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"Sports Ultrasound", advantages, indications and limitations in upper and lower limbs musculoskeletal disorders. Review article

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ABSTRACT

Ultrasonography (US) is a safe and noninvasive imaging modality that is gaining popularity in different medical and surgical fields. Its introduction in musculoskeletal and sports medicine has taken this advanced subspecialty to a higher level. It has the advantage over other imaging techniques with regards to ease of use, availability, comfort and cost. Not to mention, in terms of safety profile, patients are not exposed to radiations, like in x-rays, and it can be performed on patients with metal or pacemaker implants, which are contraindicated in MRI. Standard diagnostic sonography doesn't have any known harmful effects on humans. In this article we will discuss the role of ultrasound in sports medicine, highlighting the diagnostic and interventional indications, uses and limitations.

1. Introduction

The story of the development of ultrasound (US) applications in medicine starts with the history of measuring distance under water using sound waves back in 1826. The term **SONAR** refers to **Sound Navigation and Ranging**. Ultrasound scanners can be regarded as a form of 'medical' Sonar. It was in 1948 that extensive studies on ultrasonic medical imaging were starting to be undertaken in the United States and Japan [1]. Earliest report of US use in the musculoskeletal system dates back to 1972 when Baker's cyst was differentiated from thrombophlebitis [108]. Then in 1978 US was utilized to demonstrate synovitis and evaluate the result of treatment in rheumatoid arthritis [109].

Ultrasonography (US) use is a non-invasive imaging procedure. At odds with X-rays and computerized tomography (CT) scan, it doesn't expose the patient to ionizing radiation, and unlike magnetic resonance imaging (MRI), it's considered safe even in patients with cardiac pacemakers and metal implants and in those with claustrophobia. Overall, standard diagnostic ultrasonography doesn't have contraindications.

Application of US in medical and surgical fields covers many subjects starting from gynecology and obstetrics, urology, general surgery, vascular and orthopedics surgery. Its appeal in orthopedic surgery was due to its low cost, non-invasiveness and easy availability in clinics or as portable devices. Add to it, the high resolution images and real-time assessment give the magnificent diagnostic benefits to orthopedic ultrasound, hence often referred to as the "orthopedic surgeon's stethoscope" [2,3]. Having a wide range of use within sports medicine that are not just restricted to orthopedics, the American Medical Society for Sports Medicine recently proposed changing the name of ultrasound used within medicine from "Musculoskeletal US" to "Sports Ultrasound" (SPORTS US) as a more accurate delineation of the broad and unique application of ultrasound in this sub-specialty [4,5].

Conventional ultrasound shows the images in thin, flat slices of the body. Developments in ultrasound machinery include three-dimensional (3-D) ultrasound that displays the sound wave data into 3-D images.

2. Discussion

2.1. Indications and general consideration

The indications of US use in sports medicine have increased substantially in the last few years. Yet, if used correctly, it can lead to significant reductions in healthcare cost. Parker et al. [6] estimated that replacing MRI with ultrasound for the evaluation of specific shoulder pathology would save the United States $6.9 billion in health care costs between 2006 and 2020. Moreover, Middleton et all [7] established that for assessment of shoulder problems patients opted for diagnostic

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US rather than MRI. The Institute for Healthcare Improvement has established an Initiative referred to as the Triple Aim [8], the objectives of which are to improve the patient's experience of care (including quality and satisfaction), Improve population health, and lower healthcare costs. Ultrasound has all of the elements required to meet this triple aim.

The images produced by US are exquisite. It is able to delineate anatomy of structures in relation to their echo textures. In other words, images are created based on physical changes in composition while, with MRI, images are provided based on chemical changes in the structures. They yield higher resolution images of superficial soft tissue anatomy than any other modality including MRI [3,5]. This helps in earlier detection of pathologies, causing tiny calcifications in soft tissue, tendon tears or reparative hypertrophic changes on bone surfaces, than with x-rays, CT or MRI [9,10].

Moreover, and most importantly, ultrasonography is a hands-on and interactive examination where you can interact with the patient while imaging [11]. Additionally, we can't undervalue the significance of the dynamic real time diagnostic capability of the sports US in assessment of joints, tendons movements and stability, ligamentous injury, nerve compression, structural abnormalities, infection and detection of fracture nonunion [11,12].

Apart from its diagnostic utility, US imaging is ideal for guiding most musculoskeletal interventional procedures [13–17]. Real-time ability to intervene and check the response is beneficial for therapeutic techniques, like aspiration of a joint or cyst, and guiding biopsy of soft tissue masses [18–22]. Repeatability is another feature as well, helping in monitoring the disease progression (e.g. in partial tendon tears) and response to treatment. Worth mentioning is the ability to compare targeted findings with those of the contralateral side. Summary of SPORTS US advantages in Table 1.

Despite its several advantages, its user dependency and thus the lengthy training period might appear as a relative limitation/challenge against its wide use in sports medicine. Operators should be familiar with the limitations of US examination which are summarized in Table 2. US produce a high resolution picture of a small area under examination. When patient presents with a diffuse shoulder pain, then it's wise to consider MRI or CT scan studies. The limited penetration of US into deeper structures presents difficulty in assessing deep body regions, morbidly obese patients and areas deep to bone, e.g. sub acromial space or inferior border of clavicle [23].

2.2. Basic technical consideration

At the time of examination, comprehensive knowledge of anatomy is required. Likewise accurate selection of US machine, settings and a sound review of the US machine manual. Probe selection can be crucial for optimum visualization. In summary (Fig. 1), lower-frequency curvilinear probes (3–5 MHz) target deeper structures, like knee and hip joints [24,25], they allow deeper US penetration which come at the cost of poorer resolution [26]. At the other side, higher-frequency linear probes (7–15 MHz), lack the depth penetration of lower-frequency probes, but provides marvelous resolution and images, hence it is used for injecting superficial structures [27,28]. High frequency, hockey stick transducers have a smaller footprint and permit better contact between small irregular surfaces, improving probe contact and visualization, hence ideal in guiding injections around the foot and hand [29].

Table 1
Advantages of SPORTS US.

Non invasive
No radiation exposure
Portable (availability)
Relatively inexpensive
Safe in patients with pacemaker and metal implants
No claustrophobia
Higher resolution images of superficial soft tissue anatomy than MRI
No known contraindications
Real time assessment
Dynamic examination
Can interact with the patient while imaging
Rapid contralateral limb examination for comparison
Repeatability to monitor disease progression or treatment
Guide procedures (injections, aspiration, biopsy)

Table 2
Disadvantages and limitations of SPORTS US.

Technique	Limited field view
	Incomplete evaluation of bones and joints
	Limited penetration
Operator	Experience dependent
	Lengthy training period
	Dearth of certification development

Fig. 1. Commonly used ultrasound transducers in musculoskeletal ultrasound. Left, High-frequency (15-7 MHz), smallfootprint, linear array transducer, also called a “hockey stick” transducer. Center, High-frequency (17-5 MHz) linear array transducer. Right, Low-to medium-frequency (5-2 MHz) curvilinear array transducer. Both linear transducers are used for superficial imaging, whereas the curvilinear transducer's lower frequency facilitates examination of deeper regions such as the hip (Philips iU22 Ultrasound Machine; Philips Medical Systems, Bothell, WA).

2.3. Shoulder

Shoulder disorders are extremely common. One in three people experiences shoulder pain at some stage of his/her life [30]. It is the most common musculoskeletal symptom after cervical and lumbar pain [31]. 30% and 70% of such shoulder pain arises from pathology of the rotator cuff [32,33]. Rotator cuff tears are the most common non-traumatic upper limb cause of disability in people over 50 years. Given the popularity and the availability of high resolution transducers, US is at the forefront as a diagnostic tool in many patient with shoulder pain [34,35].

Recent studies utilizing arthroscopy or MRI for validation of ultrasound have demonstrated sensitivities of 58–100% and specificities of 78–100% for full-thickness tears [36,37]. In certain cases, the lower values reflected investigator bias or poor-quality equipment. Studies using current machines and skilled operators report a high overall accuracy of 96%, a sensitivity of 100%, and a specificity of 85% [38]. In experienced hands ultrasound can identify the presence and extent of partial-thickness and even full-thickness rotator cuff tears with an accuracy similar to MRI [39–44].

Some operators prefer to face the patient and others favor standing behind when scanning over the patient's shoulder [45,46]. Structures orientation in (Fig. 2).

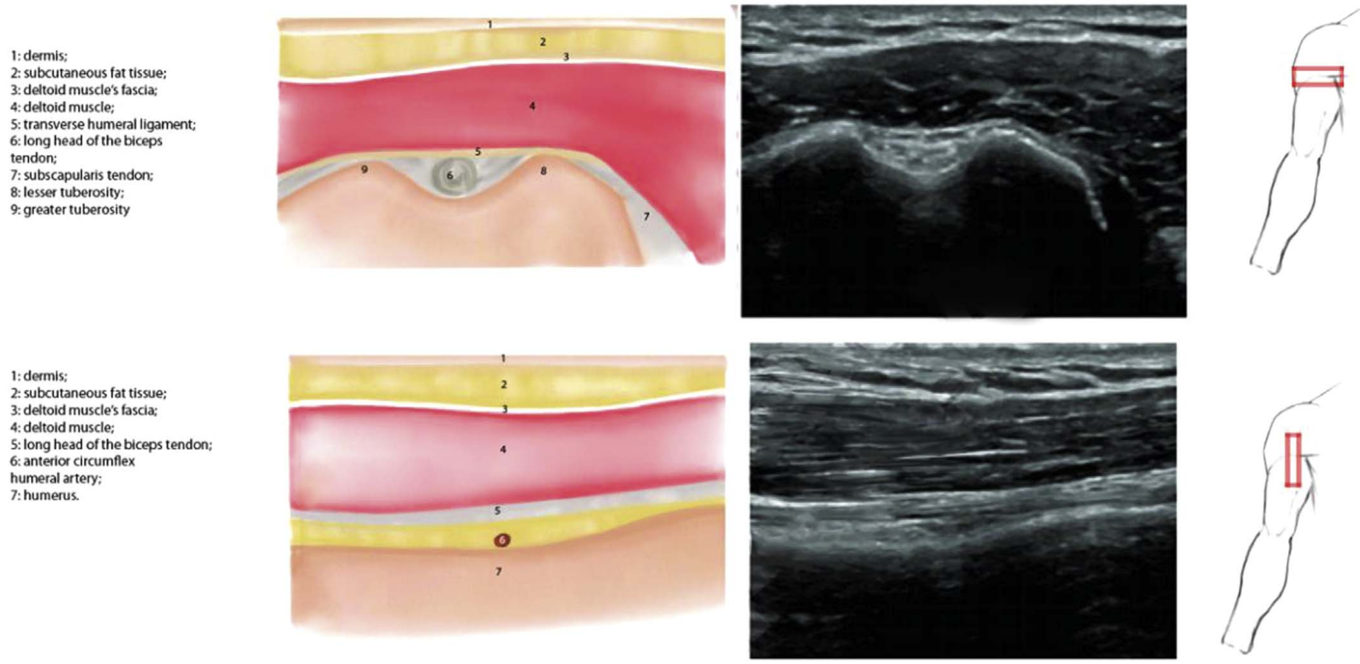

Fig. 2. US image at shoulder region and structures orientation.

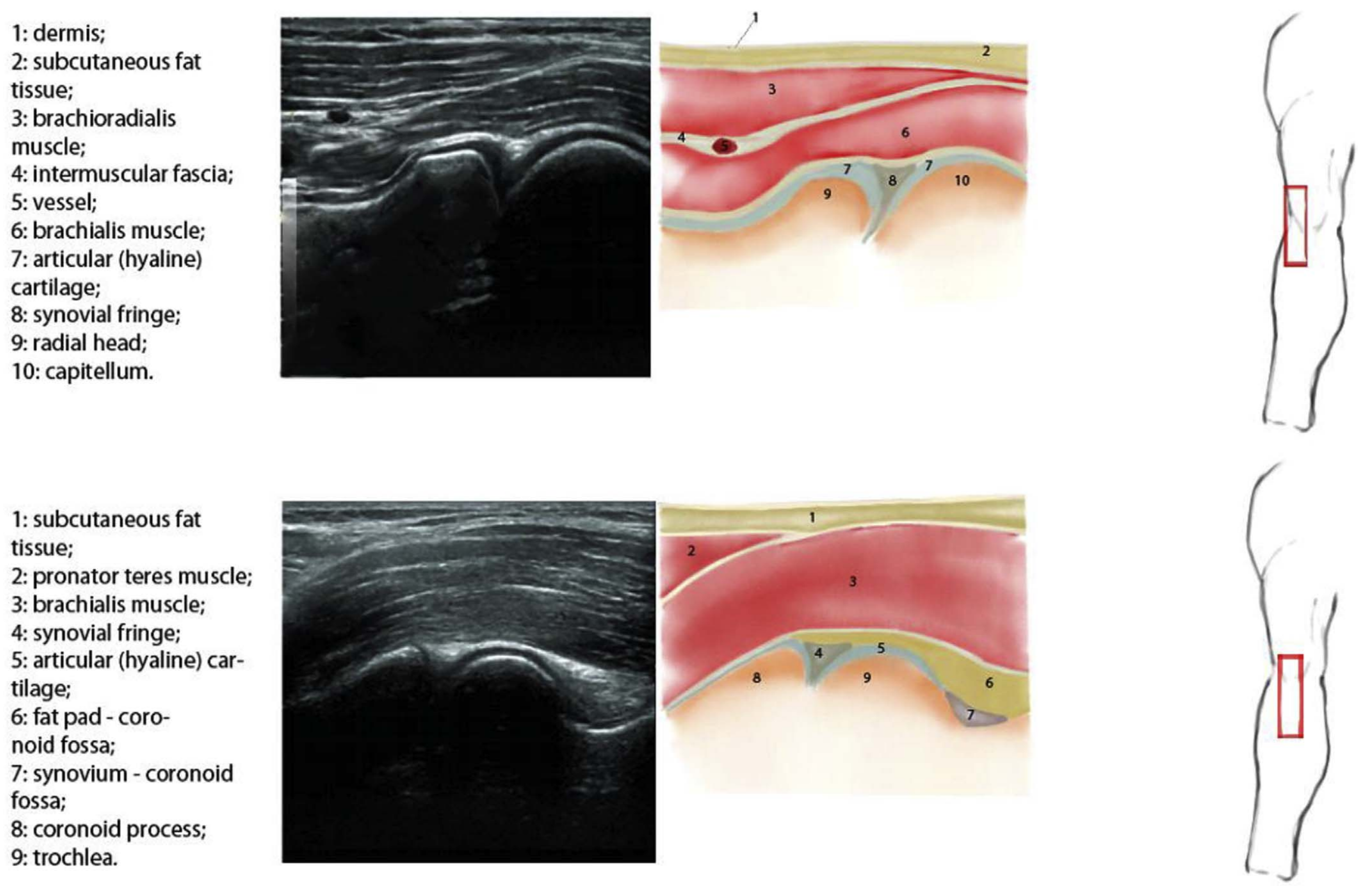

Fig. 3. US image at elbow region and structures orientation.

US is used to identify and distinguish tendon disorders affecting the biceps and rotator cuff, including biceps tenosynovitis, tendinosis, and partial- or full-thickness tears [47,48].

Ultrasound provides significant advantages over MRI and CT scans to evaluate the postoperative shoulder, diagnostic evaluation is most commonly performed to exclude rotator cuff tear after rotator cuff repair or total shoulder arthroplasty [49]. Examination of the post-operative shoulder is one of the most challenging diagnostic musculoskeletal examinations and should only be performed by experienced practitioners [50].

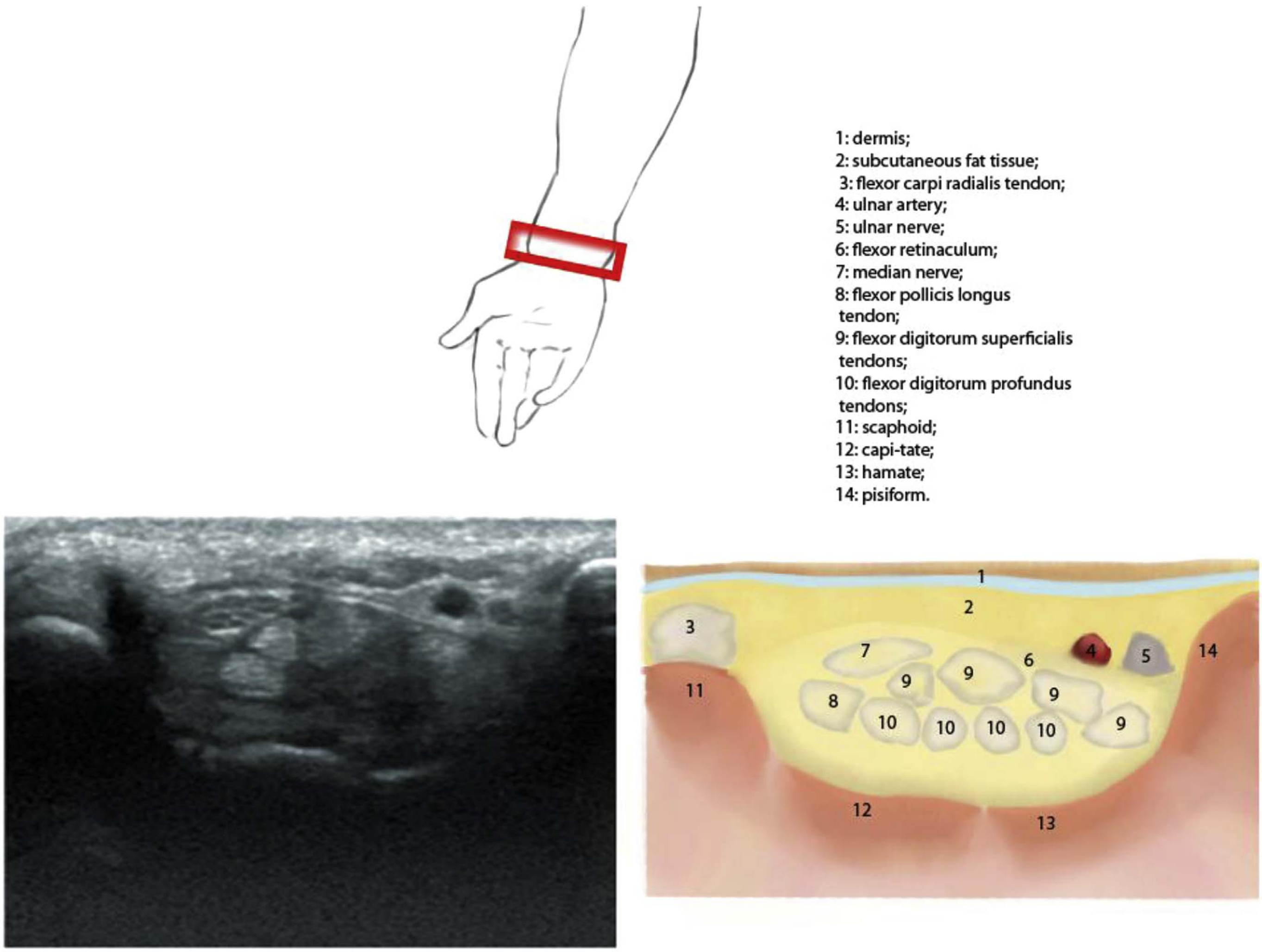

Fig. 4. US image at wrist region and structures orientation.

The subacromial bursa is frequently affected by rotator cuff pathology. A pathologic subacromial bursa appears thickened (> 2 mm) and hypoechoic. There may be a fluid collection at its dependent side 3–4 cm distal to the rotator cuff attachment on the greater tuberosity. This is called as the "teardrop" sign. Ultrasound cannot differentiate between septic and aseptic pathology of the bursa and for that aspiration, preferably under US guidance is mandatory [104].

US use in shoulder examination as in other region in the body is imperfect in obese patients and views of the tendons are limited in patients with severely restricted range of motion. US cannot be used to directly image the subacromial space, hence retracted end of torn tendon can't be accessed in this position, and it offers no information about the inferior surface of the acromioclavicular joint or beneath the bone surfaces [51].

2.4. Elbow

Elbow is another superficial structure which makes US a superior modality of examination above other modalities [3,5]. This superficial location is supplemented by use of high-frequency linear transducers resulting in outstanding image quality. Furthermore; accessibility, direct patient interaction, which helps to correlate with site of pain and allow dynamic real-time assessment, intervention and ability to compare with contralateral elbow are all added benefits of US over other techniques [18–22]. Dynamic imaging is particularly helpful in assessing the collateral ligaments, subluxation of the ulnar nerve or triceps tendon, and intra-articular bodies [52]. US examination of the elbow joint can be done with the patient seated and the elbow placed on an examination table or with the patient supine. Numerous US techniques like extended field of view, spatial compound sonography, and harmonics can improve diagnostic imaging [53]. Structures orientation in (Fig. 3).

It's usually the symptomatic area to be examined but it's recommended to have a systematic approach for a complete evaluation of elbow with its three joints (radiocapitellar, ulnotrochlear, and proximal radioulnar), muscular attachments and neurovascular structures. To simplify the approach is to divide the elbow into anterior, lateral, medial, and posterior compartments [54]. Each having its structures and pathologies which are beyond the scope of this article.

2.5. Wrist and hand

Numerous pathological conditions around the wrist and hand can be amenable to the US diagnosis and guidance as all those involved, are superficial structures. Using high frequency US with "hockey stick" probe gives superb images (Fig. 4). These conditions include joint swelling, inflammatory conditions like tenosynovitis or tendinitis, trigger finger, ganglia and osteoarthritis. US can guide therapeutic procedures which account for up to 35% of all upper limb procedures like aspiration and tendon sheaths or joints injections with De Quervain's disease being the most frequent [55–57]. It's reported to increase procedure accuracy as compared to palpation guided procedures [58].

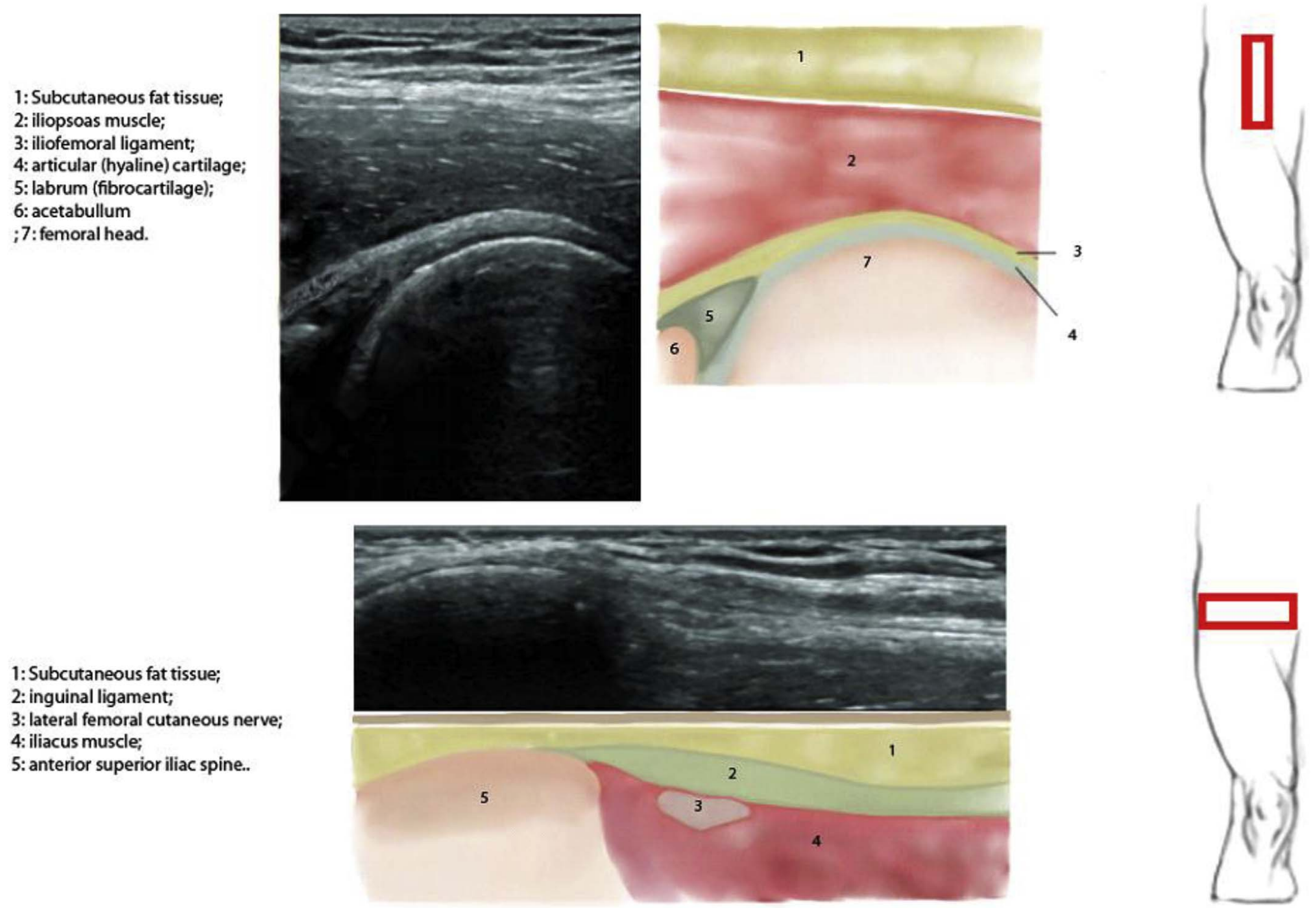

Fig. 5. US image at hip region and structures orientation.

Needless to say all ultrasound-guided interventional procedures can be achieved easily in ward or clinic but should be done with strict aseptic technique in order to avoid any risk of contamination by infectious organisms [59,60].

2.6. Hip

Five to Six percent of adult sport related injuries and 10–24% of injuries in children are related to hip pathology [61–63]. Whether the patient is a seasoned veteran or a fan who practices with his friends. Age plays a huge part in diagnosing the hip pathology. Children as young as 2–12 have been reported with muscle/tendon strains, ligament sprains or contusions in 62% of acute injuries [64]. In Adults, athletes have a risk of developing Osteoarthritis of the hip with the men being 4.5% more likely to develop osteoarthritis, the risk increases to 8.5% in veteran athletes [65]. Out of all the physically demanding sports, Ballet Dancers have been reported to have the most hip related problems [66,67]. Structures orientation in (Fig. 5).

High Frequency US excels at visualizing superficial injuries like Muscle and/or Tendon Sprains, Ligament Tears and Contusions whilst low frequency US allows diagnosis of extra-articular collections like hematomas, seromas [68,69] bursal collections [70], common bursal inflammations of the hip region as well as determining if any fluid collection can be drained properly [71]. Often the injuries of the deep structure create confusion to the sonographer by mimicking other injuries, as is the case of illiopsoas bursitis mimicking an inguinal hernia; for such cases, a dynamic ultrasound and instructing the patient to move allows proper assessment and diagnosis. Ultrasound is also capable of diagnosing bone pathologies like, occult fractures, bone erosions [72,73], synovitis and the early diagnosis of arthritis [74].

Ultrasound is already the primary imaging modality when it comes to extra articular pathologies of the hip region like fluid collections, joint degeneration, hip dysplasia, hip trauma, capsular laxity [75–77] and labral tears [78,79] and any kind of capsular enlargement/Fluid collection in or around the joint and prosthesis [80,81]. By comparing the difference between the affected hip joint with the unaffected, the Sonographer can estimate the level of the pathology.

2.7. Knee

Sonographic assessment of the knee is fairly simple because of its superficial anatomical landmarks which are often visible to the naked eye, thus the most common injuries are readily visible and easily assessable (Fig. 6). Excluding the Bone pathologies, the common Knee pathologies are of the soft tissues, such as: Tendon/ligament tear, sprain, fluid collection [82,83], meniscus tears and cysts, contusion, fracture and dislocation of the patella [84,85]. US have limitation in visualizing the menisci as only the peripheral parts can be seen as compact hyper-echoic triangular structures. One should suspect presence of tear in presence of irregular hypo-echoic clefts within the substance of the menisci [105].

It has been noted that assessing tendons/muscles in CT and MR Imaging is somewhat challenging on account of the muscles/tendons running oblique to one another, this is not the case in sonography where one can scan/visualize the muscles in their entirety by running the probe up/down the muscle, practically isolating the muscle for

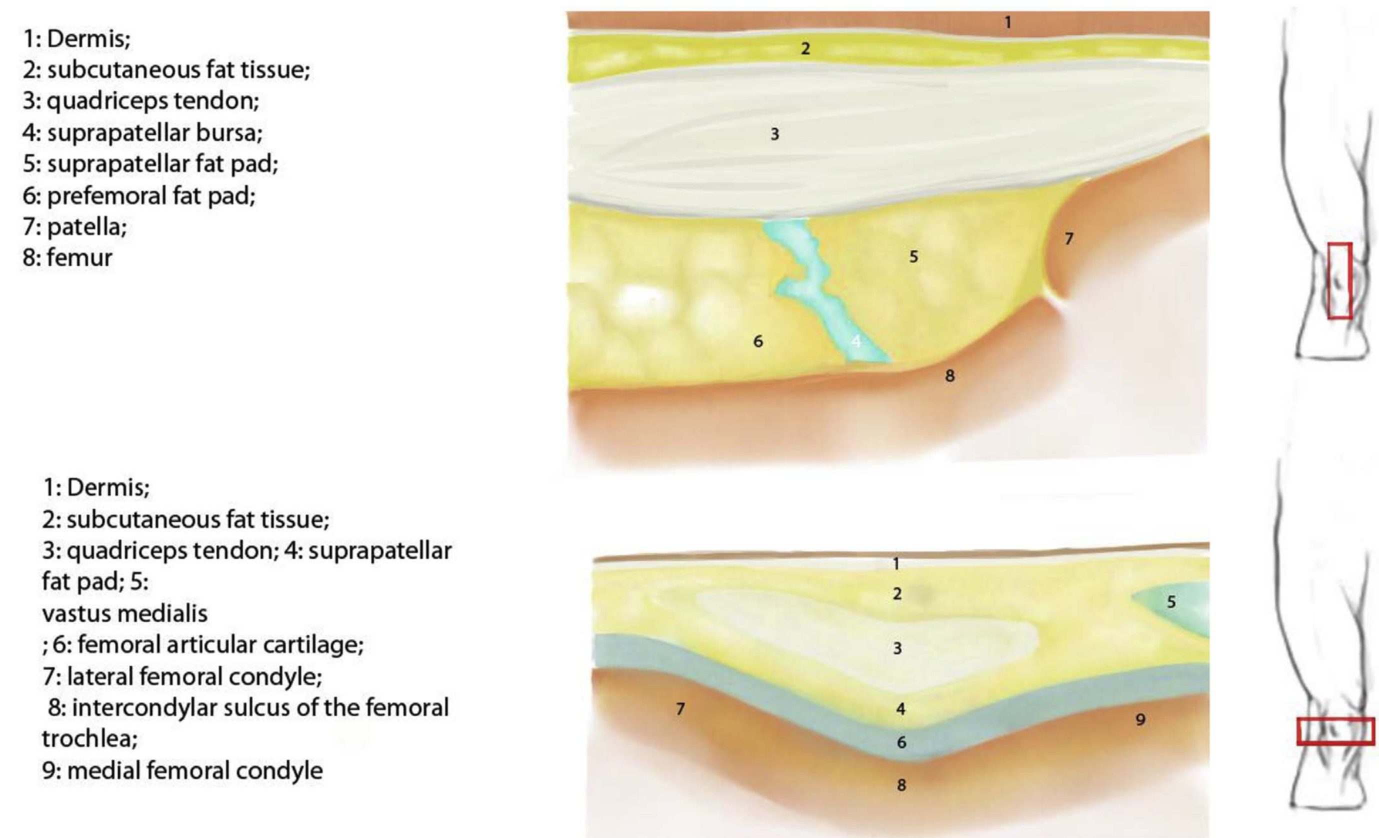

Fig. 6. US image at knee region and structures orientation.

scrutiny. By noting the disruption in the tendon striations, normally seen as parallel lines of dense and hypo-dense echoes, the sonographer can accurately diagnose the point of the tear or hematoma [86]. Of the deep structures, the Cruciate Ligament pathologies are best left for MR Imaging on account of the severity of the injuries that commonly involve them, yet US has been successful in assessing the Cruciate Ligament injuries enough to diagnose the type and degree of the injury [87,88]. That's true for posterior cruciate ligament (PCL) which can be visualized from a posterior approach as enlargement of the normally hypo-echoic ligament when compared to the contralateral normal PCL [106].

Doctor Jay Smith, MD, a physician at the Mayo Clinic in Rochester, MN, presented “Clinical Applications of Musculoskeletal Ultrasound in Sports Medicine” at the 20th Annual American Medical Society for Sports Medicine Meeting. The conference, with over 1000 sports medicine physicians from across the United States and 5 countries around the world featured several lectures on advances in sports medicine. Dr. Smith highlighted several areas where musculoskeletal ultrasound was helpful with the in-office care of patients. Specifically he presented two cases demonstrating quadriceps contusion and MCL injury where ultrasound showed calcific areas that were undetectable on MR and X-ray. Dr. Smith said, “Ultrasound can show calcium deposits sooner than other imaging modalities.” He added, “musculoskeletal ultrasound has established itself as a significant diagnostic tool in musculoskeletal medicine and sports medicine [89].” Furthermore US can be used in intervention and guide procedures around the knee especially injections. Joint can be missed by palpation method. American Medical Society for Sports Medicine had a recent statement regarding ultrasound-guided procedures. They concluded that mean accuracy of ultrasound-guided knee joint injections versus palpation-guided injections was 97% and 77%, respectively [107].

2.8. Ankle and foot

Injuries around the ankle are usually superficial, making them amenable for US examination. Sports Injuries are mainly ligament/tendon tears, tendinosis, dislocation, tenosynovitis, sprain, rupture and tarsal fractures of the foot. Ultrasound is more sensitive to Ankle/Foot injuries as compared to MR Imaging thanks to its higher spatial resolution when scanning superficial structures with a high frequency probe [90,91]. Physical assessment of an injured ankle/foot can be very challenging because of the inflammation and increased tenderness thus Ultrasound is the primary imaging modality for injuries of the ankle/foot [92,93].

Dynamic scans allow the sonographer to visualize the injury from all points and by applying certain pressure tests, the sonographer can even predict the level of injury and evaluate each tendon individually and fully unlike in MR Imaging where all tendons are clumped together [94–96]. By noting the tendon impingement during motion, the sonographer can diagnose an osseous abnormality otherwise not found in radiology [97]. Pathologies of the Achilles tendon are fairly common in athletes and are difficult to diagnose using MR Imaging but are easy to diagnose using Ultrasound with slight physical manipulation of the injured area [98].

In athletes involved in professional running and jumping [99,100], the most common foot pathology is the rupture, inflammation of the plantar fascia presenting as heel pain. The risk of developing Plantar Fasciitis is increased in athletes suffering Achilles tendon disease [101]. There are many causes of heel pain, thus diagnosing plantar fasciitis can be challenging without Ultrasound which has been reported to have 80% sensitivity and 88.5% specificity [101,102]. Ultrasound has also shown high accuracy in detecting metatarsal bursitis and metatarsal fractures due metatarsalgias [103].

3. Conclusion

In summary, US use in sports medicine is very promising and cost-effective in diagnosing conditions related to joints, tendons and muscles as well as therapeutic procedures like aspirations or injections. It's superior to MRI in some instances. Moreover US is a technique without proven contraindications. It's the stethoscope of an orthopedic surgeon. The only limitation is the learning curve which can be overcome by proper training and experience.

Ethical approval

Review article applicable for exemption by our Ethical Review Committee ERC.

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Author contribution

Obada Hussein did the writing of first draft.

Naveed Baloch helped in writing, editing, and supervision of the manuscript.

Mir Muzamil Jessar in writing and ultrasound pictures and figures.

Soichi Hattori helped in writing.

Shin Yamada in editing and supervision.

All authors read and approved the final manuscript.

Conflicts of interest

No conflict of interest.

Research registration unique identifying number (UIN)

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Guarantor

All authors accept full responsibility for the work.

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