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REVIEW ARTICLE

Application of Ultrasound in Sports Injury

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The ability to make correct ultrasonographic diagnosis in sports injuries is improving as advancing technology allows for high-resolution images in contemporary medical ultrasound. Ultrasonography demonstrates tissue structure with two-dimensional grayscale images. Blood flow in the tissue can be rapidly depicted with color and power Doppler technique. Furthermore, ultrasonography is the preferred imaging modality to study soft tissue lesions dynamically. With high-resolution images afforded by ultrasonography, injuries of the muscle, tendon, ligament, bursa, bony structure, cartilage, and subcutaneous tissue can be accurately diagnosed if the examiner is well trained. A panoramic view makes the ultrasonographic images better understood by the sports clinicians. The advanced technique of sonoelastography examination, which facilitates understanding of stiffness in the soft tissue, is also a potential tool in diagnosis of sports injuries. Recently, compact ultrasound machine machines are becoming increasingly available, leading to prompt ultrasonographic diagnosis of sports injuries on the field. In this brief review, we will discuss common sports injuries of these structures, their clinical implications, and ultrasound key points.

Introduction

The resolution of ultrasound images has improved rapidly in recent years. Ultrasound machines with high-frequency (12–15 MHz) linear array transducers provide better image resolution and are widely used to evaluate superficial soft tissue structures such as muscle, tendon, ligament, and bursa. They are therefore commonly referred to as musculoskeletal ultrasound (MSUS) machines. Grayscale techniques provide anatomic pictures for target lesions, while color and power Doppler detect soft tissue vascularity. Panoramic images depict extended fields of view that can demonstrate the whole vision of lesions and their relationship with adjacent structures. The availability of compact portable ultrasound machine makes it possible for physicians to perform real-time assessment for patients. On the event field, sports practitioners can now perform

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prompt scanning, draft an exact treatment protocol, and start treating the injured athlete immediately [1]. Indeed, MSUS is recommended as the first line imaging tool to evaluate sports injuries [2].

In this article, applications of MSUS to common sports injuries will be reviewed. The limitations and possibilities of further development of MSUS will also be briefly discussed.

Application of MSUS to the muscle in sports injuries

About 30% of sports injuries occur in the muscles [3]. Most acute muscle injuries occur from violent eccentric muscle contractions or a direct blow to the muscle, and usually occur at the myotendinous junction [4,5], especially for the muscles crossing two joints [6]. Magnetic resonance imaging (MRI) provides accurate diagnosis to an acute muscle injury but the equipment is usually reserved for medical use [7]. MSUS provides compatible resolution to visualize the normal and injured muscle structures and is available on the field to assess the severity and extent of injury.

Muscle injuries can be classified into three degrees according to their severity [3]:

1. First degree injury: In this class, muscle injury is subtle, and loss of muscle function is insignificant. Nevertheless, there are changes of echogenicity and integrity of the perimysium under ultrasound examination. Loss of normal pennate pattern of the perimysium (Fig. 1A) can be detected if the transducer is properly placed. Comparison of the muscle lesion to the sound side is recommended for grading the severity of the injury.
2. Second degree injury: In this class, parts of fibers in the muscle belly are torn and are usually diagnosed as a partial muscle tear. The function of target muscle is affected clinically to a variable extent. Ultrasound is extremely useful in localizing and measuring the size of partial tears. Localized hypoechoic or anechoic area can be depicted in such partially torn muscles (Fig. 1B). Subtle ruptures of muscles can by asymptomatic clinically. However, the gap of fibers may be widened and becomes evident in ultrasonography especially when the affected muscle contracts. Thus, dynamic ultrasonographic study with active movement of the affected muscle should be routinely performed in suspicion of muscle injuries.
3. Third degree injury: In this class, full-thickness rupture of the muscle happens (Fig. 1C) and loss of function can be significant. Ultrasound is useful in both determining the extent of injury and finding the torn ends of the muscle for surgical repair.

Hematoma usually develops later within the torn muscle. It always causes functional compromise of the involved body part. Serial sonographic follow-ups help in understanding the process of healing. In follow-up examinations, this study found that the injured muscle may be replaced by fibrotic tissue, which reduces in its elasticity and strength. For elite athletes, ultrasound provides valuable information about healing of muscle injuries and help physicians to determine appropriate timing for returning to fitness [8].

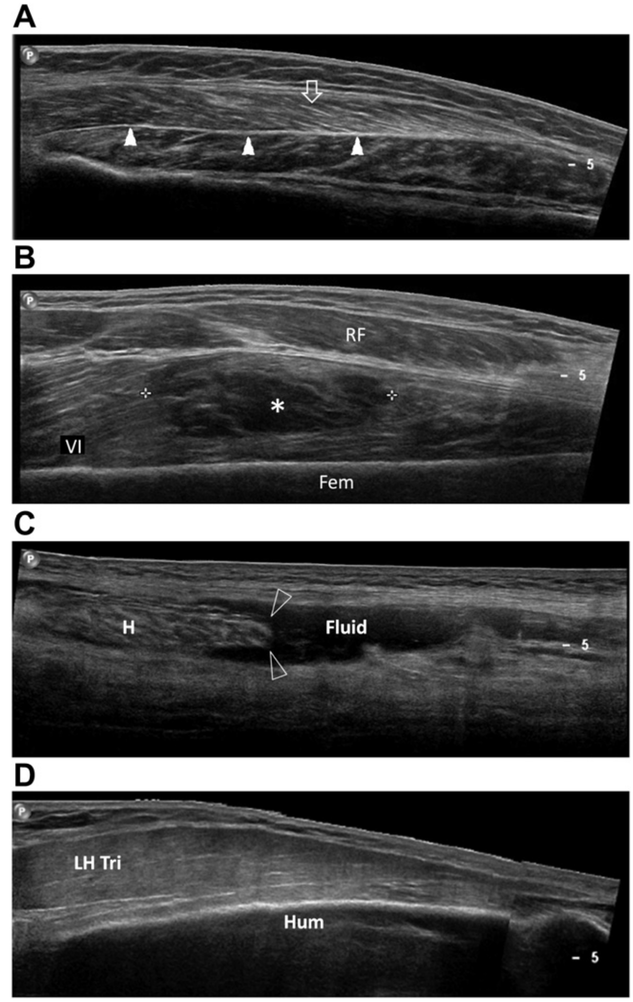

Fig. 1 Ultrasound pictures from various pathologies of the muscles. (A) Normal sonographic picture of the muscle. The perimysiums depict parallel echogenic lines (open arrow) and the fascial (arrowheads) between the muscles. (B) Partial tear of the muscle showing hypoechoic area (*) in the vastus intermidialis muscle (VI) between rectus femoris muscle (RF) and femoral bone. (C) Complete rupture of right hamstring muscle (H). Margin of ruptured muscle (open arrowheads) can be seen in the anechoic fluid. (D) Rhabdomyolysis of long head of triceps muscles (LH Tri) showing diffused echogenic change of the muscle. The perimysiums in the muscle are hard to identify.

Sports-related rhabdomyolysis is a severe and potentially life-threatening condition [9]. Exertional rhabdomyolysis usually follows prolonged or strenuous exercise such as marathon running [10,11] and body building [12,13]. Exercise in a high-temperature environment leading to hyperemia is also a cause of rhabdomyolysis [14]. Without prompt treatment, acute renal failure may develop. Clinical presentations as well as laboratory data and MRI establish good diagnosis for this disease. However, ultrasound provides direct visualization of the echogenicity change and perimysial breakdown of the affected muscle (Fig. 1D).

Application of MSUS to the tendon in sports injuries

MSUS plays an important role in evaluation of tendon injury. MRI is able to detect the integrity of tendon structure, whereas MSUS helps to depict detailed intratendinous pathologies. Alterations in echogenicity, thickness, shape, contour, or blood flow indicate possible tendinopathy. Fluid around the tendon or in the tendon sheath can also be easily identified under ultrasound.

When scanning the musculoskeletal system, especially the tendons, it is important to minimize anisotropy [15,16] by keeping ultrasound beams from the transducer perpendicular to the site of interest to allow maximal signal reflection. Tilting or tiptoeing of the transducer improperly may cause more refraction than reflection and thus the echogenicity of target structures may be reduced. The lesion may be falsely graded as hypoechoic or even anechoic. Such technical pitfalls may result in false diagnosis of tendinopathy or rupture in a normal tendon.

With color or power Doppler techniques, the intra- or peritendinous vessels can be easily identified without additional contrast medium (Fig. 2). Hypervascularity in the injured tendon is compatible with inflammatory process after injury. Degree of hypervascularity may be proportional to the intensity of inflammatory pain in a hyperemic tendon [17]. For example, Osgood—Schlatter lesion, a common sports related apophyseal lesion in young athletes, may be extremely painful or completely asymptomatic [18,19]. The typical sonographic appearance is bony irregularity at the tibial insertion of distal patellar tendon (Fig. 3A). Hypervascularity under color Doppler suggests active inflammation of the lesion (Fig. 3B), which may direct a physician to advise the athletes to rest their knees.

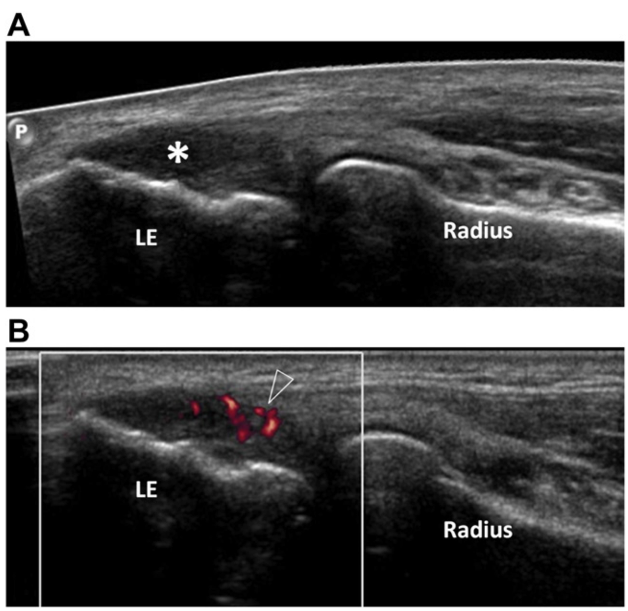

Fig. 2 Sonographic pictures of common extensor tendon at lateral elbow. (A) Hypoechoic change of the tendon (*) at its insertion to the lateral epicondyle (LE). (B) Intratendinous hypervascularity (open arrowhead).

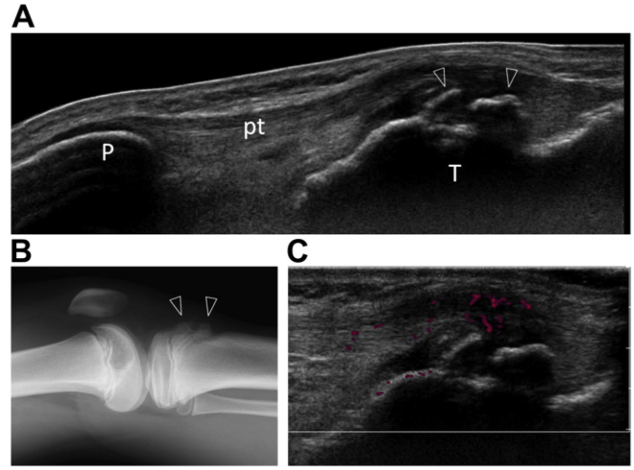

Fig. 3 Sonography from a 10-year-old male athlete. The patient complained of a painful lump at his anterior knee. The clinical diagnosis was Osgood—Schlatter syndrome. (A) Sonographic appearance of anterior knee shows patellar tendon (pt) inserting to tibia (T) and patella (P). Note the irregular margin of the tibial insertion (open arrowheads) compared to that of the smooth margin at patellar insertion. (B) Lateral view of roentgenogram of his knee shows identical bony irregularity (open arrowheads) at tibia. (C) Power Doppler ultrasonography depicts increased blood flow in the affected tendon.

Hypervascularity is not obligatory in chronic tendon injuries or tendinosis (chronic degeneration of tendons). In this stage, anti-inflammatory agents may show reduced treatment effect. An ultrasound-guided injection of sclerosant [20] or platelet-rich plasma [21] may be helpful in dealing with such tendinopathy.

Rupture of tendons is common in sports injuries. In such cases, examiners should determine the location and measure the extent of ruptures. Any change in echogenicity, thickness, and continuity from normal tendon should not be overlooked. In a sheathed tendon, well-margined fluid in the intact sheath might disguise a torn tendon as severe tendinosis because of their marked hypoechogenicity. Chronic tendon rupture in which the injured tendon is replaced by echogenic fibrotic tissue can also be overlooked.

Dynamic views should be part of the standard examination for tendon lesions. Scanning of a moving tendon provides information of its interaction with the surrounding tissues. For example, dynamic examination with passive or active abduction of the shoulder may reveal impingement of an abnormal rotator cuff or bursa by the coracoacromial arch [22]. Another common clinical scenario is "climber's finger" [23,24]. In this situation, the annular pulleys of flexor tendons in the fingers are torn in sports injury such as rock climbing. The practitioner can scan the target flexor tendon along its long axis as the finger flexes resistively. With this maneuver, the tendon may be displaced from the volar surface of phalanx due to pulley rupture and is straightened to form a typical bowstring appearance (Fig. 4B).

Steroid injection is a commonly used procedure in managing sports injury. Injection to the peritendinous structure in an acute tenosynovitis or peritendinitis is very

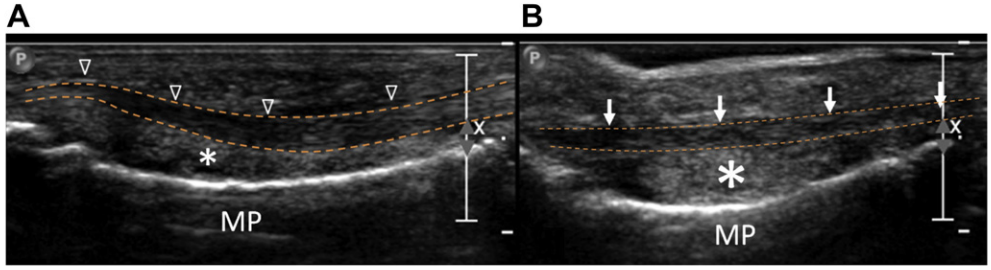

Fig. 4 Sonographic appearance of "climber's finger" shows (B) straightened flexor tendon (arrows) compared to (A) normal curved shape (open arrowheads). The margin of tendons is marked with broken lines. Note that gaps (*) between flexor tendon and volar surface of metacarpal bone (MP) is increased in (B).

practical for sports injuries. Because of the close relationship of the nearby structures, a delicate injection with ultrasound guidance is recommended to avoid a potentially harmful intratendinous injection [25]. The ultrasound transducer and skin for needle insertion should be carefully sterilized before injection. Free-handed ultrasound-guided injection to a fine structure can be successfully performed by an experienced practitioner.

Application of MSUS to the ligament in sports injuries

The histology of a ligament is similar to that of a tendon. However, the ultrasound appearance of a ligament is usually hypoechoic due to anisotropy effect. Proper positioning to make ligaments taut for scanning helps to reduce this effect. For the superficial ligaments, ultrasound provides good visualization. However, for ligaments located deeply or intra-articularly, such as the anterior cruciate ligament (ACL) of the knee, ultrasound does not offer direct information because of the physical limitation. MRI is indicated for evaluating deep structures, particularly if ultrasound reveals indirect evidence of injuries in these structures.

Over-stretched ligaments in a vigorous sports activity may result in their sprain or rupture, which may lead to instability of the affected joint. The ligament integrity and joint stability can be assessed with ultrasound. For example, the ankle is among the most frequently sprained joints being referred for sonographic examination. The anterior talofibular ligament, anterior inferior tibiofibular ligament, and calcaneofibular ligaments should be routinely checked in a lateral and/or high ankle sprain. When examining the lateral ankle, a passive force inverting the ankle joint makes the lateral ligaments taut for better visualization and helps demonstrate joint instability under ultrasound. For medial ankle sprains, deltoid ligaments should be carefully checked in the same way for possible pathologies.

Other superficial ligaments frequently checked in sports injuries include the anterior bundle of the ulnar collateral ligament (UCL) of the elbow, UCL of the metacarpophalangeal (MP) joint of the thumb, and medial and lateral collateral ligaments of the knee. Tiny ligaments on the wrist and hand, such as scapholunate ligament, can be imaged providing a high frequency transducer is equipped.

The anterior bundle is the most important part of UCL of the elbow joint. It connects medial epicondyle of the humerus and coronoid process of the ulna and is often injured by repetitive valgus stress to the elbow in major league baseball players or javelin throwers [26–28]. Microtear or complete rupture of this ligament usually happens with repetitive pitching and throwing (Fig. 5). Static and dynamic scanning demonstrates the pathologies of this ligament and stability of the joint.

Excessive valgus force to the thumb may cause injury of UCL in the MP joint, such as "game keeper's thumb" or "skier's thumb" [29–31]. Swelling or rupture of the

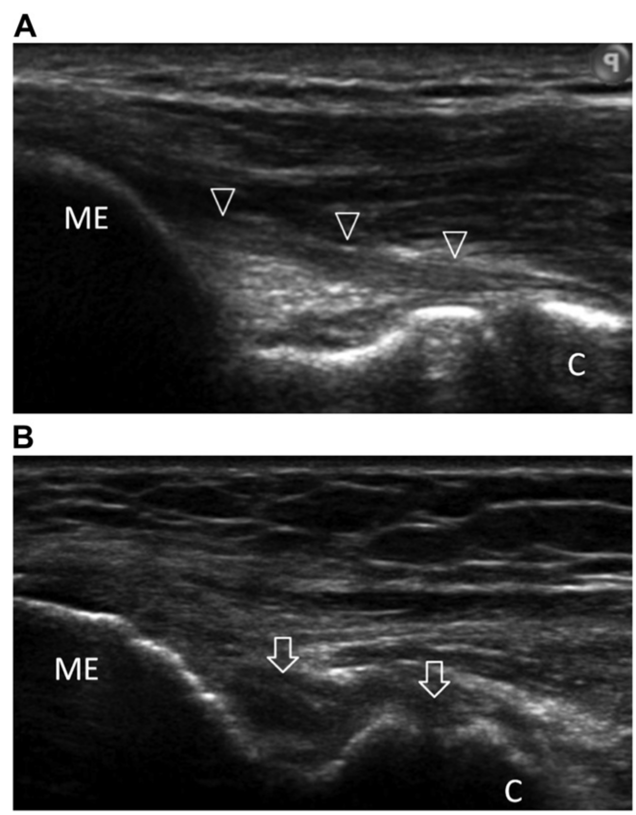

Fig. 5 Sonography pictures of medial elbow shows anterior band of ulnar collateral ligaments (UCL). (A) Normal UCL between medial epicondyle (ME) and coronoid process (C) depicted as a hypoechoic band because of anisotropy effect (open arrowheads). (B) The injured ligament (open arrows) shows inconsistency of both thickness and bony irregularity in its insertion.

ligament can be readily detected with ultrasound. Stener lesion is the condition where a torn UCL is interposed with aponeurosis of adductor pollicis superficial to the ligament. Early referral for surgical intervention for such lesions is necessary because spontaneous healing is less possible.

Rupture of the medial collateral ligament (MCL) of the knee may happen when excessive valgus force is applied to an external rotated tibia. The force can be a noncontact twist or a direct blow to the lateral knee. Sonographic findings with hypoechoic thickening at the superficial portion of the MCL, especially at the femoral portion, is the most frequently presentation of an abnormal MCL. Chip fracture is not uncommon at the proximal insertion of the MCL (Fig. 6). Sprain or tear of the lateral collateral ligament is less frequent than that of the MCL. When it happens, injuries of popliteus tendon and/or iliotibial band are commonly associated and they should therefore be evaluated routinely under ultrasound examination.

For intra-articular ligaments of the knee such as ACL, which cannot be directly visualized with ultrasound, MRI is the best imaging tool for their investigation [32]. However, in an acute ACL rupture, hematoma can be frequently found around its insertion to the medial border of lateral femoral condyle. Sonographic detection of such hematoma provides strong indirect evidence for an acute rupture of the ACL [33,34].

Application of MSUS to the bursa in sports injuries

A normal bursa contains a small amount of fluid, which appears as a thin anechoic layer in the sonographic image. A large amount of fluid accumulation in a traumatized bursa is usually seen as an anechoic mass with or without internal synovial proliferation. Surrounding hypervascularity indicates an acute inflammatory status, which may respond to anti-inflammatory medication. When scanning a bursa, attention should be paid to avoid excessive pressure by the transducer to the body surface. External compression by the transducer to a fluid-rich bursa may flatten it and lead to a false-negative result.

Numerous bursal lesions happen in sports injuries. The most commonly encountered are subacromial—subdeltoid bursitis at the shoulder, olecranal bursitis at the elbow (Fig. 7A), prepatellar and/or deep infrapatellar bursitis at

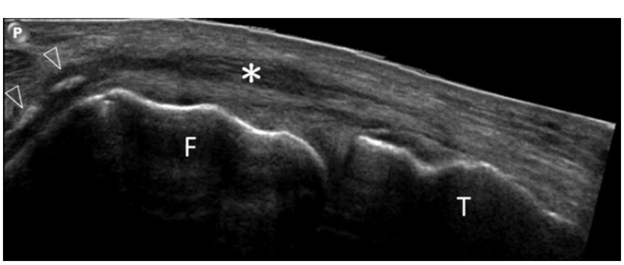

Fig. 6 Ultrasound image from the painful medial knee of a 43-year-old woman after stream tracing, showing hypoechoic thickening (*) at superficial component of medial collateral ligament (MCL). Avulsion fractures (open arrowheads) are noted at its proximal insertion to the femur (F). T = tibia.

Fig. 7 A case of prepatellar bursitis showing swelling of soft tissue (*) with fluid (f) accumulation superficial to the patellar bone (P). The patellar tendon (pt) is unremarkable.

the knee, and retrocalcaneal bursitis (Fig. 7B) at the ankle. If intrabursal steroid injection is planned, ultrasound guided injection is recommended because it is more accurate and effective than a blind injection [25,35].

Application of MSUS to the bony structure in sports injuries

It is difficult for ultrasound beams to penetrate the bony structure. When performing ultrasonographic examination, the information from beneath the bony cortex is very limited, whereas bony surface can be clearly demonstrated. In minimally displaced fractures, multiplanar ultrasound scanning may provide more detailed evaluation than plain films.

The incidence of fracture in talus is underestimated with routine plain film. Additional attention should be paid to scan its medial and lateral processes in suspicion of fracture. Confirmatory computed tomography of the ankle should be considered if ultrasonography reveals abnormalities in the talus (Fig. 8).

Stress fracture in athletes is often overlooked because a subtle fracture is not always seen in the plain film. In such cases, MRI is better than other image tools because it evaluates not only the bony surface but also the bone marrow [36—38]. In young athletes, fracture of the epiphysis should be examined since it is usually missed in the traditional roentgenogram. Ultrasound provides good visualization to this lesion [39] (Fig. 9).

Application of MSUS to the subcutaneous tissue in sports injuries

Direct lash or shearing force to the subcutaneous layer may result in an internal hematoma. In a serious condition, rupture of subcutaneous layers can happen with separation between layers of fatty tissue. It is also called "fracture" of the subcutaneous layer. Sonographic findings of fluid-filling gaps in the cutis with possible internal fat droplets may be depicted, known as a Morel—Lavallee lesion [40,41] (Fig. 10). Treating this lesion with fluid aspiration is

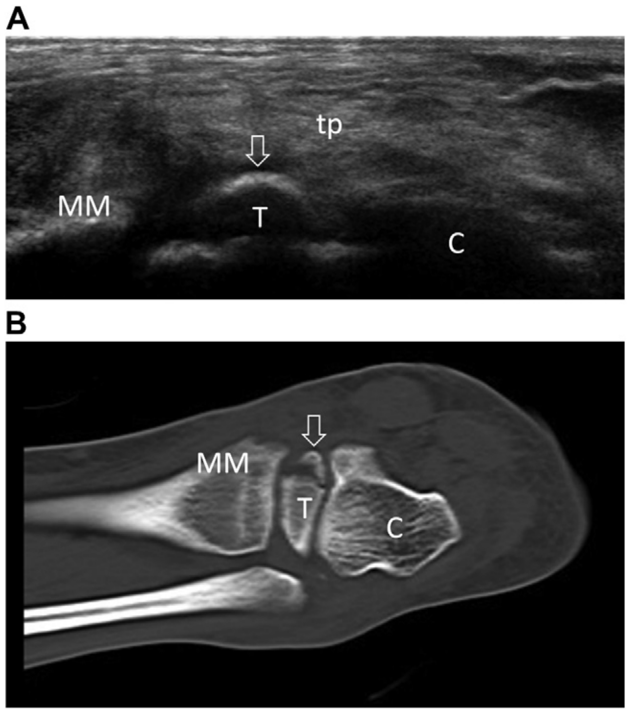

Fig. 8 Sonography and computed tomography scan from a 26-year-old woman 2 months after an ankle sprain. Initial roentgenogram reports were negative. The ankle persisted to be painful and swollen in spite of vigorous physical therapy and medication. (A) Ultrasound picture of medial ankle shows an echogenic loose body (open arrow) between posterior tibialis tendon (tp) and talus (T). (B) Fracture of the postero-medial corner of talus (arrow) is confirmed by CT. The calcaneal bone (C) and medial malleolus (MM) are intact.

frequently followed by fluid reaccumulation. Surgical intervention is usually necessary.

Chronically, fat degeneration or fat necrosis can turn into a hard lump over a previous injured site. Ultrasound can document these changes and provide information for a treatment plan.

Limitations of applying ultrasonography in sports injuries

A major limitation of ultrasonography is that the ultrasound beam hardly penetrates bony cortex. It cannot directly visualize intra-articular lesions but can only provide indirect evidence. MRI remains the gold standard for diagnosis of such lesions. Additionally, ultrasonography is very operator-dependent. It requires a long training course to master its scanning technique and related diagnosis. Detailed knowledge of musculoskeletal anatomy is necessary before skillful ultrasonographic scanning can be achieved.

The future of ultrasonography in sports injuries

There are some questions in ultrasound for sports injury requiring better solutions. Two-dimensional grayscale

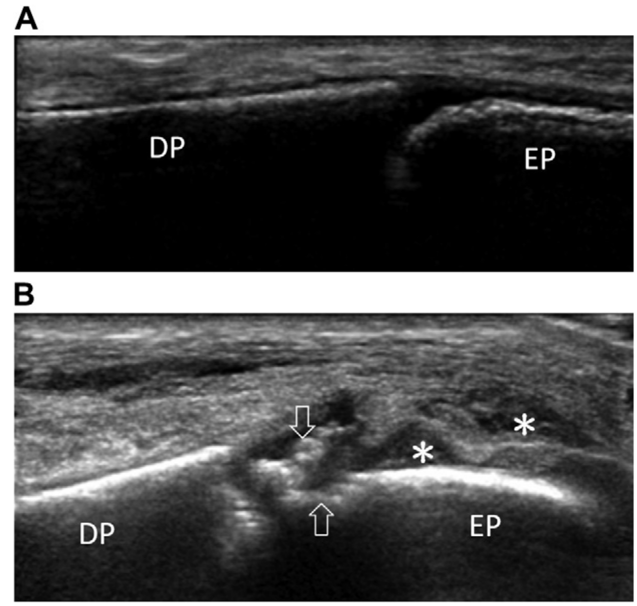

Fig. 9 Sonography of a 12-year-old skier on Day 4 after a sprain to his right lateral ankle. The X-ray picture did not reveal any bony fracture at his right ankle. (A) Ultrasound image of his asymptomatic left ankle shows smooth bony cortex at diaphysis (DP) and epiphysis (EP). (B) Fracture of the proximal end of the epiphysis (open arrows) with subperiosteal hematoma (*) and marked soft tissue swelling are noted at his right ankle.

ultrasonography has sufficient resolution for anatomic diagnosis, but three-dimensional ultrasound imaging still has suboptimal resolution for practical use. Color or power Doppler can detect vascularity but they cannot quantify vascularity reliably, especially for microcirculation of the lesions. Sonoelastography is continuously improving [42], and if applied to the post-traumatic tissue in the future,

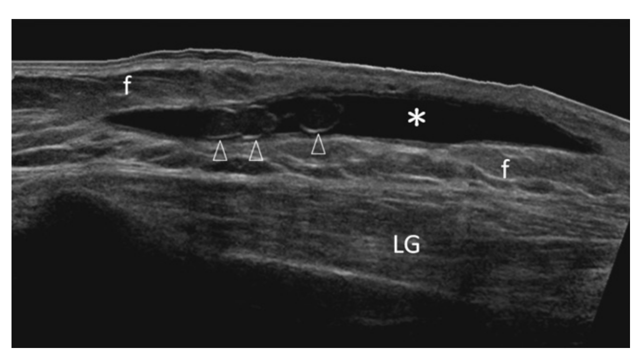

Fig. 10 Sonograms of a 16-year-old female athlete. The patient had received fluid aspiration to her swollen lower leg several times. Recurrent lower leg swelling occurred a few days after the last fluid aspiration. Longitudinal view of her lower leg shows ruptured subcutaneous fat (f). The subcutaneous layer shows discontinuity with a large amount of fluid (*) superficial to lateral gastrocnemius muscle (LG). Some fat droplets (open arrowheads), which floated during compression with the transducer, are seen at the rupture site.

may help practitioners to individualize the retraining plan for the injured athletes.

Conclusion

Application of ultrasound to sports injuries facilitates detection and localization of the lesions, helps clarify the staging and severity of the injuries, and aids clinicians to tailor management plans. Two-dimensional grayscale and color and power Doppler techniques provide high-resolution imaging of superficial muscles, tendons, ligaments, and other important structures in sports injury. A panoramic view yields a wider vision of the whole lesion. Dynamic sonographic examination demonstrates the interactions between the injured tissue and the surrounding structures. Ultrasound-guided aspiration of the hematoma in the injured soft tissue can be performed immediately on the field if needed.

In conclusion, musculoskeletal ultrasound is a useful and handy tool for diagnosis and intervention of sports injury.

References

[1] Nofsinger C, Konin JG. Diagnostic ultrasound in sports medicine: current concepts and advances. Sports Med Arthrosc 2009;17:25—30.

[2] Megliola A, Eutropi F, Scorzelli A, et al. Ultrasound and magnetic resonance imaging in sports-related muscle injuries. Radiol Med 2006;111:836—45.

[3] Peetrons P. Ultrasound of muscles. Eur Radiol 2002;12:35—43.

[4] Malliaropoulos N, Papacostas E, Kiritsi O, et al. Posterior thigh muscle injuries in elite track and field athletes. Am J Sports Med 2010;38:1813—9.

[5] Bianchi S, Poletti PA, Martinoli C, et al. Ultrasound appearance of tendon tears. Part 2: lower extremity and myotendinous tears. Skeletal Radiol 2006;35:63—77.

[6] Linklater JM, Hamilton B, Carmichael J, et al. Hamstring injuries: anatomy, imaging, and intervention. Semin Musculoskelet Radiol 2010;14:131—61.

[7] Counsel P, Breidahl W. Muscle injuries of the lower leg. Semin Musculoskelet Radiol 2010;14:162—75.

[8] Blankenbaker DG, Tuite MJ. Temporal changes of muscle injury. Semin Musculoskelet Radiol 2010;14:176—93.

[9] Harriston S. A review of rhabdomyolysis. Dimens Crit Care Nurs 2004;23:155—61.

[10] Clarkson PM. Exertional rhabdomyolysis and acute renal failure in marathon runners. Sports Med 2007;37:361—3.

[11] Skenderi KP, Kavouras SA, Anastasiou CA, et al. Exertional rhabdomyolysis during a 246-km continuous running race. Med Sci Sports Exerc 2006;38:1054—7.

[12] Finsterer J, Zuntner G, Fuchs M, et al. Severe rhabdomyolysis after excessive bodybuilding. J Sports Med Phys Fitness 2007; 47:502—5.

[13] Bolgiano EB. Acute rhabdomyolysis due to body building exercise. Report of a case. J Sports Med Phys Fitness 1994;34: 76—8.

[14] Lee RP, Bishop GF, Ashton CM. Severe heat stroke in an experienced athlete. Med J Aust 1990;153:100—4.

[15] Bianchi S, Martinoli C, Abdelwahab IF. Ultrasound of tendon tears. Part 1: general considerations and upper extremity. Skeletal Radiol 2005;34:500—12.

[16] Crass JR, van de Vegte GL, Harkavy LA. Tendon echogenicity: *ex vivo* study. Radiology 1988;167:499—501.

[17] Tan S, Chan O. Achilles and patellar tendinopathy: current understanding of pathophysiology and management. Disabil Rehabil 2008;30:1608—15.

[18] Ducher G, Cook J, Lammers G, et al. The ultrasound appearance of the patellar tendon attachment to the tibia in young athletes is conditional on gender and pubertal stage. J Sci Med Sport 2010;13:20—3.

[19] Peace KA, Lee JC, Healy J. Imaging the infrapatellar tendon in the elite athlete. Clin Radiol 2006;61:570—8.

[20] Ryan M, Wong A, Taunton J. Favorable outcomes after sonographically guided intratendinous injection of hyperosmolar dextrose for chronic insertional and midportion achilles tendinosis. AJR Am J Roentgenol 2010;194: 1047—53.

[21] Filardo G, Presti ML, Kon E, et al. Nonoperative biological treatment approach for partial Achilles tendon lesion. Orthopedics 2010;33:120—3.

[22] Yanai T, Fuss FK, Fukunaga T. *In vivo* measurements of subacromial impingement: substantial compression develops in abduction with large internal rotation. Clin Biomech (Bristol, Avon) 2006;21:692—700.

[23] Schöffl V, Schöffl I. Isolated cruciate pulley injuries in rock climbers. J Hand Surg Eur Vol 2010;35:245—6.

[24] Kubiak EN, Klugman JA, Bosco JA. Hand injuries in rock climbers. Bull NYU Hosp Jt Dis 2006;64:172—7.

[25] Chen MJ, Lew HL, Hsu TC, et al. Ultrasound-guided shoulder injections in the treatment of subacromial bursitis. Am J Phys Med Rehabil 2006;85:31—5.

[26] Nazarian LN, McShane JM, Ciccotti MG, et al. Dynamic US of the anterior band of the ulnar collateral ligament of the elbow in asymptomatic major league baseball pitchers. Radiology 2003;227:149—54.

[27] Sasaki J, Takahara M, Ogino T, et al. Ultrasonographic assessment of the ulnar collateral ligament and medial elbow laxity in college baseball players. J Bone Joint Surg Am 2002; 84-A:525—31.

[28] De Smet AA, Winter TC, Best TM, et al. Dynamic sonography with valgus stress to assess elbow ulnar collateral ligament injury in baseball pitchers. Skeletal Radiol 2002;31: 671—6.

[29] Shinohara T, Horii E, Majima M, et al. Sonographic diagnosis of acute injuries of the ulnar collateral ligament of the metacarpophalangeal joint of the thumb. J Clin Ultrasound 2007; 35:73—7.

[30] Ebrahim FS, de Maeseneer M, Jager T, et al. US diagnosis of UCL tears of the thumb and Stener lesions: technique, pattern-based approach, and differential diagnosis. Radiographics 2006;26:1007—20.

[31] Schnur DP, DeLone FX, McClellan RM, et al. Ultrasound: a powerful tool in the diagnosis of ulnar collateral ligament injuries of the thumb. Ann Plast Surg 2002;49:19—23.

[32] Chiang YP, Wang TG, Lew HL. Application of high resolution ultrasound for examination of the knee joint. J Med Ultrasound 2007;15:203—12.

[33] Skovgaard Larsen LP, Rasmussen OS. Diagnosis of acute rupture of the anterior cruciate ligament of the knee by sonography. Eur J Ultrasound 2000;12:163—7.

[34] Ptasznik R, Feller J, Bartlett J, et al. The value of sonography in the diagnosis of traumatic rupture of the anterior cruciate ligament of the knee. AJR Am J Roentgenol 1995;164: 1461—3.

[35] Lew HL, Chen CP, Wang TG, et al. Introduction to musculoskeletal diagnostic ultrasound: examination of the upper limb. Am J Phys Med Rehabil 2007;86:310—21.

[36] Sofka CM. Imaging of stress fractures. Clin Sports Med 2006;25: 53—62.

[37] Jensen JE. Stress fracture in the world class athlete: a case study. Med Sci Sports Exerc 1998;30:783—7.

[38] Allen GM, Wilson DJ. Ultrasound in sports medicine—a critical evaluation. Eur J Radiol 2007;62:79—85.
[39] Hübner U, Schlicht W, Outzen S, et al. Ultrasound in the diagnosis of fractures in children. J Bone Joint Surg Br 2000; 82:1170—3.
[40] Neal C, Jacobson JA, Brandon C, et al. Sonography of Morel—Lavallee lesions. J Ultrasound Med 2008;27:1077—81.
[41] Mukherjee K, Perrin SM, Hughes PM. Morel—Lavallee lesion in an adolescent with ultrasound and MRI correlation. Skeletal Radiol 2007;36(Suppl. 1):S43—5.
[42] De Zordo T, Lill SR, Fink C, et al. Real-time sonoelastography of lateral epicondylitis: comparison of findings between patients and healthy volunteers. AJR Am J Roentgenol 2009;193: 180—5.