ultrasound results is highly dependent on the knowledge and skill of the sonographers.

Figure 9: Normal Medial Collateral Ligament of the Knee.

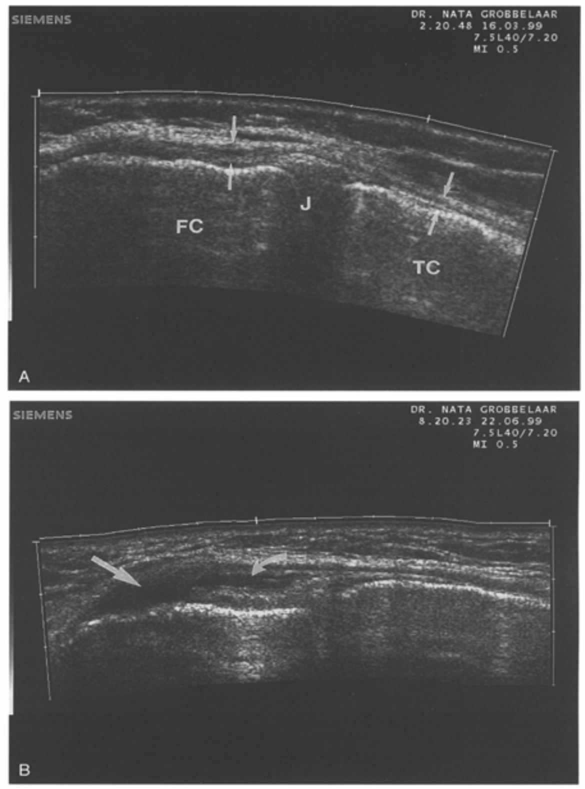


Figure 6–2 ▪ A, Normal femoral and tibial insertion of the medial collateral ligament: extended field-of-view image in the coronal plane. This image of the knee of a 30-year-old man was obtained with the patient in lateral decubitus position and his leg extended. The normal medial collateral ligament can measure up to 9 cm in length. It originates from the most proximal aspect of the medial femoral condyle (*FC*), covers the joint space (*J*), and inserts on the medial tibial condyle (*TC*) several centimeters below the margin of the tibial plateau. The locations for measuring the thickness of the proximal and distal segments of the ligament are noted (*arrowheads*). The proximal segment is measured at the depth of the concavity of the medial femoral condyle. The distal segment is measured at a point halfway between the tibial plateau and the most distal extent of the ligament. Note the trilaminar structure of the MCL, best seen at the site of proximal measurement. (Courtesy of Dr. N. Grobbelaar, private practice, Pretoria, South Africa.) **B,** Abnormal femoral insertion of the medial collateral ligament: extended field-of-view image in the coronal plane. After a fall down some stairs, this 39-year-old man observed his knee swell up rapidly. Pain on the medial aspect of the knee corresponded to the origin of the MCL. The compound image of the MCL shows a tear (*straight arrow*) in the proximal portion of the ligament. Fluid leaks (*curved arrow*) in between the layers of the more distal ligament, which is still intact. Note the significant swelling of the proximal ligament at the site of maximal concavity of the medial femoral condyle, the location at which the ligament is typically measured. (Courtesy of Dr. N. Grobbelaar, private practice, Pretoria, South Africa.)

From (Van Holsbeeck & Introcaso, 2001c).

Lee et al. (1996) concluded that highly skilled sonographers can make a correct diagnosis in all cases, within a few minutes. Diagnostic ultrasound is economical, widely available and pain free for the patient. MRI has excellent soft tissue contrast and independence of observer variability and it is the more accurate method of evaluating MCL injuries, particularly knee injuries which could potentially involve other structures such as the ACL. However MRI is more time consuming, more expensive and less readily available.

Although MRI is the modality of choice when evaluating combined knee injuries, diagnostic ultrasound imaging provides essential information concerning the presence and location of isolated MCL injuries. This information can assist in predicting the outcome, establishing the diagnosis and planning the treatment and rehabilitation of MCL injuries (Lee et al., 1996).

Figure 10: Acute Rupture of the Medial Collateral Ligament.

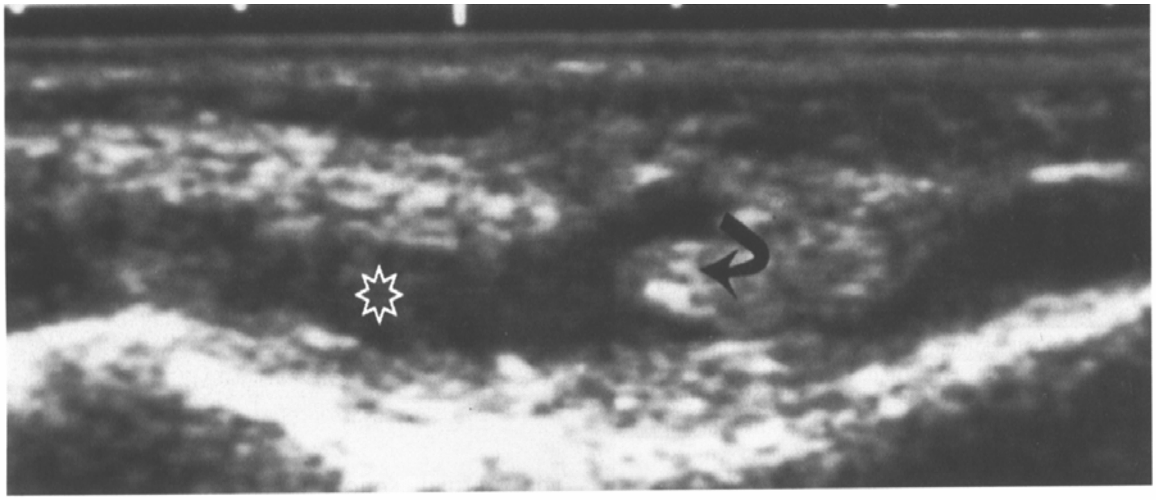


Figure 6–19 ■ Acute rupture of the MCL: detail of the tibial MCL insertion. Same patient as in Figure 6–18. No normal ligament structure is identified. Hematoma (*asterisk*) surrounds a small, retracted fragment of the distal ligament (*curved arrow*). Two weeks after this examination, a physical examination was performed and revealed a grade III MCL tear. Results of the anterior drawer test were also positive, indicating ACL rupture. Results of a MacMurray test indicated a medial meniscal tear. This is a classic triad seen in acute MCL rupture.

From (Van Holsbeeck & Introcaso, 2001c).

Like the MCL and ACL, diagnosis of injury to the ulnar collateral ligament of the thumb has traditionally relied on a thorough clinical examination. Stress testing of the thumb allows the clinician to evaluate the metacarpophangeal joint for an ulnar collateral ligament tear, which is indicated by abnormally increased abduction and/or laxity. The importance of diagnosing a complete tear of the collateral ligament is to determine which patients require surgical intervention.

A complete tear may be missed on clinical examination because the examination requires an experienced examiner who understands how to perform and interpret the stress test. Even with an experienced examiner, the ulnar collateral ligament may be difficult to examine as a result of guarding by the patient due to the pain of the injury. Because of the limitation of the clinical examination, ultrasound imaging like other methods of diagnosing ulnar collateral ligament tears could be useful to avoid missing injuries that require surgical intervention. Ultrasound imaging has been favoured in evaluating the structure of small ligaments and tendons at rest and in motion (Murphey et al., 1997).

Murphey et al. (1997) compared ultrasound stress test evaluation to clinical examination of 25 patients with suspected ulnar collateral ligament injuries of the thumb. Orthopaedic classification of these ligament injuries (GI – GIII) was used to clarify and document the extent of the injuries.

The results of both the ultrasound and clinical examinations were compared with either operative findings or clinical follow up results if conservative treatment was elected. On the basis of both physical examination and diagnostic ultrasound findings, 14 of the 25 patients underwent surgical repair and the remaining 11 patients were treated conservatively**.** The clinical examination identified the correct diagnosis in 24 of the 25 patients, while ultrasound correctly identified the diagnosis in all 25 patients.

Murphey et al. (1997) suggested their study confirms that diagnostic ultrasound is a useful method to identify injury to the ulnar collateral ligament. The authors examined the metacarpophalangeal joint both at rest and with stress testing and compared the ultrasound findings with clinical examination. Other previous papers discussing ultrasound's role in evaluating ligamentous injuries have only used static evaluation of the ligamentous structures (Murphey et al., 1997).

Ultrasound has the advantage of providing more direct evidence of the ulnar collateral ligament position compared with x-ray and clinical examination. However, an x-ray of the thumb may show indirect evidence of an ulnar collateral ligament injury. An avulsion fracture of the ulnar base of the proximal phalanx generally indicates that the ulnar collateral ligament is displaced from the phalanx.

MRI is an excellent method to evaluate injuries of the ulnar collateral ligament, as this modality provides a wide field of view, shows excellent anatomic detail and is less operator dependent. With ultrasound imaging becoming more readily utilised by experienced personnel, it is providing comparable accuracy and is much less expensive than MRI. The authors concluded by indicating that ultrasound is an accurate, low cost method to examine the ulnar collateral ligament of the thumb. Furthermore in patients with difficult clinical examinations, it provides an excellent adjunctive imaging technique to evaluate ulnar collectable ligament injuries with proven validity and reliability.

Familiarity with ultrasound imaging and its expanding clinical use, along with further controlled studies into diagnostic ultrasound's real-time applications, in conjunction with traditional clinical examination could establish ultrasound as an effective method of visualising, diagnosing and helping plan the treatment and rehabilitation of ligament and joint pathologies.

2.6 Nerves.

Nerves are round or flattened cords with a complex internal structure resembling a cable. Their formation consists of nervous fibres, grouped in fascicles composed of axons, myelin sheaths and Schwann cells (Martinoli, Bianchi, & Derchi, 1999).

Ultrasound can accurately visualise, determine pathology and abnormalities of nerve tissue including compressive lesions, traumatic lesions, nerve tumours and more recently establish the measurement of nerve motion (Martinoli et al., 1999). Nerves are well-vascularized structures compared with tendons and impulse transmissions and axonal transport depend on a local continuous energy supply, provided by the interneural microvascular system. The interneural vascular system can be detected with colour and power Doppler in some subjects (Martinoli et al., 1999)

Diagnostic ultrasound depiction of normal nerves primarily depends on both their size and course. Technology is able to visualise the vast majority of the main nerve trunks running in the limbs and extremities, including the median, radial and ulnar nerves, as well as the sciatic, common peroneal and posterior tibial nerves (Hough et al., 2000; Martinoli et al., 1999). Nerves such as the sympathetic chains and cranial nerves are unable to be visualised because of the deep lying course on interposition of bony structures.

Compressive lesions involving nerves may occur at many locations. They are more common at anatomic sites where the nerve passes through osteofibrous tunnels or beneath a prominent or abnormal band of muscle, connective tissue, or bony ridge. These structures may tether the nerve. Diagnostic assessment of nerve compressive syndromes is based on clinical features and electrophysiologic testing. The role of imaging is limited to assess difficult and atypical cases or when a mass is suspected on clinical grounds. Diagnostic ultrasound is also helpful in guiding the aspiration of fluid-filled compressive lesions that cause nerve compression. In nerve entrapment, chronic irritation or compression to the nerve may induce interference with intraneural microvascular supply and an inflammatory reaction, primarily affecting the epineurium.

In compressive syndromes, ultrasound can detect changes in both nerve shape and echotexture. Diffuse flattening or localised constriction of the nerve and associated swelling of the nerve portion proximal to the level of compression are the main findings. The most common sites of nerve entrapment that can be visualised and accurately assessed by diagnostic ultrasound include the carpal tunnel for the median nerve and both the cubital and Guyon's canals for the ulnar nerve in the upper limb, the proximal fibular for the common peroneal nerve, the tarsal tunnel for the posterior tibial nerve and the metatarsal heads for the interdigital nerves in the lower limb (Martinoli et al., 1999; Hough et al., 2000).

Diagnosis of a nerve tumour is based on detection of mass along the course of a nerve in association with clinical and neurologic signs. Neurogenic tumours are intimately related to neurovascular bundle and may be associated with subtle atrophy of the innervated muscle. Ultrasound is reliable in the diagnosis of neural tumours only when the junction between the tumour and the nerve can be imaged (Martinoli et al., 1999; Hashimoto et al., 1999; Jacobson, 1999).

Careful scanning technique by the sonographer is required and can be difficult to establish because as some tumours develop, the periphery of the nerve grow into it. Nerve tumours appear as solid hypoechoic masses however, malignant tumours cannot be differentiated from benign lesions on the basis of echogenicity and the only signs that could make the sonographer suspect malignity is present are indistinct margins and adhesions with the surrounding tissues (Hashimoto et al., 1999).

The mechanism of nerve damage in trauma is multifaceted. Nerve injuries can occur as a consequence of a direct nerve contusion or laceration, following penetrating trauma and are often associated with other musculoskeletal injuries. Nonetheless, less obvious injuries may be referred to as neural stretching or tethering, which often occur in association with repetitive sprain or strain injuries, as well as overuse. Overuse can lead to recurrent microtraumas with either tension or compression of the nerve that may result in a final cumulative trauma. The most important contribution of diagnostic ultrasound imaging however, is related to traumas with interruption of nerve continuity. In these cases, ultrasound imaging is able to image the defect in the nerve, to predict the level of nerve section preoperatively, as well as to assess its integrity and to identify early complications after reconstructive surgery.

Carpal tunnel syndrome is a nerve entrapment disorder in which the median nerve is compressed with the carpal tunnel. Causes for nerve compression include abnormal masses within the carpal tunnel and small size of the carpal tunnel. Both ultrasound and MRI have been used with success in evaluation of the carpal tunnel (Jacobson, 1999). High-resolution sonography is effective in diagnosing carpal tunnel syndrome. Sonographic measurements of median nerve cross-sectional area and flattening ratio correspond well to measurements obtained with MRI (Jacobson, 1999).

With diagnostic ultrasound the normal median nerve can be visualised. Carpal tunnel syndrome is characterised by abnormal enlargement of the median nerve. In cross-section the median nerve is abnormally enlarged if greater than 10mm squared at the level of the distal radius or pisiform bone. In the longitudinal plane, the swollen median nerve becomes compressed as it enters the carpal tunnel beneath the flexor retinaculum. An enlarged median nerve may also appear abnormally hypoechoic in carpal tunnel syndrome. Causes for median nerve compression, such as ganglion cysts and peritendinitis can be demonstrated with both sonography and MRI, although the latter may be superior to ultrasound in identifying mild nerve compression and adjacent processes. Jacobson (1999) concluded by stating both ultrasound and MRI may be considered if the clinical diagnosis of carpal tunnel syndrome is suspected. The authors go further by stating that both imaging methods produce quantitative results in diagnosing carpal tunnel syndrome. The choice of imaging depends on the preference of the individual clinician. Cost and availability again may influence this decision.

2.6.1 Measurement of Neural Motion.

Diagnostic ultrasound has been utilised to measure and quantify longitudinal nerve motion. Nerve movement occurs in the straight leg raise test, during spinal flexion and in upper limb tension testing. Tests which involve the movement or sliding of peripheral nerves are standard manual therapy techniques which have been used for some time (Hough et al., 2000). Musculoskeletal authors theorise that restricted neural movement at one location could lead to increased tension away from the site of compression. These hypotheses have led to the development and use of specific nerve gliding or stretching exercises to reduce adhesions following surgery and the conservative management of these conditions (Hough et al., 2000). However, the inference that longitudinal nerve motion is restricted has yet to be supported with direct evidence. Hough et al. (2000) stated that in the absence of a non-invasive method for measuring longitudinal nerve motion the presence and clinical relevance of restrictions in this mechanism remain speculative.

The measurement of longitudinal motion is more complex than that of the identification of focal lesions and pathologies. A technique termed speckle tracking that enhances the visualisation of dynamic longitudinal nerve motion was developed. This method involved computational recognition of the specific gray scale pattern of a target volume of tissue. This tissue is then subsequently identified in sequential images and the displacement occurring between images can be calculated. The feasibility and limitations of this method for measuring tissue motion, including three dimensional tracking methods continues to be explored (Hough et al., 2000).

Speckle tracking facilities are currently not normally available on standard diagnostic ultrasound apparatus. Hough et al. (2000) described the speckle tracking technique on the excursion of the median nerve and the elbow during wrist extension (bilaterally) in 16 healthy subjects. The technique utilises Doppler and B mode imaging with a split screen. The digital images are exported to a personal computer for measurement using analysis software.

Speckle tracking is still in the developmental stage, however the authors suggested initial reliability results have been encouraging. The application of this technique to other peripheral nerves will depend on the ability to clearly depict the nerves. Transverse motion of the nerves (axial or lateral) can move the nerves outside the Doppler sample volume. This places some constraints on possible scan locations and test movements that can be utilised.

An example of this constraint is in the forearm where the median nerve lies between flexor digitorum profundus and flexor digitorum superficialis. During some wrist movement the nerve moves outside the Doppler sample volume and the surrounding muscle into it. In this event the spectral plot represents the muscles motion, which during wrist and digital movements is typically greater than the nerve movement. The simultaneous B-mode image alerts the sonographer to this.

Hough et al. (2000) realised their study's limitations in equipment, technology and sample sizes nevertheless within these constraints Doppler ultrasound may provide a valuable tool for non-invasive measurement of longitudinal nerve motion.

Investigations of normal nerve dynamics, comparisons of these characteristics between patients and healthy populations and evaluating the effects of therapeutic intervention have been proposed. In neurodynamic studies, the technique could be augmented by B-mode measurement of cross-sectional characteristics that may indicate changes in intraneural tension and by concurrent goniometry, which would provide information on the timing of nerve movement. There is also the potential for developing diagnostic techniques if abnormal nerve motion characteristics can be identified.

Finally Hough et al. (2000) indicated further possibilities for research could be to investigate the ratio of nerve excursion compared with adjacent moving structures and in studies of entrapment syndromes. Diagnostic ultrasound within this application could have a huge impact of neural dynamic theories verifying aspects of neurodynamic theory and practice and ultimately treatment techniques and rehabilitation management.

2.7 Diagnostic Ultrasound and its role within a Physiotherapy Setting.

2.7.1 Introduction.

Within a specific physiotherapy setting the functional and clinical use of diagnostic ultrasound has been promoted and advocated by several authors. This has been exemplified by numerous publications, papers and research by Julie Hides and fellow researchers throughout the 1990's.

This team of researchers have developed, refined and are justifying the clinical role of ultrasound imaging within musculoskeletal medicine. The methodology of their papers is of a high standard. The vast majority of this section of this paper utilises these commendable studies in the review of the literature.

2.7.2 Biofeedback.

Hides et al. (1998) and Stokes et al. (1997) in their review papers on ultrasound imaging for feedback described a number of potential clinical uses. Research into muscle deterioration in patients with lumbar spine pain has identified that there is impairment in specific muscles, such as the transversus abdominis and the multifidus. Research has evaluated the efficiency of specific rehabilitation exercises that focus on co-activation of these deep muscles. Evidence has suggested that it is important to target these deep muscles specifically in rehabilitation and ensure they can be activated separately from other trunk muscles (Hodges & Richardson, 1997; Hides, Cooper, & Stokes, 1992).

Exercise needs to be very precise as the unaffected parts of the multifidus muscle and other muscles such as the thoracic components of the erector spinae and rectus abdominis could more easily be activated when rehabilitation exercises are initiated. If separate control of the transversus muscle is lost a generalised activation of more superficial abdominal muscles will ensue. Care and precision with facilitation is required (Hides et al., 1992; Hides et al., 1998).

At present transversus abdominis is tested in the clinical situation via assessment of its action of drawing in the abdominal wall. This action is performed principally by the transversus abdominis and can be described as a corset-like action. An indirect method of quantification of the action presently used is with use of the pressure biofeedback unit and testing in the prone position (Hides, Richardson, et al., 1995).

If the patient is unable to complete a specific muscle action, the attempt is evaluated by the physiotherapist through observation of the abdominal wall and palpation of the lower abdominal region for a deep tensioning of muscle fibres. If the muscles such as obliquus abdominis externus are overactive, these can be monitored by surface EMG. The clinical evaluation of multifidus is through palpation of muscle size and consistency of activation. To assess multifidus activation in line with its stability role the segmental multifidus is palpated as the patient attempts a slow, gentle and subtle isometric contraction. Clinical skill is required to interpret the different strategies adopted by low back pain patients who have trouble activating the multifidus appropriately. Surface EMG is not very useful for providing feedback from the multifidus due to its depth and "cross-talk" from other muscles (Hides et al., 1998).

These methods are presently used clinically with much success however, there is the drawback that the muscles are deep and therefore assessment strategies are to some extent indirect. Real-time ultrasound imaging is potentially a beneficial modality as it allows immediate visualisation of contraction of the deep muscles such as the transversus abdominis and the multifidus. It is non-invasive and could be useful for both assessment and facilitation of these muscles.

The use of diagnostic ultrasound imaging as a biofeedback tool is an appealing application of real-time ultrasound imaging in rehabilitation. An ability to visualise the contraction of deep muscles and in conjunction with the more superficial overlying muscles allows the physiotherapist to assess and problem and provide the appropriate rehabilitation. Ultrasound can assist to facilitate and provide evidence of the effectiveness of a therapist's strategies in rehabilitation. The non-invasiveness of ultrasound, user friendliness and speed and ease of application are all positive features (Hides et al., 1998).

Clinicians and physiotherapists are now focusing on the deep muscles that protect and support joints. Real-time ultrasound imaging could prospectively be used to assist assessment and facilitation of various deep muscles of the body, including those of peripheral joints. There are several artefacts that can occur while imaging and collaborative work between sonographers and physiotherapists when exploring new muscles areas is ideal. Also, due to the varying mechanics and orientation of muscle fascicles in different muscles, individual muscles will appear differently when imaging when they contract. Hides et al. (1998) and Stokes et al. (1997) excellent papers have suggested that some deeper muscles could be inaccessible with ultrasound and for others acoustic windows may be found. For optimal benefit from imaging to be gained in rehabilitation for observing deep muscles, research into the best sites and techniques is first required (Hides et al., 1998).

Ultrasound is an imaging modality that has a great potential in a rehabilitation setting. Diagnostic ultrasound imaging can assess the facilitation and activation of various muscle patterns, which can clinically be difficult to assess. These imaging techniques can be utilised by patients for feedback when integrating muscle activation functionally, via motor learning exercise techniques.

For the use of ultrasound in physiotherapy clinics and rehabilitation settings the main emphasis must be on ultrasound imaging being an adjunct to assessment and treatment with good clinical skills remaining of significant importance. Diagnostic ultrasound has a huge potential to aid the physiotherapy profession with the measurement of muscle activation and in feedback in a rehabilitation setting (Hides et al., 1998; Stokes et al., 1997).

2.7.3 Measurement of Muscle Size and Action.

Lumbar spine pain is a major problem in medicine and effective management of disorders affecting the lumbar spine can be improved by objective assessments and imaging to achieve accurate diagnosis (Beattie, 1996). Lumbar spine pain can be associated with muscle atrophy and weakness, which could lead to instability and muscle damage. Trunk muscles are important for the stability of the vertebral column. It is not possible to isolate the individual paravertebral muscles for strength testing and it is therefore useful to measure muscle size using diagnostic imaging techniques such as CT, MRI or ultrasound to establish muscular strength (Hides et al., 1992; Hides, Jull, & Richardson, 1996).

Hides et al. (1992) utilised ultrasound imaging to assess its feasibility to measure the lumbar multifidus muscle. Cross-sectional and linear measurements were examined for repeatability, with the aims of the researchers to then examine the symmetry of the size and shape of the multifidus muscle and to determine the correlation between cross-sectional area and linear measurements and cross-sectional area and anthropometric measures.

Healthy subjects (N=48) were subjected to ultrasound examination. The subject lay prone on a plinth with the head in the midline position. The lumbar spine level was determined via palpation of the spine and the ultrasound transducer was placed transversely over the spinous process.

A satisfactory image of the multifidus was obtained and an electronic on-screen calliper was used to trace round the muscle border giving an immediate readout of the muscle cross-sectional area. Two linear measurements were also made and these were defined as the greatest distance from border to border and then the greatest distance perpendicular to this. These dimensions were in the lateral and anterior-posterior directions.

The multifidus muscle differed between males and females and the two linear dimensions or measurements of the cross-section were closely correlated with cross-sectional area in all subjects, but this relationship needs to be determined in wasted muscles where changes in shape may occur. The authors results were subjected to statistical analysis and deemed repeatable.

Hides et al. (1992) concluded that their study was able to demonstrate that the use of real-time ultrasound to measure the multifidus muscle of subjects is feasible in the clinical assessment of muscle wasting. Repeatability was acceptable and normal symmetry was characterised for multifidus muscle size and shape.

The high correlations between cross-sectional area and linear measurements found in both groups validates the use of linear dimensions for predicting cross-sectional area in this particular muscle when it is not wasted. The establishment of a reference range of muscle size requires that size correlates with another parameter. Muscle size correlates with muscle strength in limb muscles but is not possible to isolate and individually test the strength of the back muscles. For this reason, anthropometric measurements and internal measures from the scan, such as spinal structures used for MRI scans can be used. With real-time scanning however, the field of view is too small to include other structures other than the multifidus muscle itself in one scan. The lack of correlation between multifidus cross-sectional area and body mass index may be due to the narrow range of values produced by the body mass index calculation. The positive correlations between cross-sectional area and body dimensions among the males in the present study allow estimation of cross-sectional area at the L4 level from these anthropometric measures (Hides et al., 1992).

The multifidus shape ratios reported in this study relate only to the prone position. Gravity will affect muscle shape, which is different in CT and MRI scanning where the patient lies supine. The fact that the combined linear measurements were highly correlated with multifidus cross-sectional area has clinical implications, since linear measurements could be made rapidly in the clinic. However, this relationship still needs to be examined in wasted muscles and data from larger numbers of normal subjects in different age groups are required to provide reference ranges.

Unilateral or bilateral wasting of para-spinal muscles can be localised to one vertebral level in patients with lumbar spine pain both acutely, chronically and postoperatively (Hides et al., 1995; Hides, Jull, & Richardson, 2001). These authors investigated the measurement of the multifidus muscle using real-time ultrasound and MRI to establish the validity of the ultrasound technique utilised by Hides et al. (1992).

Diagnostic ultrasound scanning of 10 subjects was performed utilising the excellent methodology described by Hides et al. (1992). MRI testing was conducted with the muscle cross-sectional area being measured using on screen callipers, similar to the ultrasound imaging methodology.

"The ultrasound and MRI examinations were performed by independent radiographers who were blinded to the others results. Measurement of para-spinal muscles using ultrasound imaging and MRI was challenging not only because of the inherent differences between the two modalities, but also because the subjects were placed in contrasting positions (prone for ultrasound and supine for MRI). Because joint position and muscle length may have influenced cross-sectional area values of the muscles, every attempt was made to standardise the position for imaging within the prescribed constraints of the two modalities. Furthermore, every effort was made to ensure that subjects were placed in a comfortable position for both methods of imaging, because muscle contraction influences cross-sectional area measurements" (Hides et al., 1995).

"Accurate location of the imaging site was essential because of the pathology of the multifidus in the longitudinal section, necessitating accurate location of the facet joint/ lamina landmark for ultrasound and the facet joint for MRI. Location of the vertebral levels was accomplished on MRI using the pilot scan. For diagnostic ultrasound, manual location of bony landmarks was the method used. The results demonstrated a significant difference in cross-sectional area between each vertebral level, but no significant difference between the two modalities used and it was confirmed that vertebral levels were located accurately in both examinations" (Hides et al., 1995).

MRI produces excellent soft tissue contrast and demonstrates soft tissue anatomy. This makes MRI superior to diagnostic ultrasound. This study demonstrated that if a strict protocol is followed, the multifidus size of young normal adults can however be determined just as accurately using ultrasound, which is less expensive and more accessible for clinical research. However, these results cannot be compared directly to all populations. Other studies utilising MRI and CT scanning have demonstrated fatty infiltration in the erector spinae group of older normal subjects and older patients with chronic low back pain (Hultman, Nordin, Saraste, & Ohlsen, 1993; Parkkola & Kormano, 1992). A significant difference in cross-sectional area between normal subjects and the patients was not detected however, a significant difference in radiologic density was detected. Because these changes may be difficult to quantitate using ultrasound, further comparative studies are needed to demonstrate the accuracy of ultrasound with MRI before this technique can be readily adopted for assessing patients (Hides et al., 1995).

Real-time ultrasound improves compliance in learning muscle contraction and function. As further research is presented, it will prove ultrasound's validity within the role of measurement of muscle size and action. The studies of Hides, et al.,(2001) and Hides, et al., (1996) have demonstrated the potential for ultrasound in obtaining accurate measurements of muscle size and action and their reflective merits comparable to traditional imaging techniques such as MRI.

2.7.4 Electrode Placement.

Numerous papers have demonstrated that ultrasound is an effective and accurate tool in the location of foreign metallic bodies (Frankel et al., 1998; Van Holsbeeck & Introcaso 2001a). Hodges & Richardson (1997) evaluated the sequence of activation of the abdominal muscles and multifidus muscles during the performance of hip movement following prior weight shift over the supporting limb. The authors utilised EMG activity that was recorded from the transversus abdominis muscle, the internal and external oblique muscles and the posterior fibres of gluteus medius muscle using bipolar fine wire electrodes. The electrodes were threaded into hypodermic needles and inserted under the guidance of real-time ultrasound to confirm the accuracy of needle placement.

Hodges & Richardson (1997) suggested the anatomy of the rectus abdominis muscle, transversus abdominis muscle, internal and external oblique muscles and associated muscle anatomy is complex and highly alike. Clinicians often have difficulty differentiating between these anatomical structures and surface electrode information is often inaccurate and unreliable due to the uncertainty of electrode placement.

Electrode placement was checked by ultrasound visualisation of movement of the wire during gentle traction and through monitoring the EMG trace during performance of a series of manoeuvres designed to preferentially activate each of the aforementioned muscles. The authors were satisfied that the electrodes were accurately inserted and were able to precisely evaluate the sequence of muscle activation during movement.

2.7.5 Measurement of Joint Laxity.

The current interest in the mechanics of the sacroiliac joint (SIJ), specifically its stability and its relationship to low back pain requires the need for a reliable measurement to test SIJ laxity. Clinical testing has shown that existing tests to assess SIJ laxity do not have sufficient objectivity and reproducibility. Studies have investigated the use of ultrasound imaging in determining the laxity of the SIJ in relation to low back pain and muscle activity (Richardson et al., 2002; Damen, Stijnen, Roebroeck, Snijders, & Stam, 2002).

Damen et al. (2002) developed a non-invasive technique to measure SIJ laxity using low intensity vibrations and colour Doppler imaging. The authors termed this technique, Doppler imaging of vibrations (DIV), which produced laxity values of the SIJ. Very small amplitudes of vibrations far below the physiologic range of joint motion were produced and the authors were able to measure the amount of laxity SIJ. The DIV technique was validated based on the work of measurements performed on a metal and plastic pelvis model and on embalmed human pelves (Buyruk, Stam, Snijders, Lameris, Holland, & Stijnen, 1999). Damen et al. (2002) investigated the reliability of the DIV technique in assessing SIJ measurements. A total of 10 volunteers and 5 “testers” were utilised.

Vibrations were applied unilaterally to the anterior superior iliac spine and generated by a vibrator and power amplifier. The vibrations propagated in the pelvis through the ilium to the SIJ and were measured with colour Doppler imaging. The intensity of vibration of the ilium and sacrum appears simultaneously on the monitor at high threshold values. Firstly, a threshold level was read from the monitor at which the colour of the vibrating scarum disappears and changes to gray scale. Next, a second threshold level is found for the ilium. The difference in threshold levels is expressed in threshold units. Because the threshold levels as measured by DIV are directly related to the vibration amplitude of the bone, a small or absent difference between the threshold levels of the sacrum and ilium is accepted as an indication of a stiff joint. A large difference between threshold levels of the sacrum and ilium indicated a loose joint (Damen et al., 2002).

After being trained five testers performed the measurements. Only one tester was experienced all the others were inexperienced. The results from the study showed some interesting measurements and trends. To obtain accurate SIJ laxity measurements that are reliable a minimum of three repetitions was recommended during one test occasion by an experienced tester. Some variation between occasions might be inevitable, despite strict standardisation of the measurements. The results from this study indicate that specific training and experience of a tester are necessary for reliable SIJ laxity measurements. The DIV method is a promising test from both clinical and research viewpoints. The device is non-invasive and suitable for repeated measurements even during pregnancy. It might present a means for the early diagnosis of pregnancy related pelvic pain and for monitoring SIJ laxity response to therapy. It remains to be determined, however if these recommendations hold true for different patient groups.

Damen et al. (2002) stated that the laxity of the SIJ could be determined via vibrations from a mechanical vibrator that were applied unilaterally to the anterior superior iliac spine of the subjects in prone positions. The vertical vibrations propagated in the ilium up to and beyond the SIJ area. At the dorsal side the vibrations of the ilium and adjacent sacrum were picked up by a colour Doppler imaging transducer, which covered both sides of the SIJ. Coloured pixels resulting from vibration of the sacrum and ilium appeared simultaneously on the monitor at high threshold values. The authors found a threshold at which the colour Doppler image of the vibrating sacrum disappeared and changed to gray scale. A further threshold value was calculated for the ilium.

The threshold value was directly related to the vibration velocity of bone. A difference of vibration velocity was indicated by a difference between threshold values of the ilium and sacrum. A large difference indicated a lax joint and a small difference indicated a stiff joint. These values cannot at present be determined *in vivo* non-invasively (Damen et al., 2002).

Richardson et al. (2002) also utilised this methodology to help investigate the claim that the activation of multifidus, transversus abdominis and the internal and external oblique muscles help spinal stability and mechanical control of the pelvis and lumbar spine. The objective of the study was to demonstrate the biomechanical effect of two abdominal muscle patterns on exercises, which have been utilised in controlling lumbar spine pain. A biomechanical model and mechanism of action was described by the authors in which specific exercises influence stability of the SIJ, lumbar spine and pelvic joints. Two abdominal patterns that subjects utilise clinically were tested and their effects compared in relation to SIJ laxity. One pattern was contraction of the transversus abdominis muscle independently of the other abdominals and the other pattern was a bracing action that used all the abdominal muscles. Real-time ultrasound imaging of the anterolateral abdominal wall was performed, on 13 subjects and surface EMG to record these two separate abdominal muscle patterns was utilised.

The first pattern was the draw in pattern, which was a specific contraction of the transversus abdominis muscle, involving the subject drawing in the abdominal wall. Ultrasound imaging of a relaxed abdominal wall and during an in drawing of the abdominal wall demonstrated a contraction of the transversus muscle. Ultrasound images of the relaxed state then contracted state which were taken at the same time as the SIJ laxity measures, verified the changes in shape of the transversus occurring during the specific abdominal pattern. The brace pattern was a general contraction of all abdominal muscles, involving the individual performing an isometric bracing action. Ultrasound imaging of a relaxed abdominal wall and during a brace of the abdominal wall demonstrated contractions of all the abdominal muscles and images were obtained that verified the changes in shape of the individual abdominal muscles occurring during the abdominal bracing pattern.

Results of the study showed that contraction of the transversus abdominis muscle (in co-contraction with the multifidus and pelvic floor muscles) stiffened the SIJ significantly more than the brace contraction. This study demonstrated that the measurement technique was sufficiently sensitive to detect SIJ laxity changes as a result of muscle contractions. Reproducibility of the repeated tests was satisfactory. The study produced additional biomechanical evidence of the important role of the transversus abdominis muscle in the stabilisation of the lumbar region via the use of real-time ultrasound/ vibration technique.

Richardson et al. (2002) concluded that real-time imaging to calculate joint laxity and surface EMG provided objective means of verifying the resultant muscle patterns. This innovative study supported the argument for lumbar spine exercise treatments to focus on enhancing the stabilisation role of the transversus abdominis muscle by precise self bracing contractions, independently of the other abdominal muscles, rather than generalised exercise programmes.

Richardson et al. (2002) and Damen et al. (2002) results and methodology have provided opportunities for clinicians to assess and monitor SIJ laxity, allowing information to be gathered with relevance to stability, muscular control, strength and function, all key factors in rehabilitation programmes.

2.8 Diagnostic Ultrasound as a Measurement Tool in Vertebrobasilar Insufficiency.

The term vertebrobasilar insufficiency (VBI) is used when neurologic manifestations suggest insufficient blood flow in portions of the brain supplied by the vertebral arteries (VA) and basilar artery (the brain stem, the cerebellum and the posterior portion of the cerebral hemispheres). If the symptoms are transitory, the condition may be called transient vertebrobasilar ischemia. If the neurologic signs or symptoms are permanent, the term vertebrobasilar stroke is used (Rivett et al., 1998; Zwiebel, 2000).

VBI is not defined by a specific set of neurologic signs or symptoms. Atherosclerosis is the primary cause of VBI. The mechanism by which atherosclerosis generates VBI symptoms is unclear. Atherosclerotic stenosis or occlusion occurs primarily at the VA origin. The second most common site of atherosclerotic obstruction is intracranial, just beyond the C1 vertebral arch. Less commonly and with increasing age, plaque develops more diffusely at the vertebral transverse foramen, in the intracranial segments of the VA and basilar artery, or in the intracranial branches of these vessels (Zwiebel, 2000). Although atherosclerosis is the underlying cause of VBI in many cases, the exact pathogenesis is varied and is often uncertain.

Potential causes of VBI according to Zwiebel (2000) include the following; embolization, atherosclerotic obstruction of small intracranial branches, vertebrobasilar occlusive disease, usually coupled with carotid artery occlusive disease, vertebrobasilar ectasia, cardiac dysrhythmia, artery to artery steal syndromes and vertebral artery impingement (related to large cervical osteophytes).

Because the potential sources of VBI are varied, comprehensive imaging assessment of the vertebrobasilar circulation is required. Arteriography and magnetic resonance angiography are the most imaging procedures broadly recommended for comprehensive assessment of the vertebral basilar system. The combination of duplex sonography and transcranial Doppler imaging can provide a "picture" of the status of the vertebrobasilar system, but this "picture" is still quite limited as compared with MRI or angiography (Zwiebel, 2000).

VBI symptoms can be attributed to passive therapeutic manoeuvres applied to the cervical spine, by chiropractors, physiotherapists, osteopaths and medical clinicians (Rivett et al., 1998; Rivett et al., 1999; Terenzi & Di Fabio,1996). The most frequent cause of trauma from these passive cervical therapeutic manoeuvres, such as cervical manipulation and mobilisation, is trauma to the vertebral artery and on a smaller scale in the internal carotid artery. Surveys of the chiropractic, physiotherapy and other medical professions literature estimate that an "adverse reaction" to a cervical therapeutic manoeuvre, ranges from less than 1 incident in 75000 to 1 in 13 million (Rivett et al., 1998).

Despite the infrequency of neurovascular complications, their potentially serious nature has led to the development of pre-manipulative screening and testing to minimise the incidence of VBI symptoms or accidents in those patients at risk.

The current literature is inconclusive as to whether these pre-manipulative screening, testing or protocols are validate or proven reliable. Doppler ultrasound has recently been utilised to develop a more complete understanding of extracranial arterial blood flow and to determine the validity or pre-manipulative tests. (Haynes, 1996; Rivett et al., 1998). Terenzi & Di Fabio (1996) suggested Doppler sonography may be used to enhance the sensitivity of the screening procedure in patients with elevated vascular risk profiles.

Studies by Terenzi & Di Fabio (1996), Rivett et al. (1999) and Haynes (1996) have utilised similar techniques and equipment to establish, sample and quantify cerebrovascular and vertebrobasilar blood flow. The Doppler ultrasound apparatus records the analogue waveform, direction of blood flow, the depth of the sample obtained and peak systolic velocity. The diastolic velocity is obtained from the analogue waveform. Pulsatility index and mean flow velocity arc are then calculated by a computer. These samples are obtained by the recording of pulsed sound waves that have been emitted by the Doppler probe and deflected back by electrodes. The probe samples from a target region are termed the sample volume. The conglomerate of Doppler shifts is converted into an analogue waveform.

Rivett et al. (1998) supported the reliability of premanipulative testing, due to Doppler ultrasound findings of significant changes in flow velocity of the VA with the end range positions of the cervical spine obtained with therapeutic manoeuvres. Haynes (1996) study found that VA Doppler signals from patients were greatly decreased or extinguished during cervical rotation and Terenzi & Di Fabio (1996) indicated that Doppler procedures provide accurate haemo-dynamic data pertaining to intra-arterial vertebrobasilar stenosis and extra-arterial mechanical compression of the vertebral arteries, during cervical spine positional testing. All three studies utilised Doppler ultrasound to provide essential information for clinicians with regards to cervical spine therapeutic manoeuvres on VBI symptoms.

There is strong evidence that Doppler ultrasound is an effective, accurate non-invasive modality that has been proven to be a clinically useful tool in diagnosing a wide spectrum of disease within extracranial arterial blood flow (Terenzi & Di Fabio, 1996; Haynes, 1996; Rivett et al., 1999; Zwiebel 2000). Terenzi & Di Fabio (1996) stated that cerebrovascular atherogenic stenosis and mechanical compression of the vertebral arteries must be considered in the differential diagnosis of patients with VBI. Until recently diagnosis of these conditions largely relied on invasive angiographic procedures that provided only anatomical information.

Doppler ultrasound indicates vertebrobasilar haemodynamics and provides a unique opportunity to correlate vertebrobasilar symptomatology with physiological data. Zwiebel (2000) summarised by suggesting that arteriography and MR angiography can still provide essential information with regards to vertebrobasilar haemodynamics within a premanipulative screening situation. Doppler ultrasound has been shown competent in helping clinicians to further develop safe effective testing and treatment procedures with regards to cervical therapeutic manoeuvres.

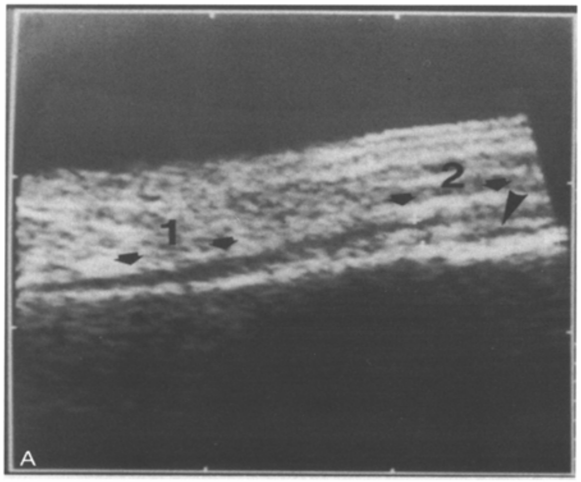
2.9 Diagnostic Ultrasound of Bone.

The clinical role of diagnostic ultrasound extends to the examination of bone. Bone is susceptible to pathology and trauma and ultrasound imaging has an increasing role to play in the diagnosis, monitoring and as a research tool with regards to bone.

The bone soft tissue interface is highly reflective, seen as a bright line with acoustic shadowing deep to the interface. The inability to image the medullary cavity of the bone using pulse-echo ultrasound has led to the misconception that it is not well suited for the evaluation of bone. However, the high reflectivity of cortical bone and the tomographic nature of diagnostic ultrasound imaging make it ideal for evaluation of bony contours (Van Holsbeeck & Introcaso, 2001e). In all musculoskeletal ultrasound examinations, the identification of grooves, fossae, tuberosities, trochanters and epicondyles guides the clinician in their examination. Clinicians, for example, can distinguish the subscapularis and supraspinatus tendons of the rotator cuff by identification of the bicipital groove. Pathological changes in the bony contours are equally well recognised. Marginal erosions and synovial inclusions found in rheumatoid disease are more easily seen on ultrasound than with conventional x-ray (Van Holsbeeck & Introcaso, 2001e).

An example where ultrasound imaging is clinically superior to x-ray examination is in the evaluation of joints. Disruption of the pubic symphysis is a relatively common injury in soccer players due to torsional stress induced while forcefully kicking. The ensuing pelvic pain is usually investigated with plain x-ray, which is invariably unremarkable. Real-time ultrasound imaging quickly and easily demonstrates the abnormal movement. Subluxation can be noted on ultrasound examination at the acromioclavicular, radioulnar and tibiofibular joints. Some of those subluxations may be intermittent or difficult to diagnose secondary to problems with x-ray projection. Ultrasound imaging can be successfully used to diagnose dislocations because the relationships of structures can be evaluated in real time. Comparison with the uninjured side can also be obtained quite easily. Stress can be applied to demonstrate instability, if this is clinically suspected (Allen & Wilson, 1999).

Figure 11: Stress Fracture Distal Tibia.



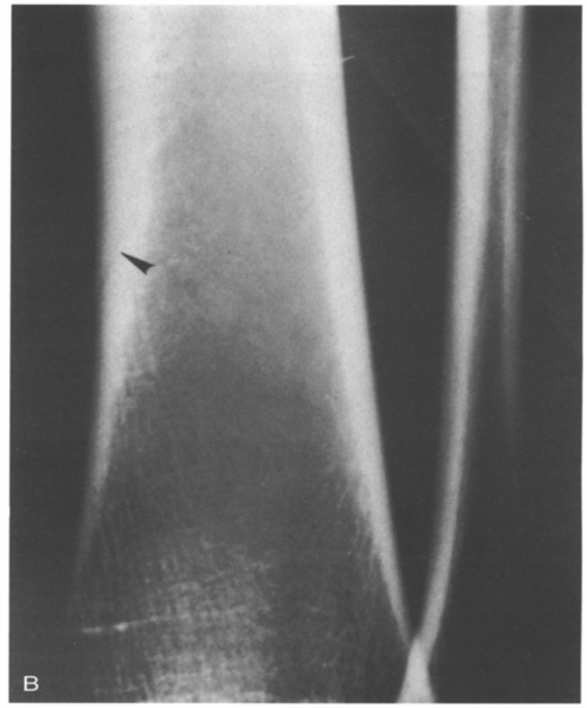


Figure 10–17 ▪ **A,** Stress fracture distal tibia: longitudinal sonogram. A 19-year-old woman who attempted to run in a marathon with little prior training. She experienced persistent pain over the distal tibia and presented 5 days after the race for evaluation. Convertional radiographs were normal. Sonography was performed because of the strong suspicion of stress fracture. The transducer was positioned over the point of maximal tenderness along the medial aspect of the distal tibia. Periosteal thickening (*arrows*) and a reaction (*arrowhead*) are observed, more prominent distally. The number *1* indicates the edge of the periosteal reaction, and the number *2* indicates the center. **B,** Stress fracture distal tibia: anteroposterior radiograph. Same patient as in **A** 8 days after injury. A tiny cortical discontinuity (*arrowhead*) is identified in the medial cortex of the distal tibia in the region of abnormality observed with ultrasound. This was not evident on the prior radiographic examination. Stress fractures in the tibia are usually oblique, making differentiation from vascular canals difficult.

From (Van Holsbeeck & Introcaso, 2001e).

Fractures that are occult on conventional x-ray can often be detected with diagnostic ultrasound (see Figure 11). Unsuspected fracture findings are quite common in shoulder, foot and ankle examinations. Impingement in the subacromial space may be due to subacute fractures of the greater tuberosity. Greater tuberosity fractures often go unnoticed on x-ray if they are only minimally displaced. Callus formation then contributes to narrowing of the subacromial space and the patient presents with symptoms of a torn rotator cuff (Van Holsbeeck & Introcaso, 2001e).

A number of recent studies have utilised ultrasound on bony structures. Luisetto, Camozzi, & De Terlizzi (2000) completed a preliminary study to determine whether diagnostic ultrasound was able to differentiate osteomalacia from osteoporosis. The basis for differentiation was made using different patterns of graphic trace. Luisetto et al. (2000) suggested ultrasound technology is widely utilised in the diagnosis of metabolic bone disease and can predict fracture risk in postmenopausal women. The authors decided to utilise diagnostic ultrasound techniques to differentiate qualitative alterations of bones with the same mineral content. Normal bone can be differentiated from osteomalacial bone by measuring the speed of sound at a well defined point of the graphic trace, that is the lowest point of the graphic trace before it reaches a predetermined amplitude value. This finding suggests that an analysis of the graphic trace could be used to identify alterations in bone quality such as osteomalacia.

Three patients with osteomalacia and three with osteoporosis were studied. The velocity of the diagnostic ultrasound beam in bone was measured at the proximal phalanges of the hands in all subjects. The ultrasound beam velocity was measured when the first peak of the waveform reached a predetermined minimum amplitude value, as well as at the lowest point prior to the 1^{st} and 2^{nd} peaks, before they reached the predetermined minimum amplitude value. Results from Luisetto et al. (2000) study showed that the 1^{st} and 2^{nd} minimum speeds of sound were significantly lower in the subjects with osteomalacia than osteoporosis. Utilising statistical analysis, Luisetto et al. (2000) concluded that osteomalacial bone propagates a broader frequency range than does osteoporotic bone and the findings show that then speed of sound tracing, which is independent of amplitude may allow differentiation of osteomalacia from osteoporosis.

Diagnostic ultrasound imaging is a promising non-invasive method that could be used to differentiate osteoporosis from osteomalacia, but Luisetto et al. (2000) suggested further studies should be carried out before this aforementioned method or technique can be introduced into clinical practice.

Often plain x-rays do not reveal the presence of all bony injuries and often evidence of subtle fractures is overlooked. Clinicians use subjective history, objective history and plain x-rays to determine a fracture. Inflammation, the acute presentation of patients and the overlapping bony anatomy of the foot and ankle can lead to oversights and failure to recognise subtle fracture patterns (Wang, Shieh, Wang, & Hsieh, 1999).

A study by Wang, Shieh, et al. (1999) aimed to determine whether ultrasound could aid in the diagnosis of radiographically occult fractures in the foot and ankle. The authors examined 268 patients with foot and ankle injuries whose initial plain x-ray films were negative for fractures. The study was a retrospective one using an ultrasound database at a particular medial facility to identify patients who had been diagnosed as having a fracture of the foot or ankle. All the patients had symptoms of pain, swelling and tenderness in the foot and ankle area. All the patients underwent x-ray examinations before diagnostic ultrasound, but no fractures had been detected by clinicians or on x-ray.

Following ultrasound, 24 patients were diagnosed with fractures, at various locations in the foot and ankle. Wang, Shieh, et al. (1999) described the location and type of fractures present. Most patients with ankle or foot injuries undergo x-ray to rule out fracture however, the percentage of x-rays that are positive for fractures is very low, typically less than 15%. X-ray is still the desired method of choice for the detection of bone fractures however, ultrasound examination of the bone contour for fracture may be worthwhile when painful swelling adjacent to the bone is present. Bone is a natural obstacle to the transmission of sound at high frequency. The large difference in acoustic impedance between soft tissue and bone results in the formation of a very acoustic interface at their junction. The consequence is the almost total reflection of sound energy from the bone boundary. Ultrasound was used when x-ray failed to reveal fractures. Despite its inability to image through cortical bone and its operator dependence, ultrasound imaging can provide important information about soft tissue and cortical structure injuries in the foot and ankle area (Wang, Shieh, et al., 1999).

Diagnostic ultrasound imaging is a readily available, non-invasive imaging technique in which difficult, clinically suspected fractures can be visualised and costly procedures such as MRI, bone scan and CT (utilised to diagnose suspected fractures when plain x-rays are negative) can be avoided.

Early bone formation is closely associated with vascular invasion and Caruso, Lagella, Derchi, Iovane, & Sanfilippo (2000) suggested the use of colour Doppler imaging as a means to monitor the first stages of fracture callus formation. Histologic studies indicate that one of the earliest changes during new bone formation is the development of small blood vessels. The capillaries surrounding the fracture site show signs of neoangiogensis, which is accompanied by osteoblast proliferation in the first week after bone fracture. This process may be identified on gray scale ultrasound about three weeks after bone fracture. While conventional x-ray cannot visualise the repair process until 30–40 days after the trauma, colour Doppler has an obvious advantage over gray scale ultrasound and plain x-ray for early detection of callus formation or in the detection of delayed fracture healing (Caruso et al., 2000).

Monitoring of new bone formation, post trauma (external fixation) and in bone lengthening procedures is important clinically to guide the clinician with progress and to plan the patient's management. Using colour Doppler ultrasound Caruso et al. (2000) monitored 20 patients with tibial fractures with external fixation. They were assessed after surgery, then at 25 day intervals until plain x-rays demonstrated consolidation. The results showed 18 patients had a well developed callus, while the remaining 2 patients showed delayed fracture healing. In patients with normal callus development, colour Doppler imaging demonstrated the progressive formation of new vessels until about 100 days from surgery. Flow signals decreased and bone remodelling was confirmed by conventional x-ray, gray scale ultrasound and subsequent examinations. The resistance indices in these patients tended to decrease in the early weeks after surgery and then slightly increased. In contrast, the lack of development of flow signals and persistence of high resistance indices were observed in the 2 patients with delayed fracture healing.

Caruso et al. (2000) state that because ultrasound imaging can show early evidence of callus formation at fracture sites, it is suitable for follow up of both traumatic lesions treated with external fixation and bone lengthening procedures. Although often subjective and operator dependent, diagnostic ultrasound can provide an early guide to variations in the flexibility of the external fixation-bone complex and better determination of the adjustment rate for corticectomy lengthening.

Two main vascular phenomena occur after a bone fracture. First at the time of the trauma, the normal blood supply to the fracture site is disrupted, with formation of a haematoma. Then blood vessels rapidly reach this site, coming both from the peripheral soft tissue to the periosteal portion of the callus and from the medullary circulation to the endosted callus. Histologically, newly formed capillaries can be recognised as early as seven days after the fracture and many vessels are seen at nine days. Bone formation following a fracture is closely associated with proliferation of vascular structures hence, the use of Doppler techniques as an adjunct to gray scale ultrasound has been advocated. Colour Doppler techniques have been proven to demonstrate the presence and characteristics of the revascularisation and used to monitor the formation of new vessels during callus development.

Caruso et al. (2000) concluded that assessment using colour Doppler technique can predict, on the basis of poor or absent vascularisation at the fracture site, at about 25–30 days after surgery, whether healing is normal or delayed. Early demonstration of delayed healing can help guide treatment changes, such as variation in the flexibility of the external fixation-bone complex. Additional studies are needed to show whether colour Doppler imaging can demonstrate the return of vascularisation after changes in the rehabilitation and whether patient outcome is affected by the use of this technique in this field. Plain x-ray still remains the primary technique for evaluating callus formation.

Gray scale and colour Doppler ultrasound have both been used in assessment and follow up of bone healing. Ultrasound imaging can be used to focus on the healing of tibial fractures because of the tibia’s limited blood supply and frequent complications of its healing process. Blood vessels are observed on diagnostic ultrasound in the granulation tissue as early as 2 weeks after injury. Fibrous callus appears as hyperechoic tissue relative to the tibialis anterior muscle. Cartilaginous callus demonstrates small, hyperechoic speckles in the reparative tissue and signs of acoustic shadowing. Osseous callus is characterised by total reflection of the ultrasound beam. Ultrasound evidence of cartilaginous callus formation appears approximately five weeks post injury in open tibial fractures. Fracture healing was predicted using ultrasound imaging before it was radiographically evident in all patients’ studies (Van Holsbeeck & Introcaso, 2001e).

On average, ultrasound imaging seen using evidence of healing, precedes radiologic findings by 3 months. The first examination for evaluation of tibial fracture healing is recommended 5 weeks after injury. If callus overshadows the medullary canal, the prognosis is good. Bad prognostic signs include lack of acoustic shadowing, hypoechoic tissue in the fracture gap, absence of visible periosseous and periosteal vessels, lack of periosteal covering, and fluid around the tibial shaft. Patients who have been treated with an intramedullary nail will demonstrate callus overlying the nail when examined over the anterior, medial, and lateral aspects of the tibias if healing is progressing favourably. Delayed healing will not demonstrate these findings around the nail at 5 weeks (Van Holsbeeck & Introcaso, 2001e).

Ultrasound has a number of clinical uses within the diagnosis and monitoring of bony pathology and trauma. The investigation of occult fractures, the formation of bony callus and the differentiation of osteomalacia from osteoporosis are just some of these uses. Ultrasound imaging will continue to evolve into an adjunct for clinicians wishing to explore the area of bony pathology and trauma as further research in presented.

2.10 Thoracic Outlet Syndrome.

Thoracic outlet syndrome is a complex of symptoms caused by the compression of the neurovascular structures at the thoracic outlet region. Common causes for thoracic outlet syndrome are cervical rib and 1st rib abnormalities, or tight bands of ligaments or muscles, causing compression of the brachial plexus and the subclavian vein and artery. Diagnosis is made from a variety of clinical tests however, false positive testing is common. Therefore an objective clinical test to confirm the diagnosis of thoracic outlet syndrome needs to be established (Wadhwani, Chaubal, Sukthankar, Shroff, & Agarwala, 2001). The authors used colour Doppler ultrasound to examine 5 patients with clinically suspected cases of thoracic outlet syndrome.

Wadhwani et al. (2001) stated colour Doppler ultrasound is utilised by clinicians to detect venous thrombosis in the subclavian and axillary veins. Diagnostic ultrasound shows the anatomy the brachial plexus as well as vascular compression through the dynamic capabilities of ultrasound imaging. The aim of the study was to evaluate the ability of ultrasound imaging to objectively diagnose thoracic outlet syndrome.

Using colour Doppler studies Wadhwani et al. (2001) found in all 5 patients, altered hemodynamics in the subclavian artery and vein. The severity of the changes was different in each case. Findings of increased velocities and occlusion in the subclavian artery were found using ultrasound imaging in varying degrees of shoulder abduction. Blunted flow in the axillary artery and a rebound increase in velocities on release of shoulder abduction were also noted in some clients.

Wadhwani et al. (2001) suggested that these changes were a result of significant narrowing of the aforementioned structures which was a causative factor of the patients' thoracic outlet syndrome. The authors found that examination, using colour Doppler ultrasound was able to predict or diagnose thoracic outlet syndrome in each of the 5 clients. This study was small with only 5 patients, however, the findings could promote ultrasound's effectiveness in assisting the diagnosis in patients complaining of thoracic outlet syndrome symptoms.

Further controlled studies are required to prove the effectiveness of ultrasound imaging as a potential diagnostic tool to assist and clarify in the diagnosis of thoracic outlet syndrome. Via its real-time capabilities ultrasound has enormous potential, if used in conjunction with plain x-ray and clinical testing. Preventing false positives, misdiagnosis and even unnecessary surgery are some of the potential positive benefits to be gained from diagnostic ultrasound imaging with regards to thoracic outlet syndrome.

2.11 Diagnostic Ultrasound Imaging of Paediatric Conditions.

Diagnostic ultrasound imaging is a practical and cost effective method for primarily evaluating a variety of musculoskeletal disorders that affect the paediatric patient. Ultrasound imaging is particularly well suited for the immature skeleton in which there is an increased ratio of cartilage to bone. Diagnostic ultrasound imaging not only allows the examiner to readily distinguish cartilage from soft tissue from bone, but also to show changes in structural relationships that occur with motion and to easily compare, in different planes, symptomatic to normal contralateral sides. Importantly, paediatric musculoskeletal ultrasound rarely requires any need for sedation and even the most anxious child can be examined comfortably in the arms of a parent (Bellah, 2001).

To examine in detail all the clinical uses of diagnostic ultrasound within paediatric musculoskeletal medicine is beyond the scope of this paper. There are a multitude of uses for diagnostic ultrasound imaging within paediatric medicine, including the detection of developmental dysplasia of the hip (DDH), defining congenital skeletal abnormalities, distinguishing joint dislocations from displaced epiphyses, foreign body identification, assessment of joints in juvenile rheumatoid arthritis, a multitude of other developmental infections & inflammatory disorders and finally diagnosis of neoplastic and traumatic conditions that can affect joints and extremities and growth centres of infants, children and adolescents (Bellah, 2001; Di Pietro & Harcke, 2001). The more clinically relevant uses of ultrasound will be discussed in relation to musculoskeletal medicine.

2.11.1 Developmental Dysplasia of the Hip.

The most common use of ultrasound imaging in paediatric musculoskeletal medicine involves the detection of DDH. DDH is a disorder that involves a spectrum of conditions, ranging from irreducible dislocation of the hip at birth to simple neonatal instability. The causes of DDH are multifactorial and a combination of hormonal, familial and mechanical factors are attributable (Allen & Wilson, 1999; Di Pietro & Harcke, 2001; Bellah, 2001).

Early diagnosis and treatment of DDH is important because if the femoral head has an abnormal relationship with the developing acetabulum, the end result can be a permanently dysplastic hip. Ultrasound imaging screening programmes were developed because clinical examinations failed to decrease the incidence of late cases of congenital dislocation of the hip. Ultrasound imaging allows the detection of the majority of cases of DDH that can be missed on clinical examination alone. A protocol of hip ultrasound for infants with abnormal clinical examination or risk factors has been developed to prevent unnecessary screening and two methods of ultrasound have been developed (Graf, 1987; Harcke & Kumar, 1991).

The relationship of the unossified femoral head to the acetabulum is better seen by ultrasound than by plain x-ray films, since the cartilage can be visualised. The hip can be imaged by ultrasound statically and dynamically in a coronal plane. The methods devised by Graf (1987) and Harcke & Kumar (1991) assess acetabular depth and shape. The relationship between the bony roofline and that of the cartilage compared with a baseline, along with the use of subjective assessment of coverage of the femoral head by the cartilaginous acetabulum using a baseline along the iliac crest is used to diagnose DDH by ultrasound. These methods give an objective measure of the development of the hip.

The two separate ultrasound imaging methods employed to diagnose DDH are utilised by different institutions and often medical facilities utilise a combination of the two. Like other ultrasound applications within musculoskeletal medicine, the methods employed come down to individual preference and familiarity (Allen & Wilson, 1999). Diagnostic ultrasound has become an essential part of the management of DDH. There is general agreement that ultrasound imaging increases the rate of detection of abnormalities of the hip, but it is not yet clear whether widespread population screening is cost effective (Allen & Wilson, 1999).

2.11.2 Juvenile Rheumatoid Arthritis.

Juvenile rheumatoid arthritis (JRA) is a chronic inflammatory arthritis, affecting the knee joint most frequently. Clinical evaluation of pain and inflammation is difficult and plain x-rays are commonly used to diagnose this condition. Sureda et al. (1994) suggested that alterations of the knee joint can appear late and signs of synovial disease are indirect. Therefore an alternate form of imaging could be useful to help clinicians more accurately and readily diagnose JRA.

Sureda et al. (1994) obtained ultrasound exams of 36 children with JRA of the knee and compared them with exams in 30 healthy children. This study was designed to help determine the value of ultrasound in assessing changes in the synovial membrane, suprapatellar bursa and articular cartilage in children with JRA of the knee. The results of this study suggested that changes in the synovial membrane (synovial thickness), presence of fluid in the suprapatellar bursae and alterations in the contour of the articular cartilage showed statistically significant differences between JRA patients and the control subjects. Some specifics of JRA, such as the detection of pannus formation requires injection of contrast material and sedation of the child. Ultrasound would have limited value in this instance. MRI also more clearly visualises the changes in JRA compared with ultrasound imaging however, changes in the synovium and articular cartilage in patients with rheumatoid disease are easily depicted with diagnostic ultrasound. Sureda et al. (1994) concluded that although MRI provides a more precise image of the knee joint in children with JRA, it is expensive and time consuming and can be of limited value with children who are unable to stay sedentary for the scan. Ultrasound imaging was found to be accurate and reliable in the evaluation of joint inflammation in JRA affected knees. Its value as a primary diagnostic tool is yet to be determined and further prospective long term studies are needed to assess the suitability of ultrasound and its role in JRA.

2.11.3 Osgood-Schlatter and Sinding-Larsen-Johansson Disease.

Both patellar and tibial osteochondrosis occur at the tendinous insertions into the patella at the proximal and distal levels respectively. It has been suggested that the dynamic stress and microtrauma due to the active function of the tendon are responsible for the onset of both Osgood-Schlatter (OGS) and Sinding-Larsen-Johansson (SLJ) diseases of the knee. For this reason these osteochondroses of the knee have also been called "non-articular osteochondrosis" since they occur in ossification centres that are submitted to traction, not to compression stress. The diagnosis of non-articular osteochondrosis of the knee and of OGS disease in particular is mainly clinical. A complete diagnostic approach requires x-ray. This baseline examination needs to be repeated serially to monitor the course of the disease. X-rays cannot give complete information about the involvement of the non-calcified cartilage and of the surrounding soft tissues and these findings provide a diagnostic hallmark of the early stages of this condition. For these reasons De Flaviis et al. (1989) considered it worthwhile to assess the value of ultrasound imaging for the study of osteochondrosis of the knee.

Diagnostic ultrasound of the knee was performed on 82 young patients with clinically suspected OGS disease and on 30 normal subjects. In 45 pathological cases comparative x-ray films were taken. This study suggested that ultrasound imaging was equally or more effective than x-ray images in 100% of the cases evaluated. The typical changes of the ossification centre of the cartilage and of the surrounding soft tissues seen on ultrasound imaging were described and classified, both for OGS and SJL diseases. These signs are based mainly upon cartilage swelling and oedema, fragmentation of the ossification centre, thickening of the patellar tendon, and bursitis of the infra-patellar bursae.

In OGS disease the age of the patient, the presence of tenderness and localised swelling of the tibial tuberosity are characteristic of the disorder. X-rays are often obtained for the first evaluation of the disease, but the x-ray appearance of the tibial ossification centre varies markedly between individuals and it is common to find a fragmented nucleus in an otherwise normal subject. On the other hand, x-ray examination may not disclose swelling overlying a normal nucleus (De Flaviis et al., 1989).

The study of De Flaviis et al. (1989) demonstrated that ultrasound examination of the knee is an effective and reliable first line technique for the diagnosis of OGS and SJL disease. Ultrasound imaging yields the same diagnostic information as the x-ray image, namely the development, structure and profile of the ossification centre. In addition ultrasound imaging provides a clear picture of the superficial soft tissue structures and of the non-ossified cartilage, enabling the assessment of all the elements for correct evaluation of the extent of the disease to be available on a single image.

Ultrasound imaging is quick and simple to perform, it does not expose the young patient to ionizing radiation and it can be repeated freely. For these reasons ultrasound could be the technique of choice for initial diagnosis and repeat follow up of patients with non-articular osteochondrosis of the knee (De Flaviis et al., 1989).

2.12 Inflammatory Disease and Musculoskeletal Infections.

Infections and inflammatory diseases of the musculoskeletal system are widespread and common clinical problems. The imaging techniques traditionally used in the investigation of these conditions are plain x-rays, bone scans, CT and MRI. However, more recently Cardinal, Bureau, Aubin, & Chhem (2001) and Gibbon & Long (1999) have suggested that ultrasound imaging has emerged as a new imaging modality available to the clinician. Ultrasound imaging is now playing an increasing role in the diagnosis of inflammatory disease and infections (see Figure 12).

In the same way that plain x-rays are used for visualising bony pathology, diagnostic ultrasound imaging can be considered a first line imaging modality for infection or inflammation. Ultrasound imaging is a readily accessible tool and can be performed quickly and offering a real-time imaging advantage for interpretation.

Fluid collections commonly associated with infectious diseases are extremely well demonstrated by ultrasound, which helps the differential diagnosis by localising the process within the muscle, within joints, a bursae, synovial sheath or round a bone (Cardinal et al., 2001). Diagnostic ultrasound can be used to guide needle aspiration of the abnormal fluid collection, due to its real-time capabilities, to obtain a gram stain or culture. Diagnostic ultrasound also has the ability to assess the vascularity of the soft tissue with colour and power Doppler.

The use of ultrasound imaging is likely to increase within rheumatology clinic patients. Further controlled studies will add weight to the role of ultrasound imaging in inflammatory and infectious conditions. Increased familiarity by sonographers with its capabilities and clinical usage, will follow (Gibbon & Wakefield, 1999).

Figure 12: Hip Infection.

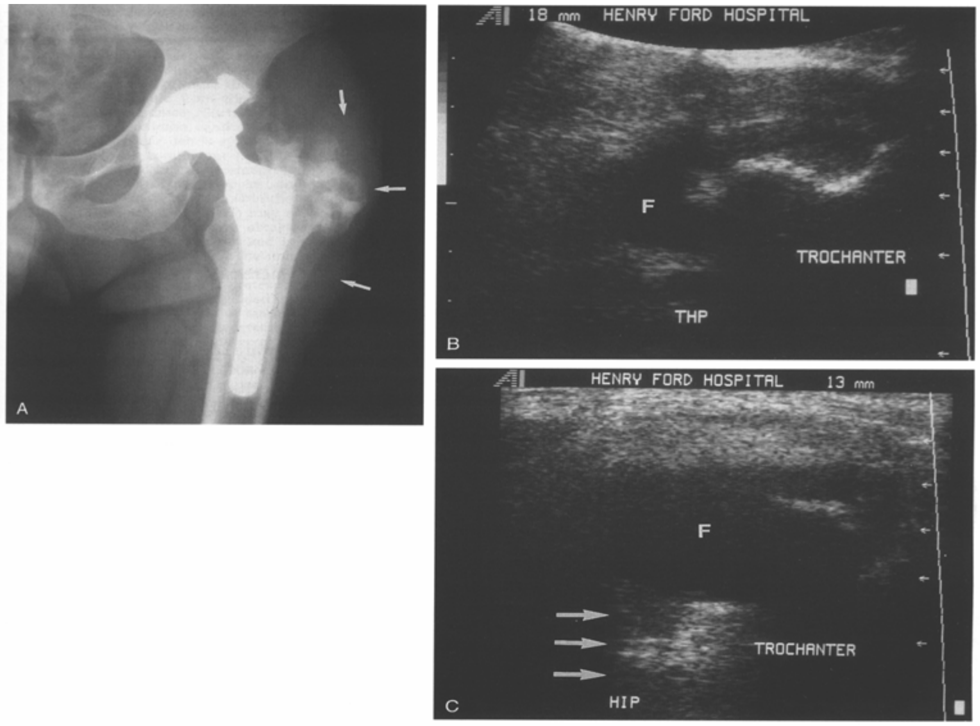


Figure 12–25 ▪ **A**, Indolent hip infection: hip radiograph. An orthopedic surgeon consulted us for evaluation of a slowly growing mass over the left greater trochanter of this 40-year-old man with a total hip replacement. Noteworthy in the patient's medical history was chronic renal failure with a kidney transplant. The surgeon was concerned about the possibility of malignancy. He stated that patients with depressed immune systems are more susceptible to the development of neoplasm. The anteroposterior radiograph of the hip demonstrates hypertrophy and sclerosis of the left greater trochanter. A soft tissue mass is noted over the lateral aspect of the hip (*arrows*). **B**, Indolent hip infection: coronal hip ultrasound. Same patient as in **A**. Ultrasound examination of the lateral hip with a curved 7.5-MHz transducer reveals a soft tissue mass overlying the trochanter and neck of the total hip prosthesis (*THP*). The lesion appears hypoechoic and was not compressible over the trochanter. This tissue is suggestive of thickened synovium. The more proximal portion of the mass seems anechoic and is probably a fluid collection (*F*). **C**, Indolent hip infection: detail of a coronal sonogram over the femoral neck. Same patient as in **A**. The fluid (*F*) component of the proximal aspect of the mass is seen in more detail with the linear 7.5-MHz over the femoral neck. Increased through-transmission (*arrows*) is noted deep to the fluid. Eight milliliters of serosanguineous fluid was obtained under ultrasound guidance. The specimen was positive for *Achromobacter xylos oxidans*, and the prosthesis was subsequently removed.

From (Van Holsbeeck & Introcaso, 2001a).

CHAPTER 3.

Discussion.

3.0 Diagnostic Ultrasound: A Comparison with Other Imaging Modalities.

The diagnosis of musculoskeletal pathologies in recent years has seen ultrasound imaging develop rapidly and experience an increase in popularity. Advances in technology and the low expense compared with other imaging modalities have made ultrasound a viable alternative imaging method for clinicians.

However, before ultrasound gains universal acceptance in the evaluation of the musculoskeletal system, it must be able to produce results similar to those of MRI or CT scans (Jacobson, 1999; Winter et al., 2001). MRI is essentially the gold standard of care for the evaluation of the musculoskeletal system at most medical facilities. MRI has been proven to be effective for a multitude of diagnostic indications. Advanced technology had resulted in improved image resolution and shortened imaging times. This has allowed MRI and to a lesser extent CT scanning to become widely accepted for evaluating the musculoskeletal system (Bouffard et al., 1993; Jacobson, 1999; Read & Peduto, 2000; Winter et al., 2001).

Advocates for ultrasound imaging's increasing use will be required to provide substantial research comparing and contrasting ultrasound to MRI, CT and other imaging modalities. The majority of the recent literature is working towards establishing the role of ultrasound imaging within musculoskeletal pathology. To date there have been a limited number of papers which have directly compared ultrasound imaging with other imaging modalities (Bouffard et al., 1993; Jacobson, 1999; Hides et al., 1995; Kalebo, Goksor, Sward, & Peterson, 1990). The papers which do compare ultrasound with other imaging modalities have focused primarily on imaging tendons and comparing these images with MRI.

Some ultrasound applications within the musculoskeletal arena have not directly been compared with other imaging modalities to date. These include neural movement and real-time applications. There are also a number of ultrasound applications where direct comparison with other imaging modalities is not applicable, such as aspiration, injection with ultrasound guidance, needle placement and biofeedback.

This section of this paper will discuss the relevant literature and draw some conclusions with reference to the advantages, disadvantages, limitations and strengths of ultrasound imaging with comparison to other relevant imaging modalities.

3.0.1 Diagnostic Ultrasound.

The utilisation of ultrasound imaging within the musculoskeletal arena is quite variable. The use of ultrasound as the primary tool for musculoskeletal imaging is limited to a number of medical facilities (Jacobson, 1999). Many radiologists not trained in musculoskeletal sonography may have inadequate time, energy or resources to acquire a new skill. Others may find it difficult to convince referring clinicians of the utility of musculoskeletal ultrasound. Clinical studies, however, are demonstrating the potential of ultrasound and interest in musculoskeletal ultrasound will continue to expand (Winter et al., 2001).

Diagnostic ultrasound does have several potential advantages over MRI. This includes its relative low cost, portability and in most cases improved accessibility. Evaluation of a soft tissue process near metal orthopaedic hardware is possible with ultrasound, without the artefact that limits MRI. Additionally ultrasound imaging can immediately guide percutaneous procedures when an abnormality such as a joint effusion is identified. Diagnostic ultrasound also allows a dynamic evaluation of joints, detecting abnormalities that may not be present during MRI positioning. Lastly the improved resolution of superficial structures demonstrates subtle abnormalities that may be difficult to visualise with MRI (Jacobson 1999).

Ultrasound images provide superb axial resolution but have much more limited lateral resolution. Ultrasound imaging demonstrates the superficial soft tissues in exquisite detail, but resolves deeper structures less impressively and cannot image through bone. It can quickly and routinely compare the normal side with the abnormal side, improving diagnostic sensitivity for subtle pathologic change, provide an objective appreciation of diffuse change, such as tendon enlargement or atrophy and provide a useful "control" for the interpretation of measurements on the symptomatic side. The real-time nature of ultrasound also allows assessment of soft tissue dynamics. This can be helpful in the differentiation of tendon rupture from tendon adhesion and is increasingly used to guide the accurate therapeutic injection of specific tendon sleeves or paratendon spaces (Read & Peduto, 2000). Consequently, the majority of the current literature has focused on comparing ultrasound with other imaging modalities with specific reference to tendon pathology.

Diagnostic ultrasound is the modality of choice in screening for and the characterisation of tendon disorders. The sonographic experience accumulated in the past decade, coupled with the use of improved high-frequency transducers has improved the imaging of tendons. Diagnostic accuracy is high in rotator cuff and Achilles tendon disease. Multiplanar tomographic imaging and arthrography are needed only as complementary tests. Ultrasound imaging is considered the best way to depict tendon function and structural disorders of the tendon. In the hands of dedicated musculoskeletal sonographers, tendon pathology is accurately diagnosed with ultrasound (Bouffard et al., 1993).

Read & Peduto (2000) in their review of the literature, looked at tendon imaging and compared ultrasound with other imaging modalities. The authors suggested that tendon imaging remains controversial with a multitude of imaging modalities available to the clinician, with several factors influencing the choices of imaging modality.

Ongoing improvements in technology have "forced" radiologists to continually rethink and adjust their diagnostic strategies, with examination techniques and clinical applications always evolving. There have been a number of factors influencing imaging practice and choice of modality. These have included the difficulty of access to suitable equipment, the availability of adequately trained and experienced sonographers, peculiarities and differences of the individual facility's reimbursement setting and the obvious personal biases of the referring physician or radiologist (Bouffard et al., 1993).

Tendon, tendon sheath, ligament, muscle and all other soft tissue except fat have exactly the same water density appearance on x-ray. Therefore with regard to tendon pathology, x-rays can only be used to detect gross alterations in tendon size and contour, calcifications that sometimes can be quite subtle or “cloud-like”, bony changes at points of tendon attachment, bony features such as spurs or osteophytes and paratendon changes that can be appreciated as alterations in adjacent fat pad contour. X-ray cannot be used to further characterise focal noncalcified pathologic changes within a tendon. Because radiographic techniques utilise ionising radiation, plain films should only be obtained when clinically necessary. X-ray should only be advocated whenever patient treatment is compromised by either an uncertain diagnosis or failed treatment (Read & Peduto, 2000).

Tenography, arthrography and bursography are all invasive tests that carry a small risk of complication such as transient chemical synovitis or infection and further increase the dose of ionising radiation received by the patient. They require the radiologist to be skilled at injection, familiar with correct radiographic technique, or experienced at the imaging interpretation of complex musculoskeletal anatomy. Cross-sectional imaging modalities such as ultrasound and MRI have now largely replaced these tests, as they are not only safer but provide much more comprehensive information (Jacobson 1999).

Advancing age can cause normal tendons to be affected by a rising incidence of asymptomatic degenerative change. Degeneration can often be appreciated on imaging as altered tendon texture (diagnostic ultrasound) or signal change (MRI), insertional bone resorption and sclerosis (plain radiography) and partial-thickness tears, or even full-thickness tears in situations of chronic overuse or advancing age. Thus, there is always a need to establish the clinical relevance of abnormal imaging findings, regardless of which test is used by careful and appropriate correlation with the background setting of symptoms and signs. The choice of imaging technique in deciphering changes in tendon age appears to be dependent on clinician bias or clinical availability (Winter et al., 2001; Hashimoto et al., 1999).

Diagnostic ultrasound and x-ray both detect calcifications within tendons, with consistent sensitivity. In contrast MRI often depicts calcification poorly owing to the inconspicuous blending of its dark signal with a similar hypointense tendon background (Read & Peduto, 2000; Hashimoto et al., 1999).

On MRI, tendon ruptures are diagnosed with confidence whenever a hyperintense signal defect, indicative of fluid, organising haemorrhage, or synovitis interrupts normal tendon continuity is visualised. Reported sensitivities and specificities for diagnosis of full-thickness tears of the rotator cuff range from 78% to 99% respectively (Read & Peduto, 2000). By comparison ultrasound imaging is able to assess supraspinatus and infraspinatus muscle quality, but cannot provide a reliable assessment of subscapularis muscle quality or glenoid labral integrity. In tears of the rotator cuff conventional MRI can have problems in differentiating some full-thickness cuff tears from partial thickness tears and in differentiating partial thickness tears from tendon degeneration. For this reason, as well as a perceived need to improve visualisation of the glenoid labro-ligamentous complex, shoulder MRI that employs both fat suppression and arthrographic technique has become prevalent (Bouffard et al., 1993).

The accuracy of examination using ultrasound for the diagnosis of full thickness tendon rupture is highly variable, reflecting the strong operator and equipment dependence of this modality. Most of the available data relate to full-thickness tears of the rotator cuff and the literature sharply divides between a very high accuracy of greater than 90% and those who question the reliability and reproducibility of ultrasound imaging (Bouffard et al., 1993; Read & Peduto, 2000). Nevertheless, these figures show that experienced sonographers can achieve results at least equivalent to MRI.

More importantly an advantage of examination using ultrasound imaging is that it is an interactive test. Unlike MRI, the examiner is in the room with the patient, probing the affected part with the transducer and directly correlating the site of reported pain or tenderness with its scan appearance. Furthermore, the arm can be moved through range and muscle testing performed while an image is obtained. This targeted approach can be invaluable in achieving a clinically relevant diagnosis, because all imaging modalities detect a high incidence of asymptomatic (often degenerative) pathology. However, ultrasound is also particularly operator-dependent modality that only achieves high levels of accuracy and reproducibility when the examining radiologist is well trained and experienced (Jacobson, 1999).

Ultrasound imaging has an obvious advantage over MRI, where contraindications are present which mean that the patient cannot obtain MRI. Examples include metal foreign bodies near critical organs and certain ferromagnetic devices or implants. Additionally MRI may not be feasible because of claustrophobia and lack of health insurance or finance. In these situations, ultrasound should be considered as an alternative to MRI (Winter et al., 2001).

3.0.2 Magnetic Resonance Imaging.

There are several advantages of MRI over ultrasound. The primary advantage is relative lack of operator dependence. This achieved through the use of standardised MRI protocols. Another advantage is the ability of MRI to evaluate globally and thoroughly an anatomic area including deep soft tissues, bone marrow and joint cartilage with high sensitivity. MRI images are also familiar to both the radiologist and referring physician and can be interrupted in a time and cost efficient manner (Jacobson, 1999).

MRI will remain the most common, advanced imaging method of the musculoskeletal system until research demonstrates that ultrasound can produce similar results. MRI has produced repeatable, reliable and accurate results. In recent years its accessibility and cost have made MRI a practical imaging modality (Bouffard et al., 1993).

MRI examination is more costly and less accessible to most of the population. The principal advantage of MRI is the ability to display tendons in a larger field of view in relation to surrounding soft tissues and bone. The MRI entails longer image-acquisition time and necessitates more cooperation by the patient. Multiple surface coils are needed for various areas. Stress studies and motion analysis cannot be applied routinely. The examination of patients with metallic orthopaedic or other appliances is precluded (Read & Peduto, 2001).

MRI is a comprehensive multiplanar cross-sectional imaging technique. Unlike diagnostic ultrasound, it provides a panoramic anatomic overview and is not restricted by the presence of overlying bone or air. The panoramic format of MRI provides recognisable anatomic landmarks and make this test much easier for the clinician to understand and therefore more reliable than ultrasound. Follow-up studies with MRI are also more objective. Although image acquisition is less dependent on the skill of the operator than ultrasound, scan interpretation remains highly operator-dependent and of course the financial cost of MRI is high (Jacobson, 1999).

To date, limited kinematic studies have been possible using MRI and experimental work on real-time MRI has now also started. The real-time assessment of tendon movement may become possible in the future with MRI by using magnets of open configuration. This "real-time MRI" has huge implications and applications within sports and muscle medicine, in reference to accurate dynamic testing, which at the present time is limited to diagnostic ultrasound (Read & Peduto, 2001).

3.0.3 CT Scans.

Except for restrictions due to metals, CT of tendons has many of the same limitations as MRI, especially in the study of ankles or feet where tendons change direction rather abruptly. Geometric constraints limit CT scanning planes, whereas any plane or section can be obtained with ultrasound. Reformatting or reconstruction of CT images in the desired planes usually does not give full information about tendons or ligaments because of limitations in slice thickness and immobilisation of the limb. The spatial resolution of reconstructed images does not compare favourably with direct axial or coronal scanning. With CT axial images, attenuation differences between normal and affected tendons are not obvious and CT attenuation measurement cannot distinguish tendon oedema from blood. Ultrasound has greater sensitivity in differentiating normal hyperechoic tendons from ruptured or inflamed tendons, which will appear hypoechoic (Winter et al., 2001).

Of particular interest is a study by Kalebo et al. (1990) comparing radiology, CT and ultrasound. This paper provides a thorough insight to the comparison of imaging modalities, with specific relevance to CT and ultrasound.

Kalebo et al. (1990) investigated the comparison of radiography, CT and ultrasound in partial Achilles tendon ruptures. The varying results in conservative and surgical care of partial Achilles tendon ruptures may be due in part to a lack of definitive objective diagnostic techniques. The value of a physical examination in most cases of Achilles tendon pathology is questionable, as it is difficult for the clinician to accurately diagnose a partial tendon rupture without diagnostic input (Kalebo et al., 1990).

The aim of the study was to assess the diagnostic performance of radiography, CT and ultrasound by means of a relative comparison and in some cases by correlating the imaging results to surgical and histological findings. A total of 39 patients suffering from "chronic localised" painful Achilles tendon swelling were examined. All the patients had undergone a previous clinical examination, resulting in a clinical diagnosis of a non-healed partial tear in 62 out of the 78 tendons. Kalebo et al. (1990) examined the tendons via radiography, specifically evaluating the soft tissue. This showed unspecific tendon pathology such as thickening and diffuse tendon margins. CT scanning was then performed. The results showed a better delineation of intratendinous as well as extratendinous abnormalities compared with radiography. Various pathologic changes were seen on CT, in 29 tendons and these included localised intratendinous hypodensities which indicated partial ruptures. Finally an ultrasound examination was performed, in which abnormal changes were observed in 69 tendons, of which 54 had discontinuity of tendon fibres, focal hypoechoic areas and localised swelling - indicating partial ruptures of the tendon. The authors followed through on nine cases with surgically proven partial ruptures, in which ultrasound was 100% correct and which CT was false negative in three situations.

Partial ruptures are often overlooked due to misinterpretation and confusion with other pathology of the Achilles tendon such as tendonitis or paratendinitis. A mixture of lesions complicating the clinical evaluation may be present simultaneously such as partial rupture and paratendinitis, partial rupture and bursitis. It is important to differentiate between partial ruptures and other abnormalities of inflammatory or degenerative nature because the therapy in these lesions is different (Kalebo et al., 1990).

Radiography is a relatively insensitive technique in the evaluation of Achilles tendon lesions. Indirect evidence of tendon rupture such as swelling and a diffuse outline of the tendon could easily be detected however, these findings are non-specific. The inability to image intratendinous changes except for calcifications is a drawback with this method, particularly in cases with suspected partial tears. It is doubtful whether radiography adds more information about partial ruptures than does a clinical examination. However, radiography may contribute with additional information on bony changes and spurs, soft tissue calcifications and bursitis (Kalebo et al., 1990).

CT scanning has the advantage over radiography of better contrast resolution, enabling imaging of focal intratendinous abnormalities. The sensitivity of the method seems to be moderate, since 3 out of 9 tendons with surgically proven partial ruptures were negative on CT scanning. CT scanning was less sensitive than diagnostic ultrasound. The three tendon ruptures missed on CT scanning showed very small partial ruptures on ultrasound. The limited contrast and spatial resolution by CT scanning compared with high frequency diagnostic ultrasound might explain these false-negative results.

Diagnostic ultrasound seems to be the method of choice in the evaluation of partial ruptures. Ultrasound imaging has several advantages since it is inexpensive, fast, repeatable, non-ionising and has the potential for dynamic examination. The method was significantly better than the others. Ultrasound detected more pathologic tendons than the clinical examination. However, the significance of the abnormal ultrasound findings in the asymptomatic tendons is unclear. This may be due to the high sensitivity of diagnostic ultrasound, by which it is possible to detect other tendon abnormalities such as degenerative changes.

Kalebo et al. (1990) concluded that ultrasound imaging is a valuable technique in the assessment of partial ruptures. Further studies are necessary in order to clarify the accuracy of diagnostic ultrasound as a preoperative diagnostic tool and to assess the value of postoperative follow-up examinations.

CT scanning involves exposure to ionising radiation and is vastly inferior to both MRI and ultrasound in soft tissue resolution. (Hashimoto et al., 1999; Winter et al., 2001). However, Read & Peduto, (2000) suggested that in the shoulder, CT is a viable and highly accurate alternative to MRI for the diagnosis of a rotator cuff tear and in a number of medical facilities CT is the imaging modality of choice.

3.0.4 Operator Dependence.

Successful imaging has always required technical expertise because many aspects remain operator dependent. The demand for such expertise has increased as imaging instruments have become more complex. Diagnostic ultrasound requires a skilled operator because echogenicity is very angle dependent. For CT scanning to detect certain subtle stress fractures the CT gantry must be correctly angled, the bone windows the correct width and scan slices suitably narrow. Detection of focal tendon tears and subtle fractures with MRI requires selection of the appropriate coil, tailoring the MR sequences and sections carefully to the clinical problem. Failure to attend to this leads to false-negative results (Jacobson 1999).

Ultrasound imaging continues to evolve. Currently ultrasound imaging, CT scanning and MRI are the most informative tests, but plain radiography remains an essential component of patient examination. The choice of which cross-sectional modality to use to supplement the initial radiographs depends on local circumstances and the specific clinical questions to be answered. The use of MRI, CT scanning or ultrasound imaging can provide sufficient information to guide patient management appropriately and at a lower cost to the patient and the community. MRI may be preferred or necessary if adequate ultrasound expertise is not locally available, the ultrasound findings are equivocal or significantly inconsistent with the clinical diagnosis or additional pathology involving other structures such as cartilage or bone is strongly suspected. However, ultrasound has unique strengths that include the interactive aspect of direct clinical correlation as well as an ability to assess tendon dynamics and accurately guide percutaneous interventional procedures (Jacobson 1999).

All imaging modalities within the musculoskeletal arena are operator dependent however, the use of standardised protocols for MRI has somewhat negated this and allowed MRI to produce repeatable and reliable results. Ultrasound will continue to be operator dependent until it can achieve consistent, reliable and accurate results (Winter at al., 2001).

3.1 Diagnostic Ultrasound: Apparatus and Technology - Current and Prospective Applications.

With technological developments, advances in machinery and apparatus and the seemingly infinite scope for the expansion of the role of diagnostic ultrasound imaging within musculoskeletal medicine, prospective applications or uses will evolve.

Clinicians, technicians and research companies will find and develop new and improved applications for diagnostic ultrasound. Several papers have discussed some of these prospective uses, which are being trialled currently. Further papers and research into these applications will validate the efficiency and accuracy of ultrasound imaging and possibly expand and broaden the role of ultrasound imaging within musculoskeletal medicine. Allen & Wilson (1999) reported areas of current interest in ultrasound technology and apparatus include 3D surface reconstruction, the use of power Doppler and contrast agents to show vascularity or hyperaemia in inflammatory joint disease and the

4dynamic assessment of joints. With the exception of the last, the new techniques have an unproven clinical use, but serve to illustrate the developments in the rapidly expanding area of diagnostic ultrasound imaging. It is likely that ultrasound imaging will gain a greater place in the management of rheumatology, sports injuries and trauma, subsequent to these developments, together with the superior quality of superficial soft tissue visualisation afforded by modern equipment (Allen & Wilson, 1999). An example of this current change in technology is the utilisation of 3D over 2D sonography.

3.1.1 Two Dimensional versus Three Dimensional Ultrasound.

Radiography, MRI and CT are the principal methods for the evaluation of trauma and pathologies within the musculoskeletal system. However, ultrasound imaging represents a quick and inexpensive technique that can be used during the initial investigation of suspected musculoskeletal disorders to allow the clinician to determine the need for other more costly and invasive investigations (Hunerbein et al., 2001).

The lack of acceptance of ultrasound imaging is mainly caused by the inability to assess static diagnostic ultrasound images accurately. 2D ultrasonography does not provide standardised views and spatially orientated images. This makes reliable interpretation difficult and limits the diagnostic information of ultrasound images. Recently 3D ultrasound systems have been introduced into clinical practice (Alder, 1999; Hunerbein et al., 2001; Von Herby & Haussinger, 2001).

Hunerbein et al. (2001) investigated the feasibility and the diagnostic value of 3D ultrasound imaging in bone and soft tissue lesions. The authors performed 3D ultrasound on 83 subjects with a multitude of muscle disorders such as fractures, tumours, tendon lesions and rotator cuff tears. All patients underwent conventional diagnostic assessment, including clinical examination, radiography and 2D ultrasound prior to the 3D ultrasound.

3D ultrasonography was performed by one investigator who was made aware of the clinical situation and the plain films. The findings of 3D image analysis were compared with conventional 2D ultrasound and other imaging methods. Hunerbein et al. (2001) used the following four criteria to assess the value of 3D ultrasound; display of details, improved spatial orientation, facilitated overall interpretation and additional findings with clinical reference such as occult fractures. 3D sonography confirmed the findings seen on the 2D scans in all patients and interactive analysis of 3D ultrasound data improved the evaluation of details while providing a better spatial orientation and facilitated the overall interpretation of the images (Hunerbein et al., 2001).

The section mode improved the comprehension of the anatomy by multiplanar display and by previously unobtainable scan planes. Subtle lesions and topographic relations of relevant structures such as joints, muscles and tendons were displayed more clearly. This technique proved to be very helpful for evaluation of complex anatomical situations that are normally difficult to assess such as rotator cuff tears. The section mode allowed the display of global views of the anatomy with complete spatial orientation.

Conventional ultrasound imaging plays only a limited role in the evaluation of bone although most lesions of the cortical bone can be detected. It has been demonstrated that this technique can be valuable to identify occult fractures, epiphysiolysis in children, osteomyelitis and various other lesions. 2D ultrasound images of bone are by far more difficult to interpret than comparable x-ray or CT images. Diagnostic ultrasound can now display lifelike views of fractures, exotoses and malignant bone tumours in 3D surface reconstructions. 3D imaging provided additional information to the conventional examination in 11 of 50 patients with bone lesions. In some cases the reconstructed ultrasound images can be even complementary to radiographs. By the use of 3D ultrasonography additional radiologic imaging studies such as special x-ray studies, CT and MRI could have been avoided in 6 out of 50 patients (Hunerbein et al., 2001).

There were also limitations of 3D diagnostic ultrasound. The maximum volume acquired with 3D scanning may be too small to capture large targets entirely. Voluntary patient motion during the scanning process can result in artefacts that may lead to misinterpretation of the findings. Certainly, there is a significant learning curve for 3D ultrasound imaging and the equipment is not yet widely available. 3D ultrasound imaging appears to be a valuable adjunct to conventional ultrasonography. This technique provides previously unattainable scan planes and realistic 3D views. Both could be particularly helpful for the evaluation of bone lesions. It is possible to display spatially orientated and standardised views, which may reduce the operator dependence and enhance the comparability of follow up studies (Hunerbein et al., 2001).

Since the development of pulsed wave Doppler, colour Doppler and power Doppler sonography, blood flow abnormalities can be diagnosed non-invasively. However, the documentation of complex anatomic structures in one picture by conventional 2D imaging is difficult. 3D ultrasonic angiography is a new power Doppler ultrasonographic imaging mode that appears to improve the visualisation of both vascular and muscle anatomy (Von Herby & Haussinger, 2001).

Von Herby & Haussinger (2001) investigated the ability of 3D ultrasound to visualise abdominal structures. The authors performed a series of ultrasound examinations on the abdomen. Using 3D ultrasound imaging the topographic documentation of vessels is improved, especially for the analysis and documentation of the relationship to vessels running nearby. A sonographer can easily retrieve all needed information mentally to reconstruct the organisation of the studied region. However, the understanding of a series of documented 2D images is often difficult for other persons, because they cannot coordinate the images with the position of the transducer. 3D images allow a quick understanding of a complex situation even for non-specialists. Furthermore the technique of 3D reconstruction allows visualisation of lower velocity flow even in vessels smaller than 1mm. It could be envisioned that 3D power Doppler imaging will provide much improved detection of small vessels when it is combined with sonographic contrast enhancement (Von Herby & Haussinger, 2001).

The authors drew a number of conclusions and generalisations from their study. Real-time 3D ultrasonography has not yet been proven clinically practical, but it is currently under development. Direct 3D visualisation of needle passage is not possible at this time. However, 3D power ultrasonography permits determination of the exact location of a needle relative to vascular structures and the needle course can be directly visualised (Von Herby & Haussinger, 2001). The technique of 3D power Doppler sonography has the same limitations as 2D power Doppler sonography, such as flash artefacts, noise interpreted as flow and adjacent pulsation. The main conditions for successful 3D reconstruction are patient cooperation and controlled constant-speed motion of the transducer. The quality of 3D image data is dependent on the quality of the 2D image data however, the resolution of reconstructed images is not as high as that of the original planes in which the images were collected. The presence of acoustic shadowing makes Doppler flow measurements unreliable. Power Doppler sonography does not indicate the direction of flow, so arteries and veins are indistinguishable when travelling together. Further studies are necessary to evaluate the clinical benefits of 3D power Doppler sonography in comparison with other diagnostic techniques (Von Herby & Haussinger, 2001).

Alder (1999) suggested that tissue tracking and spatial registration have generated significant clinical and research interest in recent years by virtue of the appearance of extended field-of-view and 3D imaging. Whereas 2D imaging is usually adequate for diagnostic purposes, extended field-of-view permits a better overall appreciation of a pathologic process relative to its surrounding tissues. The full extent of an abnormality can be placed on a single image, thereby allowing accurate assessment of size and effect on adjacent tissue.

3D imaging permits multiplanar reformatting, enabling visualisation of the optimal image plane which may or may not be directly accessible. Imaging in the so-called C-plane, which may be thought of as a plane perpendicular to the insolating beam, provides an example of a nonaccessible image plane. Alternatively, the capability simply to reformat the data removes some of the operator dependence inherent in ultrasound imaging by allowing one to review the image data from multiple effective scan angles.

A variety of projection maps permit visualization of the entire 3D data set, providing an additional method to better appreciate spatial relationships. When combined with segmentation algorithms, which tend to be most amenable to colour Doppler data, volumetric information may be obtained. Examples include total volume of a local muscle or tendon rupture or total tumour vascularity estimates (Alder, 1999). All of these registration techniques require knowledge of the relative position of the transducer with respect to the image space in order to assign correctly a given 2D image relative to its cohort. The composite data set can then be reprocessed to display a variety of features not encompassed by a single 2D image (Alder, 1999).

3.1.2 Prospective Applications.

Balint & Sturrock (2001) suggested that future applications of ultrasound imaging may lie in the development of technology such as cableless transducers and combined diagnostic ultrasound injection probes, which will make aspiration and injection of joints even easier. Newer techniques for differentiating between solid structures and effusions are also being developed, particularly in inducing and detecting cysts.

The current literature outlines a number of specific applications involving ultrasound imaging in the role of musculoskeletal medicine with particular reference to the evolving and developing technology and apparatus. History has shown that medical imaging is still in its infancy, and several yet unthought-of applications and componentry will materialise. It is the challenge of the medical profession to develop and encourage the development of this technology, so clinicians themselves can more accurately diagnose and treat their patients. Ultimately the benefit to the patient is of paramount importance. Improved technology will heighten accurate diagnosis and improve treatment management and rehabilitation strategies. Further studies and papers will validate these prospective applications in diagnostic ultrasound apparatus and technology (Alder 1999; Balint & Sturrock, 2001).

3.2 Diagnostic Ultrasound: Its Use within a Physiotherapy Setting and Prospective Applications.

Physiotherapists are experts in the clinical diagnosis, management and rehabilitation of musculoskeletal pathologies and injuries. Physiotherapists work with muscle, tendons and joints, therefore the use of diagnostic ultrasound is an attractive option for a number of functions or roles within a rehabilitation or research setting. Specifically physiotherapists are able to utilise ultrasound imaging capabilities on tendons, muscles, nerves and arteries, to assist in diagnosis, clinical testing and to accurately determine joint laxity.

3.2.1 Biofeedback and the Measurement of Muscle Activation.

Interest in the use of ultrasound within biofeedback and the measurement of muscle activation has been greatly stimulated by the extensive work of Julie Hides and fellow researchers on multifidus muscle characteristics and in transversus abdominis muscle identification and contraction. These outstanding papers have clearly demonstrated the potential value of ultrasound as a clinical biofeedback tool. Selective muscle activation as a rehabilitation strategy may be enhanced within the near future as ultrasound becomes an integral part of the assessment of musculoskeletal injuries. Physiotherapists with appropriate ultrasound training would be well placed to utilise this modality in the clinical setting.

Utilisation of surface EMG in providing feedback as previously suggested has limitations due to the deep location of various muscles and rehabilitation strategies are to some extent indirect. (Hides et al., 1998). Diagnostic ultrasound allows immediate visualisation of the contraction of the deep muscles, such as transversus abdominis and multifidus. These muscles are paramount in functional stability (Hides et al., 1992; Hides, Richardson, et al., 1995; Hides et al., 1998; Richardson et al., 2002).

The ability to visualise the contraction of deep muscles and in conjunction with the more superficial overlying muscles could allow a physiotherapist to more accurately assess and provide adequate rehabilitation strategies. Hides et al. (1998) stated ultrasound imaging has an enormous potential for a physiotherapist within a rehabilitation setting as it allows the assessment of the facilitation and activation of various muscle patterns which are clinically difficult to assess. Ultrasound imaging could become a more prominent biofeedback tool when comparing it to traditional biofeedback apparatus utilised presently.

3.2.2 Electrode Placement.

Previous details of the application of real-time ultrasound imaging in assisting the accurate placement and to check the position of fine wire electrodes has been discussed. Hodges & Richardson (1997) stated the complexity of the anatomy where the needles were to be placed demanded accurate needle placement and real-time ultrasound did indeed accurately visualise needle placement. Physiotherapists in research situations utilise needle placement regularly in deep and more complex anatomical structures. This study has demonstrated that diagnostic ultrasound can aid researchers to confirm the accuracy of electrode placement. This methodology could have vast potential implications for further research into this specific field and open up new levels of accuracy in determining EMG readings in future research (Hodges & Richardson 1997).

3.2.3 Measurement of Joint Laxity.

Studies have utilised the ability of ultrasound imaging to measure the laxity of the SIJ (Damen et al., 2002; Richardson et al., 2002). According to both these authors this methodology could provide further opportunities to assess not just the SIJ but possibly other joints in the body, allowing information to be gathered with relevance to stability, muscle control, strength and function.

Before this measurement technique (DIV) could be adopted in the clinical situation, a number of factors would need to be considered. Firstly specific tailor made equipment was utilised in both Damen et al., (2002) and Richardson et al., (2002) studies. This equipment would need to be modified for clinical use. Secondly, the clinician would need to be trained in the measurement technique and repeatability, reliability and validity of the DIV technique would need to be established. The DIV technique in itself may be too time consuming for use in routine clinical practice.

If physiotherapists in the future are able to accurately determine joint laxity or stability, non-invasively, within a clinical environment quickly and easily, the potential benefits to patients would be enormous. Clinical findings such as stability and muscle control could be assessed using ultrasound imaging and the DIV technique. This would allow the generation of a more specific and tailored rehabilitation programme. The DIV technique would give the physiotherapist an objective measure with which they could compare their clinical findings and also would provide both the physiotherapist and the patient with some appropriate feedback. This would re-enforce treatment strategies or enable physiotherapists to alter rehabilitation programmes (Richardson et al., 2002; Hodges & Richardson, 1997).

3.2.4 Vertebrobasilar Insufficiency.

Pre-manipulative screening, testing and protocols have been developed to minimise the potential risks from patients from high velocity thrust techniques. Ultrasound is an effective, accurate, non-invasive modality that has been proven to be a clinically useful tool in diagnosing vertebral/carotid artery blood flow, specifically when the cervical spine is placed in certain positions utilised by physiotherapists to manipulate the cervical spine (Rivett et al., 1998; Rivett et al., 1999; Haynes, 1996).

As ultrasound imaging can indicate VBI haemodynamics, physiotherapists and researchers alike, who are interested in the anatomical position of the cervical spine during high velocity thrust techniques, can utilise their knowledge of anatomy, the therapeutic techniques employed by manipulative physiotherapists, as well as ultrasound imaging to effectively gain more clinical information which will help develop safe, valid and reliable testing procedures.

Diagnostic ultrasound imaging may be able, with further testing and developments to definitively assess whether cervical spine high velocity techniques are indeed placing patients at risk. Ultrasound imaging may also play a role in establishing possible “differing VBI protocols and positions”, which may with further research and testing be deemed more effective than the current procedures and protocols utilised at present (Rivett et al., 1999).

Ultrasound imaging could be further utilised clinically within a manipulative physiotherapist’s treatment room as a real-time diagnostic procedure on a patient, who is about to receive a high velocity technique. Ultrasound imaging would allow a physiotherapist to rule out vertebral and/or carotid artery compromise, which could theoretically decrease the incidence of a vertebral incident or adverse reaction (Rivett et al., 1999).

Could ultrasound be developed as a definitive, all encompassing diagnostic procedure to help clinicians reduce the incidence of VBI, by being utilised at the time of manipulation on every patient receiving cervical high velocity techniques? This would obviously increase treatment and testing time. However, the potential benefits to the patient and clinician would be to avoid the potential adverse reaction of cervical spine high velocity techniques. Physiotherapists would first have to be trained in Doppler sonography techniques. This training would need to be extensive to evaluate VBI. Repeatability and validity of this technique would also need to be established.

Time, further trials and more research papers, as well as the cost of ultrasound apparatus and training to clinicians will determine whether ultrasound has this total encompassing role to play in rehabilitation with regards to VBI. The papers of Rivett et al., (1999) and Haynes, (1996) do nevertheless raise interesting questions and implications in reference to VBI symptoms, ultrasound and cervical spine high velocity techniques and their possible prospective applications.

3.2.5 Diagnostic Capabilities.

With ultrasound imaging becoming more widely utilised and accepted, could physiotherapists ultimately have access to a diagnostic ultrasound apparatus in their clinic or treatment room? The use of ultrasound imaging for diagnosing tendon pathologies, muscle injuries and indeed its role as a biofeedback tool and its functional use in measuring muscle activation, could allow a physiotherapist with appropriate training to effectively utilise ultrasound to assist in the diagnosis and rehabilitation of patients for a multitude of musculoskeletal pathologies.

It may be the case, that if measurements made using ultrasound are found to be valid and reliable and the cost of the ultrasound apparatus, and the cost in training physiotherapists is within realistic realms, that all future musculoskeletal physiotherapists could have access to diagnostic ultrasound. The implications and advantages are numerous. A physiotherapist could differentiate the extent of an injury or type of pathology. For example a partial tear of a tendon could be ascertained, then re-evaluated to monitor "its progress" and the physiotherapist would have the ultrasound image to substantiate claims for return to sport or work. The partial tear could be differentiated from complete rupture or inflammation. Ultrasound in this situation, with a sports team/or in the workplace could be invaluable in accurately diagnosing injuries and determining the extent of pathologies, thus providing an objective indicator for return to sport or work.

The physiotherapist could also be able to visualise loose/foreign bodies, measure vertebrobasilar insufficiency and differentiate inflammatory disease or musculoskeletal infections, all within the treatment room. This information gained could help diagnose numerous pathologies.

With an ultrasound machine available within a clinical setting, the use as a biofeedback tool for determining muscle activation as described by Hides et al. (1998) and as a diagnostic tool would become a reality and not be limited to a research setting for "specialised individuals" and "specialised physiotherapists". Diagnostic ultrasound could become a readily available "hands on" tool for the physiotherapist to assist in functional rehabilitation. These implications for future practice have tremendous potential.

3.2.6 Specialised Training.

Physiotherapists have a detailed knowledge of anatomy, pathology and injuries of the musculoskeletal system. It would seem appropriate then that physiotherapists would be ideal candidates for further specialised training in sonography or diagnostic ultrasound apparatus use, particularly in a musculoskeletal setting. A physiotherapist with the skill to utilise an ultrasound machine would be able to offer a faster and more holistic diagnosis assessment to their patients, possibly decreasing the need for patients to visit the radiology department, or indeed an orthopaedic surgeon and sports physician. This could have a huge impact on costing of health monies and funding.

On the other hand if physiotherapists were to become "fluent" in sonography, there may not be a need for the radiologist to train specifically as a sonographer within a musculoskeletal setting. The option could be that the majority of musculoskeletal diagnostic ultrasound examinations may be undertaken in the future by specially trained physiotherapists? Job security and identity as well as legislative matters are questions, which would be raised when dealing with the diversity of physiotherapists' traditional role and function within the health system. As diagnostic ultrasound becomes more readily available it may be inevitable that other health professionals such as physiotherapists with the necessary skills "acquire" certain functions, like ultrasound examinations.

The current health system is constantly changing and evolving and the role of ultrasound imaging within the health system is open to this change. As ultrasound becomes accepted within musculoskeletal medicine as a valid and reliable diagnostic tool and its ease of use increases ultrasound imaging could become utilised by clinicians, such as physiotherapists, who have an immense functional and rehabilitative need for the qualities of ultrasound imaging.

Diagnostic ultrasound machines and apparatus could be available in selected physiotherapy clinics, utilised by "specialised" physiotherapists initially, then with time available to the majority of physiotherapists and ultimately postgraduate students. Presently some physiotherapy schools, in particular reference to the University of Queensland (Australia) are offering the opportunity for students to gain first hand experience in the rehabilitative capabilities of diagnostic ultrasound in reference to abdominal and pelvic muscle control, via biofeedback and muscle activation.

Legislation, the reluctance other health professions and limited valid research on ultrasound's reliability are some of the possible constraints to the expanding clinical role of diagnostic ultrasound within musculoskeletal medicine. Time will determine whether physiotherapists are able to utilise diagnostic ultrasound to its obvious utmost potential.

3.2.7 Prospective Applications.

The potential uses for diagnostic ultrasound within a physiotherapy setting, with regards to diagnoses and rehabilitation are only just beginning to be appreciated. The more traditional use of diagnostic ultrasound to examine different musculoskeletal structures by sonographers continues to be helpful for the diagnosis of tissue damage and monitoring healing. However, the examination of muscle dimensions as described by Stokes et al. (1997) is of more interest to physiotherapists than sonographers, for assessing the effects of injury on muscle dysfunction and the effects of their treatments on the pathology or injury.

More muscles, joints and other anatomical structures need to be explored and different populations of normal subjects studied to provide reference ranges for comparison with pathological patients. Currently diagnostic ultrasound within a physiotherapy setting has a number of potential uses, but with appropriate training, the availability of machinery, new technology and further research, ultrasound as unlimited prospective applications.

Richardson et al. (2002) suggested for integration into physiotherapy practice, the main emphasis must be on diagnostic ultrasound being an adjunct to assessment and treatment, with good clinical skills remaining of paramount importance. Diagnostic ultrasound has the potential to provide tremendous benefit to physiotherapy in a number of prospective applications. The challenge for physiotherapists and those clinicians advocating ultrasound's use is to introduce and implement ultrasound, via validated and reliable research in such a manner that it is used judiciously and appropriately to gain credibility and acceptance (Hides et al., 1998).

3.3 Medicalising Diagnosis with Ultrasound.

Diagnostic imaging plays a vital role in modern musculoskeletal and sports medicine. Clinicians have a subjective history and a physical clinical examination as well as imaging techniques to help with diagnosis. Imaging techniques such as CT scanning, MRI and ultrasound imaging have enabled clinicians to more accurately diagnose pathologies and injuries, which in turn aids the patients' prognosis and management options. For the purpose of this section of the paper "medicalising" has been interpreted as the diagnosis of an injury or pathology via an imaging modality specifically to obtain a diagnosis.

A number of authors have suggested that clinicians and therapists could becoming more reliant on imaging to provide the diagnosis and direct management of musculoskeletal trauma (Khan, Tress, Hare, & Wark, 1998; Zusman, 1998; Beattie, Meyers, Stratford, Millard, & Hollenberg, 2000).

Irrespective of how sophisticated and accurate imaging modalities such as CT, MRI or ultrasound imaging become, it has been suggested that diagnosis should never default to imaging for a number of reasons (see Table 5) (Khan et al., 1998).

Table 5: Reasons For Diagnosis Not Defaulting To Imaging.

Clinically irrelevant anatomic variants occur regularly.
"Abnormal" findings can in certain circumstances be physiologic.
Clinically significant pathology is not always detected by imaging.
Other previously unreported conditions arise upon imaging.
Technical factors can lead to false positive imaging appearances.
Human error can produce/ report inaccurate results.
Clinically significant pathology is not always amenable to imaging.

Adapted from (Khan et al., 1998).

All of these above factors regularly occur during imaging of musculoskeletal pathologies and injuries and contribute to incorrect treatment of patients. Clinical diagnosis and judgement are essential and should be paramount when therapists and clinicians make decisions on patient's management and rehabilitation (Khan et al., 1998).

There are a multitude of studies investigating the relationship between lumbar spine pain and abnormal anatomic variants visible on imaging. These papers have attempted to analyse the link between lumbar spine pain and abnormal anatomic variants and their findings can be linked to ultrasound and the imaging of musculoskeletal structures (Beattie, 1996; Beattie et al., 2000; Zusman, 1998).

Zusman (1998) discussed in-depth structure orientated beliefs and disability due to back pain by examining lumbar spine pain and diagnostic management and suggested that patients and clinicians rely heavily on x-ray and MRI scan findings as a diagnostic tool. Clinicians and medical professionals require a structure based method of diagnoses and other diagnostic tools such as MRI, ultrasound and CT show irrelevant anatomic variants or unrelated pathologies. There is little factual evidence to suggest all MRI and x-ray findings are clinically relevant and Zusman (1998) suggested that clinical diagnosis and judgement are essential in a patient's management.

Anatomic impairments of the intervertebral disc, radicular canal and associated soft tissues are prevalent in people with and those without lumbar spine pain or lower extremity radiculopathy (Beattie et al., 2000). This has led to confusion amongst clinicians in differentiating between symptoms generators and benign variations visible of lumbar MRI. The objective of this study was to determine how various anatomic impairments, including the magnitude and location of nerve compression visible on MRI are associated with patient reports of pain and weakness. A cross-sectional study was utilised, using 408 participants undergoing a diagnostic workup for lumbar spine pain or radiculopathy. All participants underwent an MRI (Beattie et al., 2000).

The results of the study indicated that although patients can be reliably classified on the basis of segmental pain distributions, there appears to be little association between these pain distributions and commonly observed impairments visible on lumbar MRI. The self-reported symptoms of weakness, paresthesia, or numbness showed minimal association with MRI findings. Weakness was most closely linked with disc extrusion, but this relationship was not significant. Paresthesia had significant but weak relations with nerve compression and multiple sites. Numbness was not significantly related to any of the MRI findings, with the exception of thecal sac compression, which appeared to result in a lower degree of numbness.

Beattie et al. (2000) concluded by stating that lumbar disc extrusion or severe nerve compression visible on lumbar MRI strongly predicts ipsilateral distal lower extremity pain however, the relationship between lumbar MRI findings and symptoms is unknown and may be related to other specific factors.

A study by Kovacs et al. (2001) aimed to determine whether diagnostic ultrasound allowed assessment of the dimensions of partial tendon lesions reliably enough to estimate the extent of a tendon rupture. Information regarding the size of each disruption or the condition of the torn tendon fibres can aid the surgeon in determining the appropriate treatment, conservative or surgical management. The authors cut the tibialis anterior muscle in 25 cadavers and used ultrasound imaging to determine the dimensions of each individual cut.

The results from this study were encouraging, with investigator independent prediction of the extent, depth, size and grade of tendon lesions. However the authors suggested that the information gained from ultrasound examination could have been easily ascertained by clinical examination. No further significant information was gained by diagnostic ultrasound examination that would have influenced a surgeon's decision about ongoing management, to change from conservative to surgical management or vice versa.

Ultrasound in this instance provided no further information for the surgeon regarding patient management, than the surgeon's own clinical diagnosis. Clinicians should rely primarily on their own clinical judgement and use imaging modalities as an adjunct to confirm their hypotheses or rule out further pathology (Kovacs et al., 2001).

Jumpers knee is the clinical syndrome of anterior knee pain and tenderness arising from patellar tendon degeneration. Ultrasound imaging has been used in previous studies to select and monitor the treatment for anterior knee pain or jumpers knee. Khan et al. (1997) designed a study to compare patellar tendon sonographic findings at baseline and at follow up in basketball players with and without symptoms of jumpers knee. Fifteen female basketball players, with 23 sonographically abnormal tendons were matched with 15 control basketball players with 23 sonographically normal tendons.

A sonographic abnormality was defined as either a hypoechoic region, evident in both the longitudinal and transverse scans or a fusiform swelling without hypoechoic areas. The present or absence of any sonographic abnormalities was recorded. The results were categorised and then statistically analysed. Follow up ultrasound examinations were repeated over a three month period.

The results from this study revealed that patellar tendon pathology does not necessarily mirror clinical symptoms of jumpers knee. A sonographic hypoechoic region can predate the development of jumper's knee symptoms, be associated with symptoms of jumper's knee and persist for at least some time after the pain of jumper's knee has resolved.

All of these findings would be consistent with the histopathology of jumper's knee being a degenerative rather than an inflammatory condition. It has been hypothesised that some of the tendon fibre may degenerate over time causing a sonographic hypoechoic region, without necessarily producing symptoms. Similarly, after the symptoms of jumper's knee resolve, pathologic evidence of tendon scar or the sonographic hypoechoic region may remain (Khan et al., 1997).

Importantly and irrespective of eventual histopathological explanation of the phenomenon, the findings of this study demonstrated that sonographic hypoechoic regions can both predate and postdate symptoms of jumper's knee and therefore the authors strongly disagree with any suggestion that the presence of such regions should serve as an indication for surgery. Conservative management is the first line therapy for jumper's knee and surgery should be contemplated only when appropriate conservative management has failed.

Although ultrasound appearances may provide evidence supporting the clinical diagnosis of jumpers knee an athlete, there is no evidence for using the sonographic appearances of the patellar tendon as a guide to prognosis and management at the expense of clinical findings. Further longitudinal studies are required in order to correlate imaging appearances and clinical outcomes. The fact that ultrasound pathology of the patellar tendon and clinical features of jumpers knee do not necessary marry perfectly may also have implications for management and investigation of other major tendon conditions. Further research is warranted in conditions such as rotator cuff disease and Achilles tendon conditions.

The combined use of clinical examination, diagnostic imaging and clinical reasoning would seem the most logical approach when planning patient management. In conclusion, Khan et al. (1997) emphasized that the presence of clearly defined hypoechoic regions should not be used as an absolute indication for surgery. These ultrasound abnormalities are commonly seen in chronic jumper's knee, a non-inflammatory degenerative condition of the infrapatellar tendon that generally responds well to conservative management.

Initially the limited availability and high cost of MRI and CT examinations limited the evaluation on symptomatic individuals however, as access to MRI and CT expanded and the cost of examinations reduced, clinicians used these imaging modalities on asymptomatic individuals and found a range of pathologies and non-symptomatic symptoms on imaging. With respect to disk degeneration and herniation for lumbar spine pain and sciatica, clinicians began to question their specificity when a high prevalence of these findings was noted in asymptomatic individuals.

Beattie (1996) discussed in his review of the literature, the data from studies evaluating the presence of asymptomatic disc bulges on MRI scan. A number of studies indicate single or multilevel disc degeneration or disc bulges visible on MRI between 28% to 85% of the adult population, who do not have activity limiting lumbar spine pain. Notably the prevalence of these findings is dramatically higher in the elderly population.

Clinical implications are such that all but the most severe findings of disc degeneration or herniation visible on MRI are non-specific for lumbar spine pain or radiculopathy (Beattie, 1996). The finding of disc abnormality, however, may have a profound effect on a patient’s belief regarding the severity of their clinical condition. A patient who has incorrectly been told that the finding of a degenerative disc is responsible for their symptoms may perceive a higher degree or morbidity than is actively warranted. This perception may lead the patient to believe that their spine is permanently damaged and convincing a patient that the prognosis for acute lumbar spine pain remains favourable despite the abnormalities observed on MRI can be a difficult task (Beattie et al., 2000).

The conclusions Beattie et al. (2000) can be related directly to ultrasound imaging and clinical findings in the patellar tendon from Khan et al. (1997) study on jumpers knee, the Achilles tendon and other unrelated pathologies in the rotator cuff. Pathologies that manifest themselves on imaging are not necessarily relevant clinically. With the expanding usage of diagnostic ultrasound, asymptomatic findings observed by sonographers may have little clinical bearing similar to Beattie (1996) and Beattie et al. (2000) descriptions of MRI and lumbar disc prolapses.

This could lead to numerous medical-legal implications of ultrasound imaging. The pathologic abnormalities observed on ultrasound are often considered as “diagnostic”, similar to MRI or CT evidence and may be important in such instances as personal injury litigation. A sonographer must consider that an anatomical variant may have been present prior to the onset of a patient's symptoms and may not necessarily be causally related to the patient's current clinical condition. For example a degenerative rotator cuff tear on ultrasound may not be the causative factor for a patient's shoulder pain after a fall or accident at work. Conversely, a professional sports person could have full function, but show on ultrasound imaging a partial tear of the Achilles. Does the medical team allow the player to participate? Injury to the player would have significant ramifications when insurances and the finances involved in professional sports are calculated, if further injury was sustained.

The fact that some conditions do not lead themselves to imaging seems self-evident. But all clinicians have seen patients who are frustrated after been told by doctors that nothing is wrong because a number of diagnostic tests were normal. Tendon dislocations, chronic joint instabilities, nerve entrapments and referred pain do not lend themselves to imaging. Diagnosis requires clinical assessment and once these diagnoses are suspected, there may be a role for imaging to rule out alternative diagnoses. Real-time ultrasound in part could play an increasing role in diagnosing tendon dislocations and joint instabilities (Khan et al., 1997).

The more expensive or an increased number of tests are not necessarily the most appropriate for a given clinical situation. Plain lateral radiographs of the anterior ankle in an athlete with anterior impingement, if taken with the patient lunging forward and reproducing the pain, would provide more useful information than bone scan, CT and MRI of that site.

If imaging is warranted the imaging request must include detailed case notes and a well conceived ordered list of differential diagnoses as an absolute minimum, because this improves accuracy or reporting (Beattie, 1996). Certain clinical cases should be listed as "particularly difficult" (e.g. persistent symptoms despite appropriate treatment) and these may require both the clinician and the radiologist to be present at the time of the investigation in order to interpret the films and obtain further specific views as necessary, or indeed select the relevant imaging procedure. (Khan et al., 1997).

It has been suggested that clinical examination is the foremost "clinical tool" when determining whether an athlete returns to sport, or an individual returns to work (Khan et al., 1997; Beattie, 1996; Beattie et al., 2000; Zusman, 1998). Would re-evaluating a musculoskeletal injury on a weekly basis with diagnostic ultrasound, give the clinician an accurate picture of the progress of healing?

Khan et al. (1997) showed that clinical examination is still of vital importance. Diagnostic ultrasound should only be used as an adjunct to clinical examination for clinicians. The clinician who disregards clinical judgement and relies solely on imaging to confirm an athlete's diagnosis or return to sport could be placing themselves and their patient in jeopardy.

Diagnostic ultrasound has a valuable role to play in visualising the progression of musculoskeletal pathologies and injuries. Ultrasound may prospectively be utilised on a daily or weekly basis to evaluate the progress, or lack of progress on tendon pathologies. However it's "clinical role" and to what extent clinicians rely on ultrasound in the re-evaluation of muscle and tendon injuries within the sporting arena, is still yet to be firmly established.

Ultrasound imaging has allowed clinicians to explore, diagnose and aid in the management of patients. However, clinicians should rely on their clinical judgement, experience and diagnostic skills, and utilise ultrasound as an adjunct, to confirm their diagnosis or clarify the extent of the pathology. Diagnostic ultrasound can compliment other imaging modalities such as CT, MRI and x ray.

At present clinical examination should supersede ultrasound examination findings where possible and diagnostic ultrasound findings should be "linked" back to the clinician's initial hypothesis, when planning rehabilitation and management. As suggested there are a number of factors which can influence ultrasound findings, including clinically irrelevant anatomic variants, technical factors (i.e. artefacts) and human error in diagnosing. To rely solely on ultrasound findings without relating them clinically, is detrimental to the clinician and indeed the patient.

3.4 Reliability and Validity.

The review of the literature on the role of ultrasound within musculoskeletal medicine provides evidence that it has significant input into the diagnosis of musculoskeletal injuries and pathology.

Any assessment tool or outcome measure must be shown to be valid, reliable and have repeatability before it can be adopted for clinical or research purposes. An assessment tool or clinical modality is considered to be valid when it is well supported by fact. That is, does the assessment tool or modality measure what it was designed for. Validity of ultrasound imaging would be obtained by comparison to a gold standard such as MRI. Reliability involves assessing the accuracy of repeated measurements made by the same observer and different observers. A reliable piece of research is one which can be redone under similar conditions and similar results obtained. While the repeatability of ultrasound, would involve the same operator obtaining the same results at different assessment sessions and at different days (Allen & Wilson, 1999). It is important that repeatability and validity studies are carried out if ultrasound imaging is to be established as a reliable and suitable assessment and diagnostic tool.

Although the recent literature has provided evidence of the role of ultrasound imaging within musculoskeletal medicine, there are only a limited number of research papers that validate and prove its reliability (Stokes et al., 1997). I am in agreement with Stokes et al. (1997) and believe that the majority of the current literature lacks statistically significant subject numbers, suitable methodology and reliability. Most current papers on the role of ultrasound imaging with musculoskeletal medicine present case studies, research with few subjects or statistically insignificant numbers, or the author's own impressions and personal experiences with the clinical use of ultrasound imaging.

These papers despite their shortcomings do however, impart ultrasound's positive and expanding role within the musculoskeletal arena. There are papers, which explore the validity and reliability of ultrasound imaging (Balint & Sturrock, 2001; Hides et al., 1995; Kalebo, Allenmark, Peterson, & Sward, 1992; Damen et al., 2002). As authors attempt to promote diagnostic ultrasound's role with the musculoskeletal arena, further papers will be required to attempt to validate and effectively clarify the reliability of ultrasound imaging.

In their review of the literature on ultrasound and orthopaedic disorders Allen & Wilson (1999) commented on the validity and reliability of ultrasound imaging, by stating a distinct disadvantage is the dependence on a skilled operator and the long learning curve.

It is easy for the inexperienced sonographer to produce dangerously inaccurate results. Diagnostic ultrasound examinations are very patient-interactive and subjective and the images of an examination previously could not be adequately reviewed away from the patient.

The dynamic aspects of the examination are also extremely important. Advances in computer technology have enabled clinicians to adequately view images “offsite”, thus eliminating this disadvantage. Quality must be monitored by measures of outcome, comparison with the results of other imaging and by correlation with the findings at operation. These tasks require a level of organization and effort, which may be overlooked in a busy medical facility.

However, Allen & Wilson (1999) suggested that ultrasound has a number of established indications, in which its value has been proven in well controlled trials. The authors review of the literature summarised these indications (see Table 6).

Table 6: Established Indications of Ultrasound.

Developmental dysplasia of the hip.
Irritable Hip.
Pathology of the Rotator Cuff.
Soft-tissue Masses.
Tendon and Ligament Abnormality.
Monitoring of Limb Lengthening.

(Adapted from Allen & Wilson, 1999).

Persistent pain in the Achilles tendon that lasts longer than six months may be caused by a partial tendon rupture, which is defined as a partial disruption of tendon continuity with haematoma. This injury is frequently resistant to conservative treatment and surgery is often necessary to relieve the pain. The diagnosis of an underlying partial tendon tear is usually suspected after a physical examination has failed to detect the problem. However, since the causes of Achilles tendon disorders may vary considerably, differential diagnostic problems sometimes occur (Kalebo, Allenmark et al., 1992).

One reason for an unsatisfactory outcome after surgery may be a missed pathologic entity resulting in insufficient exploration of the injured tendon. Hence a reliable preoperative diagnostic method would be beneficial in finding these injuries.

The assessment of the use of ultrasound imaging in the detection of partial ruptures of the Achilles tendon has been limited and its reliability has yet to be established (Kalebo et al., 1992). The author's evaluated 37 patients with surgically treated Achilles tendon disorders, comparing findings of preoperative ultrasound images with findings at surgery, to investigate the reliability of ultrasound imaging in diagnosing partial ruptures of the Achilles tendon.

Discontinuity of tendon fibres, a focal sonolucency and localized tendon swelling were positive findings suggestive of partial ruptures. Kalebo et al. (1992) study found the use of ultrasound imaging to be safe and reliable with a sensitivity of 94%, a specificity of 100%, and an overall accuracy of 95%. From their results the authors suggested that ultrasound showed a number of abnormal findings indicative of a partial rupture. These included discontinuity of tendon fibres and a focal low-echoic intratendinous area often in conjunction with a local thickening of the tendon. In general the signs were either a relatively transverse discontinuity of the tendon fibres combined with a localised oedema and swelling, or a sonolucent area with a loss of normal tendon structure combined with a local tendon thickening. Signs of bursitis such as the swelling of the retrocalcaneal bursa or wall thickening were frequently found in cases with distal partial tears.

Thirty partial ruptures were correctly diagnosed using ultrasound imaging and were later confirmed at surgery. The location of the abnormality as detected by ultrasound imaging correlated well in all cases with the findings at surgery. In five cases surgery was performed in spite of normal diagnostic ultrasound findings. However the surgery and histopathology did not show any partial rupture. Instead unspecific findings such as local oedema, paratendinitis, or postoperative changes were found. The authors did not find any false-positive results.

Kalebo et al. (1992) suggested the term tendinitis is non-specific and poorly defined, it is merely used as a clinical diagnosis in cases of pain in the Achilles tendon that range from diffuse pain to severe local painful swelling and inflammation. Two major signs on ultrasound imaging of partial tears appear to be discontinuity of the tendon fibres with localized oedema and a focal sonolucency combined with a local tendon thickening. Kalebo et al. (1992) concluded by stating the major advantages of ultrasound compared with MRI are its availability and real-time imaging faculty. This study demonstrated the reliability of ultrasound imaging in diagnosing partial ruptures of the Achilles tendon.

Stokes et al. (1997) in their review paper on musculoskeletal diagnostic ultrasound imaging discussed the validation of ultrasound against other imaging techniques. The authors concluded MRI and CT were suitable for assessing the reliability of diagnostic ultrasound images, since both MRI and CT have been shown to provide valid measurement and identification of anatomical structures, pathologies and injuries. The authors provided a discussion of ultrasound's validity, in reference to muscle cross-sectional area. Measurements of quadriceps size made by CT and ultrasound imaging were highly correlated. Diagnostic ultrasound images of the lumbar multifidus muscle were compared with those made by MRI (Hides et al., 1995). Bilateral measurements were made at different vertebral levels and analysis of variance and post-hoc tests showed that there were no significant differences between the cross-sectional area measurements made with the two techniques. However, a strict protocol was used to ensure that the position of the lumbar spine was similar for both modalities, as subjects were positioned prone for ultrasound imaging and supine for MRI. Anatomical landmarks were also used to ensure accurate location of imaging sites (Hides et al., 1997).

Most studies addressing the issue of reliability have only examined repeated measurements by the same operator such as test-retest or intra-rater reliability (Stokes et al., 1997; Read & Peduto, 2000). Certain factors need to be considered when measurements made on different occasions are to be compared. Care in the ultrasound procedure is important and should be carried out in the same way each time. Positioning of the subject influences cross-sectional area, as different limb positions and joint angles will alter muscle length and should therefore be standardized for each muscle. Relocating the scanning site can be aided by using external or internal landmarks. Examples of internal landmarks are the echogenic vertebral lamina when scanning the lumbar multifidus muscle or the tibia and fibula when scanning the anterior tibial muscles. Stokes et al. (1997) concluded in their review article on ultrasound that inter-rater reliability studies of ultrasound imaging are lacking and the authors were unable to find any relevant studies.

Balint & Sturrock (2001) investigated the repeatability and reproducibility of ultrasound measurements at the anterior surface of the femoral neck and iliofemoral ligament. It is a common view that one of the major disadvantages of ultrasound imaging is operator dependency. In diagnostic ultrasound imaging the images generated are mainly qualitative and agreement has to be reached by different observers as to the presence or absence of pathological signs or disease. If quantitative measurements are required, then intra and interobserver errors become more important (Balint & Sturrock, 2001). The authors attempted to determine the magnitude of inter and intraobserver errors using diagnostic ultrasound imaging for the measurement of the distance between the iliofemoral ligament and the femoral neck in 22 hip joints from an unselected group of normal controls and patients with inflammatory joint disease. Individuals with a history of previous hip surgery were excluded from the study. The authors selected the hip because it is a deep joint and not easy to palpate and hip joint effusions are not easily detected by clinical examination. However, the iliofemoral ligament and neck of femur are easily identified on diagnostic ultrasound imaging. There is an extensive literature describing the ultrasound appearances of the anterior hip joint recess on health and disease, but only non-blind studies calculating intra and interobserver errors.

Two independent investigators studied 22 hips. One investigator had previous experience in diagnostic ultrasound within a musculoskeletal setting, the other investigator had undergone a short course in hip sonography for only 3 hours. Balint & Sturrock (2001) stated both investigators were blinded to their own and each other's results. Normal anatomical reference landmarks were established. The femoral neck-iliofemoral ligament distance was measured in triplicate in quick succession. Observers took 10 vertical measurements. Each observer's measurement errors were calculated with within subject standard deviation correlation coefficients were used to assess the linear relation of the 2 sets of mean measurements between the two observers. Balint & Sturrock (2001) utilised 152 images. The first investigators intraobserver error was 4.75%. The second investigators intraobserver error was 7.00%. After 20 examinations the first investigators intraobserver error was 1.11% and the second investigators intraobserver error was 1.47%.

Every image obtained was of acceptable quality. With well-defined anatomical landmarks and with predetermined criteria the interobserver variation between the two observers was acceptable (Balint & Sturrock, 2001). However, for ultrasound imaging of the hip the measurements were taken in the sagittal plane only, as this is the standard approach of the ultrasound image for the hip. Most ultrasound imaging is performed in two different planes which might lead to greater interobserver errors at the same depth. None of the patients studied weighed more than 90kg and it is well known that ultrasound imaging of the hip is less reliable in obese subjects and therefore more likely to increase the possibility on intraobserver variation. The positioning of ultrasound probes is critical in obtaining an interpretable ultrasound image and a slight alteration in the angle of the probe in relation to the skin surface or a variation in the amount of gel used can greatly distort the image obtained and increase the occurrence of artefacts. Musculoskeletal ultrasound is now becoming a tool increasingly used by clinicians, most of whom have had no formal training in imaging techniques. Balint & Sturrock (2001) study demonstrated that a clinician with experience of ultrasound imaging can train a novice within a relatively short space of time to produce acceptable images of the hip and with relatively small interobserver variation.

Damen et al. (2002) utilised the Doppler imaging of vibrations (DIV) technique to measure the laxity of the SIJ. The authors investigated the reliability of SIJ laxity measurements under different conditions, including multiple testers, occasions and repetitions. The results of Damen et al. (2002) study indicated that testing of the SIJ using testers/ observers who were not experienced produced unreliable results with statistically insignificant results. Specific training and experience of a tester/ observer are necessary for reliable SIJ laxity measurements. However, Damen et al. (2002) concluded from their results that the DIV technique for SIJ laxity measurements, when performed by an experienced tester/ observer, who is familiar with sonography, anatomy and the stability of joints, is a reliable technique. Further studies of the DIV technique, which include statistically significant numbers have been suggested by the authors for future studies.

In summary ultrasound imaging needs studies which can provide evidence that it is a reliable and valid diagnostic tool within the musculoskeletal arena. I feel it is clear from the literature examined that there is a distinct lack of the aforementioned studies. These studies should compare ultrasound against MRI or CT, have statistically significant subject numbers, appropriate methodology and be clinically relevant (Allen & Wilson, 1999).

The majority of clinicians who utilise diagnostic ultrasound effectively are highly skilled sonographers with an excellent understanding of anatomy and pathology. However, ultrasound has shown to be operator dependent and subjective and will need to be proven reliable with further controlled testing. As diagnostic ultrasound becomes more accepted clinically and its use within the musculoskeletal and sporting arena expands, further papers and studies will be presented which should clarify and provide suitable evidence for the reliability and validity of ultrasound imaging. Without this evidence the future application of diagnostic ultrasound imaging may be to only be utilised as an “adjunct’ or as an imaging modality “with potential” within the sporting and musculoskeletal arena.

3.5 Safety.

The medical applications of diagnostic ultrasound have dramatically increased in recent times. The development and subsequent incorporation of new technology into a commercially available tool has made ultrasound readily accessible. The increased acceptance of diagnostic ultrasound can partly be attributable to the fact it does not use ionizing radiation.

The expanding and evolving role of ultrasound imaging within the musculoskeletal arena has exposed large populations to this diagnostic modality. Therefore the safety and suitability of ultrasound as an imaging tool needs to be addressed. Stokes et al. (1997), Hough et al. (2000), Whittingham (1999), and Duck (1999) have all suggested that there are no known or proven effects from ultrasound imaging, nevertheless diagnostic ultrasound should be used with care as if there is a risk, since ultrasound is a form of energy with the potential to produce a biological effect on tissue.

Some of the possible mechanisms by which diagnostic ultrasound interacts with matter are, repeated use or overexposure, a thermal effect and cavitation. These physical processes may give rise to the secondary actions of microstreaming and altered chemical reaction rates.

3.5.1 Repeated Use and Overexposure.

The application of ultrasound imaging to musculoskeletal medicine is slightly different from its conventional use, in that its repeated imaging could raise safety concerns. Hides et al. (1998) stated that ultrasound imaging would not commonly be performed once or twice a week for consecutive weeks. Whereas, in a musculoskeletal setting a clinician could utilise ultrasound in a biofeedback situation frequently. Could continued "over exposure" or use of ultrasound for biofeedback, expose the patient to potential mechanical risks? To date there are no known relevant papers dealing with ultrasound's use within a musculoskeletal setting. Further detailed studies are required to explore this possibility.

Whittingham (1999) in his review of ultrasound imaging safety, explored the effects of diagnostic ultrasound on frequent exposure to lung and intestinal tissue. Some animal experiments have shown modified cell adhesion due to the modest but frequent heating associated with exposures and some “unspecified damage” in lung and intestines on small mammals such as monkeys and pigs. Although animal studies provide a good indication of potential damage and can aid in the establishment of suggested levels of safety, they possess limitations with regards to human populations. It cannot be assumed that humans will respond in the same manner as certain species of animals. Nevertheless, observations made in animals are essential in determining the mechanisms of interaction and assessing the risk in humans. At present no human studies with relevant methodology have been undertaken.

Physiotherapists are familiar with the potential of therapeutic ultrasound to induce thermal effects and cavitation caused by high acoustic pressures. However, damage of tissues has not been documented with diagnostic ultrasound imaging. The output (intensity) has been traditionally preset on diagnostic ultrasound equipment and is not adjustable. When the output is adjustable, the lowest available setting, which provides an adequate image to reduce the potential of overexposure, should be selected. While heating and cavitation are recognised bio-effect mechanisms, radiation forces should be considered also. The streaming it causes is the only biophysical effect which may be routinely observed in current clinical practice (Hides et al., 1998; Stokes et al., 1997).

3.5.2 Thermal Effects.

Clinicians need to be aware of the potential safety issues when selecting an output setting and utilise an appropriate setting accordingly. Whittingham (1999) concentrated on the potential thermal effect of ultrasound imaging with obstetric sonographs. A debate with regards to the current literature exists about the thresholds of temperature rise for the human foetus. A temperature rise of 1.5°C is considered to be without hazard even for indefinite exposure, whilst one of 4°C maintained for five minutes should be considered potentially hazardous. The actual temperature that diagnostic ultrasound apparatus generates is difficult to predict and no current research is available to clarify the exact thermal hazard ultrasound potentially could be creating. This potential safety issue can be carried over to diagnostic ultrasound within a musculoskeletal setting with similar concerns for soft tissue.

Whittingham (1999) described a theoretical tissue heating model, using detailed worst-case temporal average intensity. The results indicate that for Doppler mode, temperature rises as high as 6°C might be produced in bone and around 2.5°C in soft tissue. In Doppler mode, some machines are capable of producing hazardous temperature rises but even in B-mode, temperature elevations as high as 1.4°C were calculated for both soft tissue and bone. Most modern scanners can now cause some warming of tissues *in vivo* and may cause bruising of lung surfaces when used at their highest output levels (Duck, 1999).

Hough et al. (2000) studied the measurement of longitudinal nerve motion using ultrasound. The authors suggested that recently there has been a changing acoustic output from diagnostic ultrasound systems and apparatus. Maximum Doppler intensities are usually higher than those of B mode and as previously suggested are being utilised more prominently by sonographers. Could Doppler compared with B mode, be a potential safety or health risk due to its change usage with a higher intensity?

Alteration in regulations in the early 1990's with regards to diagnostic ultrasound apparatus and usage has influenced the way clinicians utilise ultrasound. All new scanners now have display indices which inform those using the machine of its exact output. The maximum intensity which is allowed for diagnostic ultrasound examination in soft tissue investigations has been changed. New scanners and equipment with clinician attention to their output should theoretically minimise the thermal hazard from ultrasound (Duck, 1999).

Duck (1999) in his review article of safety issues in diagnostic ultrasound, condensed a number of reports and articles. Duck (1999) summarised that some ultrasound pulses have the ability to damage tissue when it lies immediately next to gas bubbles, haemolysis can occur in the presence of contrast materials and capillary bleeding can occur in the lung surface. Embryological studies demonstrate developmental changes at exposures a little higher than those used diagnostically. Heating studies show that many diagnostic fields can cause the exposed tissue to be warmed by a few degrees.

However Duck (1999) along with Whittingham (1999) Hides et al. (1998) and Stokes et al. (1997) all have stated that ultrasound imaging has an enviable record for safety. Diagnostic ultrasound is not a form of ionizing radiation and indeed it is partly due to the lack of toxicity of ultrasound imaging which has allowed it to expand, so it is now widely utilised as a diagnostic imaging tool within the musculoskeletal arena. To date the evidence has suggested that ultrasound is safe and presents no actual risk to the patient.

It is essential that in the search for even safer diagnostic efficiency, the pre-eminent place gained by ultrasound, as a safe diagnostic imaging tool is not prejudiced. The expanding use of ultrasound imaging as a feedback tool, it's utilisation in research and its use for monitoring and imaging muscle pathologies will pose further questions with regards to potential safety issues.

Further studies are required to validate the present claim that ultrasound imaging is a safe diagnostic imaging tool and investigations into thermal radiation force and repeated exposure needs to be undertaken and explored. It is the responsibility of those clinicians engaged in the diagnostic use of ultrasound to ensure that it remains a safe, effective diagnostic tool (Hides et al., 1998).

3.6 Conclusion.

The literature has suggested that ultrasound imaging has an expanding clinical usage within the musculoskeletal arena. The primary advantages of ultrasound imaging over MRI, CT scanning and x-ray, are that ultrasound imaging provides exquisite soft tissue detail, is generally cheaper, faster and tolerated better than MRI or CT scanning and can routinely compare the normal side with the abnormal side, improving diagnostic sensitivity. The real-time nature of ultrasound imaging allows the assessment of soft tissue dynamics and is an interactive test improving clinical correlation. Ultrasound imaging is nonionizing, expanding its clinical use to the paediatric and pregnant populations (Read & Peduto, 2000; Jacobson, 1999; Bouffard et al., 1993).

However, as discussed diagnostic ultrasound is a particularly operator dependent modality, that only achieves high levels of accuracy and reproducibility when the sonographer is experienced, with good training and a detailed knowledge of musculoskeletal pathology and anatomy. Plain x-ray, CT and MRI and indeed clinical examination are all still advocated in the diagnosis of musculoskeletal injury and pathology.

To date authors and researchers have generally presented only case studies, clinical usage and research with limited methodology and subject numbers on the role of ultrasound imaging in musculoskeletal medicine. The lack of substantiated research into ultrasound imaging has prevented it from being further utilised. Further studies will need statistically significant numbers, appropriate methodology and will need to be clinically relevant. With this evidence, the future use of ultrasound imaging in musculoskeletal medicine will be clarified and advanced. Ultrasound has an enviable record for safety. This reason alone has allowed ultrasound to expand so it is further utilised as a diagnostic imaging tool.

Medicalising diagnoses with ultrasound and other imaging modalities has been debated. Imaging modalities such as ultrasound have been compared with clinical examination and clinical reasoning. A number of pertinent reasons for ultrasound being an "imaging adjunct" to a clinician have been raised, highlighting the need for sound clinical judgement and accurate imaging procedures.

Numerous studies have shown that diagnostic ultrasound has a current and prospective role to play in physiotherapy within a musculoskeletal setting. Further studies in the role of ultrasound imaging within physiotherapy will eventuate, broadening its use within a physiotherapy setting. Physiotherapists traditionally involved in rehabilitation and treatment will utilise ultrasound increasingly in more non-traditional physiotherapy settings. Physiotherapists could with their excellent knowledge of pathology and anatomy, be trained as sonographers, particularly if physiotherapists plan to utilise diagnostic ultrasound imaging in a research setting or as a feedback tool.

As ultrasound imaging becomes more accepted clinically, through further substantiated research, the demand for diagnostic ultrasound examinations could increase. Technology will also change and advance, decreasing the cost of ultrasound apparatus and therefore maximising the application of ultrasound imaging. This could ultimately lead to an increase in demand for ultrasound examinations, thus increasing the need for sonographers.

Physiotherapists utilising ultrasound as a diagnostic tool or within rehabilitation/ research settings could find themselves being employed primarily as a "sonographer" specialising in musculoskeletal medicine. This however, would require specialised training outside physiotherapy's present scope of practice. Within the near future diagnostic ultrasound could become an integral part of the assessment of musculoskeletal injuries and physiotherapists with this appropriate training in sonography would be well placed to utilise ultrasound in a clinical setting.

Improvements in high-resolution gray scale imaging technology will undoubtedly continue. Development of digital beam formers, two-dimensional arrays along with exploitation of non-linear techniques to achieve higher resolution and use of ultrasound contrast to improve flow sensitivity will all contribute to the utility of diagnostic ultrasound in the musculoskeletal system.

It is essential that members of the radiologic community become familiar with these techniques not only for economic reasons, but also because of the rich complement of future applications of this modality. In addition to improved images of tissue pathology, diagnostic ultrasound may play a role in the functional and quantitative assessment of soft tissues. Prospectively ultrasound could play a role in the evaluation of prosthetic implants, bone mineralisation, cartilage integrity, be used as a feedback tool and used within a research setting. Thus, the role of this modality in future musculoskeletal applications may significantly impact clinical diagnosis and therapy.

This paper has demonstrated the current significant contribution and role of ultrasound imaging within musculoskeletal medicine. Ultrasound imaging will continue to gain further acceptance and use within musculoskeletal medicine as more research and studies are presented which justify and clarify its reliability and validity. As technology changes and advances and new equipment is developed, further, unrealised applications will be bought forward, to advance ultrasound as one of the foremost readily available, cost effective and assessable diagnostic tools within musculoskeletal medicine.

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