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Ultrasound in Sports Medicine

Relevance of Emerging Techniques to Clinical Care of Athletes

Eugene Sun Yim[1,2] and *Gianmichael Corrado*[1]

1 Division of Sports Medicine, Children's Hospital Boston, Boston, MA, USA
2 Harvard Affiliated Emergency Medicine Residency, Beth Israel Deaconess Medical Center, Boston, MA, USA

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Abstract

The applications of ultrasound in managing the clinical care of athletes have been expanding over the past decade. This review provides an analysis of the research that has been published regarding the use of ultrasound in athletes and focuses on how these emerging techniques can impact the clinical management of athletes by sports medicine physicians.

Electronic database literature searches were performed using the subject terms 'ultrasound' and 'athletes' from the years 2003 to 2012. The following databases were searched: PubMed, Web of Science, Cochrane Library, CINAHL, and SPORTDiscus™. The search produced 617 articles in total, with a predominance of articles focused on cardiac and musculoskeletal ultrasound. 266 of the studies involved application of ultrasound in evaluating the cardiovascular properties of athletes, and 151 studies involved musculoskeletal ultrasound. Other applications of ultrasound included abdominal, vascular, bone density and volume status.

New techniques in echocardiography have made significant contributions to the understanding of the physiological changes that occur in the athlete's heart in response to the haemodynamic stress associated with different types of activity. The likely application of these techniques will be in managing athletes with hypertrophic cardiomyopathy, and the techniques are near ready for application into clinical practice. These techniques are highly specialized, however, and will require referral to dedicated laboratories to influence the clinical management of athletes. Investigation of aortic root pathology and pulmonary vascular haemodynamics are also emerging, but will require

additional studies with larger numbers and outcomes analysis to validate their clinical utility. Some of these techniques are relatively simple, and thus hold the potential to enter clinical management in a point-of-care fashion.

Musculoskeletal ultrasound has demonstrated a number of diagnostic and therapeutic techniques applicable to pathology of the shoulder, elbow, wrist, hand, hip, knee and ankle. These techniques have been applied mainly to the management of impingement syndromes, tendinopathies and arthritis. Many of these techniques have been validated and have entered clinical practice, while more recently developed techniques (such as dynamic ultrasound and platelet-rich plasma injections) will require further research to verify efficacy. Research in musculoskeletal ultrasound has also been helpful in identifying risk factors for injury and, thus, serving as a focus for developing interventions.

Research in abdominal ultrasound has investigated the potential role of ultrasound imaging in assessing splenomegaly in athletes with mononucleosis, in an attempt to inform decisions and policies regarding return to play. Future research will have to demonstrate a reduction in adverse events in order to justify the application of such a technique into policy. The role of ultrasound in assessing groin pain and abdominal pain in ultraendurance athletes has also been investigated, providing promising areas of focus for the development of treatment interventions and physical therapy.

Finally, preliminary research has also identified the role of ultrasound in addressing vascular disease, bone density and volume status in athletes. The potential applications of ultrasound in athletes are broad, and continuing research, including larger outcome studies, will be required to establish the clinical utility of these techniques in the care of athletes.

1. Introduction

Ultrasound has served as a valuable imaging modality in medicine for decades, and has gained increasing attention in the field of sports medicine over the past few years. The earliest applications of ultrasound in athletes date back to the 1970s, with pioneering work using echocardiography (ECHO) to describe the 'athlete's heart'. Research by Rost and colleagues in the early 1970s and another study by Morganroth and colleagues soon thereafter were the earliest published applications of ultrasound in athletes.[1,2]

This seminal work inspired an appreciation for the cardiac adaptations in the athlete's heart, as well as theories to explain how athletic activity causes these physiological changes. Of these theories was the influential Morganroth hypothesis that explained how differential haemodynamic loading of the heart during endurance and strength training leads to different forms of ventricular hypertrophy in the athlete's heart; endurance training leads to eccentric cardiac hypertrophy as a result of a primary volume overload, while strength training leads to concentric hypertrophy as a result of pressure overload.[3]

Although accepted by many as a plausible and valid theory, subsequent investigation and analysis have identified potential inadequacies of the theory. Of note, studies have demonstrated ventricular wall thickness to be increased more in endurance athletes than in strength athletes, while other studies have detected no morphological changes in resistance athletes.[4] Although they may not have resulted in definitive doctrine regarding the athlete's heart, these initial studies were invaluable in generating momentum for the investigation of ultrasound in the care of the athlete.

Historically, ultrasound has also been used to address musculoskeletal illness in athletes. The earliest published applications focused on the examination of Achilles tendinopathies. In 1986, Bruno D. Fornage published a study of 24 athletes, documenting the use of ultrasound to detect

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a variety of abnormalities of the Achilles tendon in a symptomatic population.[5] Soon thereafter, a research group in Germany published a retrospective study of 78 athletes, demonstrating a correlation between clinical and sonographical findings related to the Achilles tendon.[6] Although they did demonstrate correlation between clinical and sonographical findings, they also identified cases of structural changes seen on ultrasound without subjective complaints, as well as cases in which athletes with clinical symptoms did not demonstrate detectable abnormalities in ultrasound. Therefore, the ultrasound technique did not prove to be sensitive or specific for Achilles tendinopathy, at least according to preliminary research.

Early research in ultrasound also examined a number of other conditions in athletes: cartilaginous and soft tissue lesions in shoulder injuries,[7] partial patellar ligament ruptures,[8] quadriceps muscle architecture,[9] lower extremity haematoma,[10] abdominal arteries in ultraendurance athletes,[11] bone metabolism and density,[12,13] and groin pain.[14] Research over the last decade has continued to expand knowledge in these areas but has also ventured into unexplored realms. The breadth of applications of ultrasound in athletes was showcased during the 29th Summer Olympics in Beijing, China in which ultrasonography was used to treat athletes with a spectrum of issues: abdominal pain, musculoskeletal disorders, gynaecological issues, cardiac conditions, small parts and vascular problems.[15]

The review article presented here will examine the recent research that has been published regarding the potential use of ultrasound across this broad array. Recent advances in technique and the portability of ultrasound have elevated this technology beyond the theoretical and have presented it as an effective technology that can impact the clinical care of athletes. We provide commentary on the potential of these techniques as diagnostic and therapeutic tools, and whether they are ready to be applied in the care and management of athletes in sports medicine. We also describe how they should be incorporated into practice, whether as a point-of-care technique performed by sports medicine physicians or as specialized testing executed by trained technicians. In cases where results are preliminary, we provide recommendations on the future directions of research.

2. Literature Search Methodology

Electronic database literature searches were performed using the terms 'ultrasound' and 'athletes' over the past 10 years, from 2003 to 2012. The following databases were searched: PubMed, Web of Science, Cochrane Library, CINAHL, and SPORTDiscus™. In addition, references from the extracted publications were examined.

3. Search Results

Our literature search produced 617 articles in total. The set of manuscripts identified in our search represented a spectrum of applications of ultrasound in athletes. The most prominent applications of ultrasound were cardiovascular and musculoskeletal ultrasound, which comprised more than half of the studies found. Of the studies, 266 involved application of ultrasound in evaluating the cardiovascular properties of athletes, through specific techniques in ECHO, and 151 involved musculoskeletal ultrasound. Other applications of ultrasound included abdominal, vascular, bone density and volume status.

4. Findings and Discussion

4.1 Cardiovascular Ultrasound

Consistent with historic trends, our review identified ECHO as the predominant application of ultrasound in athletes. Expanding upon the seminal work of Morganroth and colleagues[2] in describing the concept of the athlete's heart, recent research has investigated the changes to the physiological parameters of the heart that are seen in athletes. More specifically, research has identified particular parameters of the athlete's heart that differ significantly from the norm. Research has also investigated how the athlete's heart is affected by the haemodynamic loads of exercise, and how this physiological response differs from changes seen with pathological haemodynamic loads. We present the research based on

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anatomical distribution in order to help organize the forthcoming discussion.

Historically, studies have focused on changes to the left ventricle (LV) of the athlete's heart, with specific types of hypertrophy expected in different types of athletes.[16-18] According to Morganroth, endurance training should lead to eccentric cardiac hypertrophy as a consequence of repetitive volume overload, while strength training should cause concentric hypertrophy due to pressure overload produced during strenuous resistive exercise. A recent appraisal of research related to the Morganroth hypothesis described how research thus far has been inconclusive.[4] The review describes how research has been inconsistent, with some studies demonstrating increased LV wall thickness in endurance athletes, while other studies have reported no morphological changes in resistance athletes.

Furthermore, there is evidence to suggest that the LV adaptations in the athletes may not be as significant as previously assumed when compared with their nonathletic counterparts. A recent prospective study of 114 Olympic athletes followed over two to five consecutive Olympic games demonstrated that extreme and uninterrupted endurance training over long periods of time are not associated with deterioration in LV function, significant changes in LV morphology, or occurrence of cardiovascular symptoms or events.[19] Another recent study of 511 Olympic athletes (categorized in skill, power, mixed and endurance sport disciplines) used 3-dimensional (3-D) ECHO to demonstrate no difference in remodelling indices between athletes and controls, with a balanced adaption of LV volume and mass, as well as preserved systolic function across all disciplines.[20] The presumed goal within this line of research was to identify aspects of LV physiology that differed in athletes compared with the general population, in order to identify normal parameters expected in athletes. The research appears to be inconclusive so far and therefore has limited application to clinical practice in sports medicine.

In an attempt to gain clinical relevance, another line of research has focused on comparing the physiological changes to the LV seen in exercise to those seen in response to pathological forms of haemodynamic stress. Novel techniques in ECHO have been employed to investigate this. A series of studies has focused on how physiological changes to the LV caused by pathological cardiomyopathy, as a result of hypertension or hypertrophic cardiomyopathy, compare with the changes induced by exercise. A recent study of 19 sedentary controls, 22 top-level rowers and 18 newly-diagnosed patients with hypertension used speckle-tracking ECHO to demonstrate how certain parameters of the LV (global circumferential strain, global radial strain and torsion) are similarly affected in athletes and patients with hypertension, while other parameters, specifically the global longitudinal strain, are different in patients with hypertension than in athletes.[21] Another study comparing patients with pathological LV hypertrophy from nonobstructive hypertrophic cardiomyopathy with elite athletes demonstrated similarly that global longitudinal strain, as well as regional peak systolic strain, were significantly reduced in patients with pathological LV hypertrophy while they were normal in athletes.[22]

This complements previous research that has used other ultrasound techniques to distinguish pathological from physiological LV hypertrophy. One study using myocardial contrast ECHO identified relative blood volume at rest as the most accurate parameter that can differentiate pathological changes to the LV due to hypertrophic cardiomyopathy and hypertension from exercise-induced cardiomyopathy.[23] Another line of research has used 3-D ECHO to demonstrate that parameters such as the mass dispersion index may be reliable in differentiating hypertrophic cardiomyopathy of the LV from cardiomyopathy caused by exercise and hypertension.[24] Therefore, recent studies have expanded upon previous research, helping better characterize the physiological adaptations of the LV in the athlete's heart, as they contrast to loads placed on the heart in pathological conditions such as in hypertension and hypertrophic cardiomyopathy. Such techniques thus hold the potential to impact the management of athletes who require differentiation between pathological and physiological changes in the heart. Since these techniques are highly special-

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ized and require advanced techniques and protocols, sports medicine physicians will likely not conduct the tests in a point-of-care fashion but will order these diagnostics to be completed in dedicated laboratories staffed by trained technologists. These diagnostic tests will help guide the care of athletes with cardiac hypertrophy, by helping to distinguish changes that are pathological and worrisome from those that are expected from normal physiology.

Although most research has focused on changes to the LV in the context of the athlete's heart, recent research has also investigated other chambers of the heart. A study by D'Andrea and colleagues began to investigate changes in the left atrium (LA) that can differentiate endurance from resistance athletes. In a study of 615 elite athletes (370 endurance and 245 resistance athletes), they demonstrated that measurements of the LA differed between the two types of athletes, while LV mass index and ejection fraction did not significantly differ.[25] Shifting focus on this debate to another anatomical parameter of the athlete's heart, the recent studies by D'Andrea and colleagues have posited the LA diameter as a potential parameter that may reliably differentiate the two types of athletes. Additional research will be required to verify these preliminary results and to further identify physiological parameters that differ between these athletes. The clinical relevance of these changes has also not been clearly delineated. As with the corresponding studies involving LV physiology in athletes, another challenge will be to find and verify a relevant application of such a technique in the care and management of athletes. Future research comparing physiological changes to those seen in pathological forms of cardiac pathology may provide such relevance.

Recent research has also started to investigate parameters of the right side of the heart that may be relevant to the care of athletes. In a study of healthy male endurance athletes and matched controls, Scharhag and colleagues demonstrated that right ventricular (RV) end-diastolic diameter may be a helpful parameter to differentiate athlete's hearts from normal hearts.[26] Using magnetic resonance imaging (MRI) as a comparison to ultrasound in that study, additional parameters were demonstrated as significantly different in athletes: RV end-diastolic volume, RV long axis and RV mass.

This complements other research that has demonstrated changes to the RV associated with exercise. In a study of world-class speedskaters, Poh and colleagues identified other parameters of RV remodelling and function that are seen in athletes: larger basal RV dimensions, attenuated RV systolic function at rest, lower RV systolic strain rate, better RV diastolic function at rest, augmentation of RV systolic function with increased RV fractional area change.[27] The inconsistency between this research and the recently published study, however, is in what parameters of the right side of the heart differ in athletes. The study by Scharhag and colleagues[26] suggests that only the RV end-diastolic diameter is a reliable measure that differentiates the hearts of athletes from the general population, while Poh and colleagues[27] suggested that a number of parameters may differ. Further research will be required to clarify which parameters of the athlete's heart can reliably be measured in athletes to differentiate exercise-related changes from normal physiology. Apart from delineating physiology that is expected in response to exercise, this line of research appears limited in its direct applicability to the clinical care and management of athletes. Outcomes research demonstrating what clinical impact these exercise-related changes have on athletes will help establish clinical relevance.

As with the research focusing on the LV in athletes, research of the RV has also sought stronger clinical relevance by investigating particular forms of haemodynamic stress as they affect the hearts of athletes. In a recent study of 15 marathon runners, researchers used 3-D ECHO to demonstrate that the hearts of these runners sustain transient RV immediately after a marathon.[28] This is consistent with previous research using other forms of ECHO and serological testing with biomarkers to detect transient dysfunction after ultraendurance exercise.[29,30] Such evidence will inform the care of athletes in the acute phase of recovery following ultraendurance exercise, as athletes may present with signs and

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symptoms of volume overload and transient heart failure. As with the specialized techniques in ECHO mentioned previously, these techniques will likely require assistance of trained technicians. Such tests will be helpful in managing the care of athletes that develop symptoms of transient cardiac dysfunction following ultra-endurance exercise. These specialized techniques, in conjunction with laboratory tests, will help document such dysfunction and will be invaluable in monitoring progress and recovery in these athletes.

Ultrasound has not only been used to look at the heart itself, but has also been applied to investigate the anatomy closely related to cardiac physiology in athletes. This includes examination of the aortic arch and pulmonary vasculature. A recent study used ultrasound to investigate the prevalence and clinical significance of aortic root dilation in athletes.[31] In another recent study, researchers determined that aortic root diameter is significantly greater in elite resistance athletes than in matched endurance athletes.[32] Through multivariate analysis, they also demonstrated that body surface area, duration of training, and LV circumferential end-systolic stress were independent predictors of aortic root diameter in athletes. This is consistent with previous research that has demonstrated increased aortic root diameters associated with resistance training.[33] This topic is relevant to the care of athletes in that aortic root dilation can lead to adverse health outcomes such as aneurysmal formation, aortic dissection and aortic rupture. As the technique to measure aortic root diameter is relatively simple, this may hold the potential for use directly by sports medicine physicians at the bedside rather than requiring specialized technicians in dedicated laboratories. Research in the reliability and accuracy of these measurements in the hands of physicians would be a promising avenue of investigation. Regardless of how the measurements will be obtained, such a technique would contribute to the clinical care of athletes with risk factors for aortic root dilation (such as athletes with bicuspid valve or athletes performing activities associated with increased root dilation) and will help guide the management and care of such athletes in order to avoid adverse outcomes.

Research using ECHO has also investigated the effects of exercise on pulmonary haemodynamics. A recent study investigated the effects of exercise on pulmonary artery systolic pressure among highly trained athletes.[34] In that study, researchers demonstrated that pulmonary artery systolic pressure in endurance athletes can reach a physiological upper limit of 40 mmHg, due to an increased stroke volume. The study was helpful in delineating an upper limit of pulmonary artery pressure that could be considered physiological in athletes. Another recent study compared pulmonary haemodynamics in athletes with nonathletes, showing that athletes have a higher pulmonary artery systolic pressure than nonathletes during peak exercise.[35] This later study also demonstrated an increase in pulmonary vascular reserve during exercise both in athletes and nonathletes, through the monitoring of pulmonary transit of agitated contrast. These studies represent a significant line of research investigating pulmonary haemodynamics, helping to delineate the physiological changes that occur in response to exercise in order to optimize oxygen delivery during a period of increased consumption. These techniques are highly specialized, however, and will therefore require trained technicians in ultrasound laboratories. The tests would then be ordered by sports medicine physicians and would be helpful in managing pulmonary manifestations of cardiac dysfunction and disease in athletes, such as with pulmonary hypertension or cor pulmonale. Since research so far has only documented normal haemodynamics in athletes, further research will have to investigate these techniques in populations that are affected by pathological processes in order to establish clinical relevance.

4.2 Musculoskeletal Ultrasound

Musculoskeletal ultrasound has also generated increasing attention over the last decade and has demonstrated promise with regard to its current and potential applicability in the clinical management of athletes. In contrast to ECHO in athletes, musculoskeletal ultrasound has demonstrated more promise as a point-of-care technology

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used by physicians themselves, rather than through the enlistment of technologists in specialized laboratories. Musculoskeletal ultrasound has proven especially promising in this setting because it has been developed not only as a diagnostic tool but also as a therapeutic adjunct to treat an array of musculoskeletal conditions affecting athletes. To organize the research that has been published regarding the applications of diagnostic and therapeutic musculoskeletal ultrasound, the discussion hereafter is organized based on anatomical regions and will again focus on the clinical implications of ultrasound techniques.

Bedside and formal ultrasound have been used in the diagnosis and evaluation of shoulder injuries in overhead athletes, although radiography, MRI and computed tomography (CT) have also been used widely in diagnosis.[36] More recently, musculoskeletal ultrasound has not only been used for diagnosis of injury, but also to identify potential parameters detectable by ultrasound that can be used to predict risk of injury. In a study comparing 34 asymptomatic overhead athletes to matched volunteers, investigators detected subclinical effusions of the subacromial and subdeltoid bursae that may serve as early signs of shoulder pathology.[37] Recent studies have also used ultrasound to identify dynamic properties of the shoulder that may relate to a risk of injury. In a study of overhead athletes, clinicians used dynamic ultrasound to measure the displacement of the coraco-acromial ligament during simulation of throwing, proposing how this technique may be helpful in detecting abnormal humeral head migration.[38] Another study complemented these results, providing evidence that humeral torsion may correlate with risk of injury. In this study of 35 adolescent baseball players, investigators used dynamic ultrasound to demonstrate that humeral torsion of the nondominant arm correlates with the risk of injury to the throwing arm.[39]

Other potential predictors of risk have also been investigated, including posterior capsule thickness, through its effect on glenohumeral range of motion and scapular upward rotation.[40] A decreased subacromial space is also thought to contribute to the risk of shoulder injury through the impingement of the rotator cuff in a tight space.[41] A recent study of elite tennis players evaluated the role of scapular dyskinesia in limiting the subacromial space and thereby increasing the risk of shoulder injury.[42] This study demonstrated a link between scapular dyskinesia and decreased subacromial space (as demonstrated by ultrasound), suggesting that early detection of scapular dyskinesia can influence the risk of injury through identification of athletes with decreased subacromial space. The implication of such research is that training and physical therapy may be able to moderate risk in such situations by identifying at-risk athletes and targeting treatment to these athletes. Some of these techniques are likely to be incorporated into bedside practice by sports medicine physicians, but other techniques (such as the dynamic manoeuvres) may require the enlistment of specialized technicians. As the next steps in this line of work, research will have to focus on the development of interventions to moderate risk (i.e. targeted strengthening and conditioning) and the identification of appropriate outcomes to measure efficacy. Subsequent research will then have to validate these techniques through outcomes research in prospective trials.

With regards to the elbow, musculoskeletal ultrasound has been used to assess a number of anatomical derangements, including partial- and full-thickness tears of the biceps and triceps tendons, common extensor and flexor tendinosis, medial and lateral epicondylitis, radial and ulnar collateral ligament tears, ulnar nerve entrapment, cubital or olecranon bursitis, joint effusions and intra-articular bodies.[43] Most research so far has focused on the application of ultrasound to lateral epicondylitis in athletes. Increased maximal extensor tendon thickness and cross-sectional area have been demonstrated to be highly predictive of lateral epicondylitis.[44] Furthermore, the size of intrasubstance tears and the presence of a lateral collateral ligament tear on ultrasound have been used to assess the severity of lateral elbow tendinopathy and to predict response to treatment.[45] These techniques are relatively simple and thus present the opportunity for sports medicine physicians to obtain diagnostic imaging at the bedside.

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Ultrasound of the elbow has also been used to aid in the treatment modalities used for elbow pathology. The work of Mishra and Pavelko has been helpful in demonstrating how ultrasound can be used to treat chronic severe elbow tendinosis.[46] Their work has documented how ultrasound-guided platelet-rich plasma injections are effective in treating chronic severe elbow tendinosis when compared with corticosteroid injections.[47] Other techniques have been described recently but have been confirmed with less rigour in the literature. For example, a recent case report discussed the use of ultrasound-guided acetic acid iontophoresis to treat soft tissue injuries of the arm.[48] As such techniques are developed and validated, ultrasound-guided treatment of elbow conditions will likely become more prevalent in clinical practice.

Techniques in ultrasound of the wrist and hand have also been developed. Ultrasound of the joints of the wrist, for example, has been used to assess synovitis related to rheumatoid arthritis. According to recent data, the radiocarpal joint is most reliable site for these measurements.[49] Certain special techniques in ultrasound, such as contrast-enhanced ultrasound, have even proven more sensitive than MRI in detecting synovitis in rheumatoid arthritis.[50] Ultrasound has also been used to demonstrate tendon involvement of the wrist and hand in rheumatoid arthritis.[51] Outside of its application to rheumatoid arthritis, ultrasound has also been used to evaluate pronator quadratus physiology,[52] median neuropathy in carpal tunnel syndrome[53,54] and de Quarvain disease.[55] The potential clinical applications of ultrasound to wrist and hand pathology are thus numerous, and bedside use of these techniques in diagnosis demonstrate promise with regards to the potential impact on clinical practice. Some of these techniques, such as ultrasound assessment of rheumatoid arthritis and carpal tunnel syndrome, are already being incorporated into training programmes for musculoskeletal ultrasound performed by physicians and trainees.[56]

Ultrasound has also been applied to both diagnose and treat a number of musculoskeletal conditions of the hip and thigh. Recently, ultrasound has been used to document isolated injuries to the gracilus muscle in athletes, an injury previously thought to be rare due to the dearth of reports of this condition in the literature. In a case series, researchers reported a number of cases of athletes found by ultrasound to have this isolated injury.[57] Ultrasound has also been used to detect injuries to the hamstring muscles and to evaluate posterior thigh injuries in athletes.[58] With regard to imaging of the hip, ultrasound has been used to evaluate hips with prostheses, which can prove difficult to image by other modalities due to artifact.[59] Ultrasound has also been used to diagnose and guide the treatment (arthrocentesis) of septic hip.[60] Ultrasound has also been used more commonly in the diagnosis and treatment of osteoarthritis of the hip.[61] Using ultrasound to guide joint injections of the hip has proven effective and is becoming the standard of care in the treatment of these conditions due to its ease of use and improved accuracy.[62] Novel injectants, such as platelet-rich plasma, have also been studied in the setting of ultrasound guidance but will require further outcomes research to establish efficacy and superiority over other treatment modalities.[63]

Musculoskeletal ultrasound has also been used to evaluate injuries to the knee in athletes. Most research has focused on the use of ultrasound in detecting and treating patellar tendon derangements in athletes. Ultrasound has been used to characterize a new continuum model in patellar tendinopathy.[64,65] Particular measurements, such as the anteroposterior diameter of the patellar tendon, have been recently studied as an indicator of severity of tendinopathy in athletes.[66] Another recent study of Badminton players used colour Doppler ultrasonography to demonstrate how symptomatic patellar tendons are associated with higher Doppler activity.[67] The sensitivity and specificity of the imaging modality must be considered. In a previously published study, ultrasound was proven to be at least equivalent to MRI with regard to sensitivity and specificity of detecting patellar tendinopathy.[68] A more recent analysis of a larger cohort of athletes did not demonstrate a relationship between ultrasound findings and clinical symptoms, however.[69] In that study of 61 volleyball players, blinded ultrasound

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findings were compared with Lysholm's knee score and pain, demonstrating no significant correlation between the two. The research thus far is inconclusive, and the utility of ultrasound in diagnosing patellar tendinosis is unclear. More research will be required to establish its sensitivity and specificity as a diagnostic tool before these techniques are justifiably used in clinical practice.

Ultrasound of ankle pathology, particularly with regards to Achilles tendinopathy, has also received attention recently in research. Ultrasound has been used to elucidate the pathophysiology of mid-portion tendinopathy (MPT) of the Achilles tendon. A recent cross-sectional study of 50 healthy runners used synchronous real-time ultrasound to determine that Achilles tendon-aponeurosis strain is higher in male athletes with MPT than in those without.[70] There are also typical pathophysiological findings detected by ultrasound at various stages of MPT.[71] Ultrasound has also been used to determine potential prognostic factors in the development of MPT. In a recent prospective clinical trial involving 634 asymptomatic runners in an outpatient setting, investigators demonstrated that a spindle-shaped thickening of the tendon and increased intratendinous blood flow are associated with the development of MPT.[72]

Achilles tendinopathy remains primarily a clinical diagnosis, however, since ultrasound may be overly sensitive as a diagnostic tool. Consistent with this, a recent study of 40 elite gymnasts used ultrasonography to demonstrate that ultrasound overestimates the prevalence of Achilles tendinopathy, with only half of ultrasound-identified pathology producing symptoms.[73] To increase specificity of ultrasound in the diagnosis of Achilles tendinopathy, other techniques evaluating the mechanical properties of the tendon using ultrasound are being developed. For example, in a recent investigation, researchers used ultrasound sonoelastography to demonstrate that symptomatic tendons are associated with increased stiffness.[74] Special techniques, such as contrast-enhanced ultrasound are also being investigated to aid in the diagnosis of Achilles tendon pathology, but their specificity and clinical significance have yet to be fully established.[75] Due to the intricacy of these specialized techniques, these diagnostics will likely require the involvement of ultrasound technicians in dedicated laboratories.

Overall, musculoskeletal ultrasound holds potential for use as a diagnostic tool for a number of conditions, but the sensitivity and specificity of the technique is yet to be fully validated in the hands of physicians. In some cases, ultrasound has been shown to be potentially oversensitive in detecting pathology, with a significant false positive rate. More specialized techniques requiring assistance of trained technicians may prove more sensitive and specific, but will require coordination and referral to dedicated laboratories for imaging. The applications of musculoskeletal ultrasound in athletes are thus broad, and whether through bedside imaging or through referrals to a dedicated laboratory, these techniques will undoubtedly play a prominent role in the care and management of a broad array of musculoskeletal conditions afflicting athletes.

4.3 Abdominal Ultrasound

Ultrasound has also been used recently to evaluate a number of abdominal processes in athletes, such as splenomegaly with mononucleosis, long-standing groin pain and splanchnic haemodynamics, as they relate to abdominal pain. Abdominal ultrasound has been posited as a method to evaluate spleen size in athletes with mononucleosis, with the goal of informing decisions regarding return to play in contact sports. Limited abdominal ultrasound has been investigated previously as a putative method to assess splenic enlargement and time required for regression of splenomegaly in athletes with mononucleosis.[76,77] This technique may be particularly helpful in the tall, thin population of athletes with mononucleosis, who have previously proved to be problematic for clinical clearance due to the challenge of assessing splenomegaly based on physical examination alone. In a recent prospective, cohort observational study, investigators used abdominal ultrasound to determine normative parameters for spleen size in tall athletes.[78] Although helpful in establishing baseline measurements in this subpopulation of athletes, the study is limited in

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that ultrasound was not performed on patients with mononucleosis. Future studies performed on athletes with mononucleosis will provide the next steps in establishing the utility of ultrasound as a diagnostic adjunct in this setting.

Further investigation should also focus on how this technique will impact return-to-play decisions. A recent case series provided preliminary evidence of how serial ultrasound could prove useful in this manner.[79] In that study, 84% of athletes demonstrated a return of splenic size to baseline at 1 month follow-up, providing preliminary evidence of the timing that may be incorporated into policies regarding return to play in contact sports. The implication is that athletes may be able to be re-examined at such a timepoint to establish clearance for sports. Continuing research regarding other intervals of follow-up will be useful in justifying an appropriate timing for such policies. Following this, outcomes research demonstrating efficacy in reducing adverse events would be invaluable in justifying these practices. The imaging techniques are relatively simple in this setting, so there is potential for abdominal ultrasound to play a role in the bedside clinical decisions made with regards to return to play.

Abdominal ultrasound has also been used to investigate groin pain in athletes, a problem accounting for up to 5% of injuries in outdoor soccer players.[80] Athletes with long-standing groin pain (>3 weeks) pose a special challenge to clinicians due to the lack of validated diagnostic tools for this condition.[81] A review of diagnostics available for athletes with long-standing groin pain described a number of diagnostic tests that were available prior to ultrasound and MRI: adduction provocation test, pelvic belt test, palpation, Roentgen, bone scan, herniography. These tests have proven limited, however, with MRI and ultrasound providing the most promising results after clinical examination.[82]

A recent set of studies using ultrasound to measure abdominal muscle thickness has contributed to the understanding of long-standing groin pain seen in athletes. In a study of 42 athletes with long-standing adduction-related groin pain, smaller resting thickness of the transverses abdominis was found to be associated with risk of groin injury.[83] A subsequent study contributed further to this understanding by demonstrating that a pain-anticipatory behaviour may be responsible for long-standing groin pain seen in athletes.[84] The studies were limited, however, in that ultrasound examinations were not blinded and were not compared with a gold standard of diagnosis. Additional research with blinded examination using ultrasound and with comparisons to MRI will be helpful in establishing the role of ultrasound in the diagnosis and management of groin pain in athletes. The ultrasound techniques used for abdominal wall thickness are relatively simple, so there is potential for abdominal ultrasound to be applied at the bedside, to evaluate risk of groin pain in athletes and to target interventions and reduce risk.

Ultrasound of splanchnic haemodynamics has been used to investigate the development of gastrointestinal symptoms expressed during ultraendurance exercise. Previous research has documented a prevalence as high as 45% for gastrointestinal symptoms experienced by athletes during ultraendurance activities.[85,86] A number of theories have been postulated to explain these symptoms: the mechanical effect of running on viscera; reduction of splanchnic blood flow due to visceral vasoconstriction; gastrointestinal hormones (prostaglandins); intestinal dysfunction from alterations in absorption, secretion, and permeability; stress, diet and dehydration.[87] Of these, the role of splanchnic haemodynamics on gastrointestinal symptoms was addressed recently using ultrasound.

Ultrasound techniques in Duplex ultrasound of the superior mesenteric artery have been developed for use in assessment of splanchnic haemodynamics.[88] Such a technique was used in a recent prospective cohort study of 59 Ironman triathletes to assess the role of splanchnic haemodynamics on gastrointestinal symptoms.[89] The study provided evidence against this popular theory, however. There was no significant change in splanchnic haemodynamics that correlated with symptoms in these athletes. Further research with different ultrasound techniques may be able to detect a change, but for the time being, the evidence produced so far has not been promising for

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further investigation into this theory or this application of ultrasound in athletes. The techniques involved in this setting are also complicated and will require referral to specialized laboratories to impact the clinical care of athletes.

4.4 Other Applications of Ultrasound – Vascular, Bone Density, Volume Status

Although most attention has focused on cardiac, musculoskeletal and abdominal ultrasound in athletes, preliminary reports have also been published with regard to other applications of ultrasound. Vascular ultrasound is one application that has been recently reported in a number of case studies. A recent case report described a case of deep vein thrombosis and pulmonary embolism that developed in a triathlete following participation in a race,[90] posing the question of physiological changes in endurance exercise that may increase the risk of thrombosis. In another case report, a former division I collegiate football player developed a deep vein thrombosis in the lower extremity after rigorous exercise of that calf.[91] The patient had a form of sickle cell (haemoglobin SC) that may have increased his risk of thrombosis. The added effect of mechanical strain on the vessel during exercise was also proposed in that report. Deep vein thrombosis has also been described with relation to minor trauma of the popliteal fossa, as reported in another case report.[92] These case reports were instructive not only in their application of vascular ultrasound in the care of athletes, but were also illustrative with regard to risk factors particularly relevant to athletes. Larger studies will be required to substantiate the effects of these proposed risk factors on the formation of thrombosis in athletes. The techniques in this setting are relatively simple, but time intensive. As such, they may require referral to ultrasound laboratories to impact clinical decisions for sports medicine physicians.

Ultrasound has also been used to assess bone mineralization in athletes. Bone quantitative ultrasound (QUS) has been posited as a putative alternative to the use of dual-energy X-ray absorptiometry (DXA) to assess bone mineralization. The validity of this technique has not yet been fully established, with evidence that ultrasound measurements do not always correlate with fracture risk.[93,94] This could relate to known variability that exists with temperature, acoustic coupling, properties of soft tissues overlying bone and the absence of a universally accepted ultrasound phantom for cross calibration between scanners.[95,96] Although the data has been inconsistent, a recent meta-analysis of the data collected so far concluded that QUS of the heel with validated devices reliably predicts the risk of different fracture outcomes in men and women.[97] Much of the heterogeneity seen in previous research was attributed in that meta-analysis to inconsistency in outcomes measures and QUS methodology across studies.

Although studies of QUS in the general population have focused on pathological fractures in the elderly population, recent studies in athletes have focused on younger, healthier populations. A recent study of 224 male athletes described how skeletal maturity occurs earlier with particular sports, such as hockey.[98] Another study demonstrated how hockey players have increased measures of bone mineralization compared with their matched counterparts in lower-impact sports.[99] In another study, ultrasound was used to demonstrate how participation in soccer improves bone density and reduces body mass in pre-pubertal athletes.[100] Identifying relevant outcomes measures, such as fracture risk or stunting of growth/development, will help validate the clinical utility of this technique. Studies with long-term follow-up of athletes, measuring such outcomes, will be helpful in establishing the clinical utility of this ultrasound technique. Although these techniques may be relatively simple, the devices used are highly specialized and may thus require referral to specialized laboratories for evaluation. Since these techniques would be most useful in the context of screening and targeting the risk of injury, the need for referral in such a setting may limit clinical utility in a broad context of the care and management of athletes.

Ultrasound has also been used to assess hydration status and intravascular volume in athletes. Techniques in pulmonary ultrasound have been developed to evaluate the degree of pulmonary

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oedema through estimation of the volume of lung water.[101] This technique was recently applied to ultraendurance athletes to demonstrate how they develop subclinical pulmonary oedema during Ironmen races at sea level.[102] Another technique, ultrasound velocity, has been developed to assess hydration status.[103] A recent study used this technique to detect changes in the hydration status of National Collegiate Athletic Association wrestlers after undergoing acute dehydration and a 2-hour rehydration period.[104] This study demonstrated the potential use of ultrasound measures as an alternative field-based method to assess the hydration status of athletes. Therefore, such techniques would be most applicable to the care of athletes if they could be simplified so that they could be reliably performed by sports medicine physicians in a point-of-care fashion.

5. Conclusion

This review identified numerous achievements in the use of ultrasound in athletes that have developed over the past decade. The reviewed research presents preliminary evidence for the utility of ultrasound in athletes across a broad array of applications, with a number of techniques demonstrating clinical utility in the care of athletes. One of the considerations made apparent by this review is how these techniques will likely impact the clinical management of athletes. Some techniques, due to their complexity and need for specialized equipment, will require referral to specialized laboratories for appropriate imaging, while other techniques are amenable to use at the bedside in a point-of-care fashion. With ECHO, for example, most emerging techniques (such as 3-D ECHO and speckle-tracking ECHO) are highly specialized and will require the referral of athletes to ECHO laboratories for formal testing. Some measurements, such as aortic root diameter, rely on simpler techniques and may be applicable in the setting of point-of-care ultrasound performed at the bedside. This is also the case for most techniques in musculoskeletal and abdominal ultrasound. Further research will be required to establish the accuracy and reliability of such techniques in the hands of physicians. The advantages of point-of-care practice have been described previously: bedside techniques allow sports medicine physicians to provide real-time diagnostics and therapeutics for athletes, leading to increased patient satisfaction and cost effectiveness.[105]

Another relevant topic made apparent by the reviewed research is with regards to establishing clinical relevance for ultrasound techniques in athletes in contrast to simply providing theoretic value and intrigue. Research regarding ECHO has produced a large volume of data in athletes but has focused mainly on describing the physiology of athletes in response to exercise, without direct relevance to the clinical management of athletes. To gain more clinical relevance, research in ECHO has also focused on comparing normal physiology to that seen in response to pathological forms of haemodynamic stress. Musculoskeletal ultrasound, in contrast, has focused mainly on applications with direct clinical relevance. Diagnostic applications of musculoskeletal ultrasound have focused on the physiology of specific pathological conditions afflicting athletes, such as impingement syndromes, arthritis and tendinopathy. As a result, these applications of ultrasound have a more obvious application in the clinical management of athletes. In addition, musculoskeletal ultrasound has been used as a therapeutic adjunct to guide injections and treatment, further expanding its applicability to the clinical management of athletes. Future research focused on the pathophysiology of disease conditions and in the development of therapeutic applications of ultrasound will therefore be critical for expanding the clinical utility of ultrasound in the management of athletes.

Related to this, our review has highlighted the need for outcomes research to continue to establish the utility of ultrasound in sports medicine. With regard to ECHO, for example, research has demonstrated particular physiological parameters of the athlete's heart that differ from the norm, as well as from pathological forms of hypertrophy. Outcomes research regarding clinical sequelae of such changes, as well as the impact of reversing such changes will be invaluable in further establishing the clinical utility of these techniques. Preliminary outcomes research has

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been produced with regard to the ultrasound-guided treatment of musculoskeletal conditions, as with platelet-rich plasma injections for tendinopathy. This has helped to validate the clinical utility of these techniques. Research on abdominal ultrasonography in the measurement of splenomegaly in athletes with mononucleosis has similar promise, but its efficacy has not yet been proven with regard to long-term outcomes and reduction of adverse events. Before such a technique is applied to systemic policy and practice, future research will have to establish that this technique is effective in preventing adverse events and in improving long-term outcomes. The same can be argued for the use of ultrasound to evaluate bone mineral density in athletes. Previous studies using similar techniques in the general population have shown that ultrasound may not reliably assess fracture risk, so future research will face the challenge of identifying relevant clinical outcomes that are measurable by ultrasound in athletes long term.

In addition to highlighting challenges that will face future research, this review has also demonstrated promising applications that have been presented by the research so far. In particular, specific lines of research have posed opportunities for targeted preventive management of athletes. The research regarding shoulder pathology in overhead athletes has identified a number of physiological parameters that may be related to increased risk of shoulder injury. This presents an opportunity to develop targeted treatment modalities. For example, variables identified as contributors to risk (such as humeral migration and scapular dyskinesia) could be targeted by physical therapy and conditioning, with the goal of reducing the risk of injury. The same concept is applicable to long-standing groin pain in athletes, wherein abdominal wall thickness and pain-anticipatory strategies have been posited as contributors to the condition. Treatment regimens focused on these variables may thus prove fruitful in reducing the morbidity of this condition.

Overall, research over the last decade has continued to expand our understanding of how ultrasound can be used to care for athletes. Both the emerging and established applications of ultrasound will require larger studies with outcomes measures to verify their clinical utility in the management and care of athletes in the field of sports medicine. The potential applications of ultrasound to the clinical care and management of athletes are broad, however, and will continue to expand over the coming years.

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References

1. Rost R, Schneider KW, Stegmann N. Comparative echocardiographic studies on the hearts of competitive athletes and of untrained persons. Med Welt 1972 Aug 19; 23 (33): 1088-93
2. Morganroth J, Maron BJ, Henry WL, et al. Comparative left ventricular dimensions in trained athletes. Ann Intern Med 1975 Apr; 82 (4): 521-4
3. Morganroth J, Maron BJ. The athlete's heart syndrome: a new perspective. Ann NY Acad Sci 1977 Oct; 301 (1): 931-41
4. Naylor LH, George K, O'Driscoll G, et al. The athlete's heart: a contemporary appraisal of the 'Morganroth hypothesis'. Sports Med 2008; 38 (1): 69-90
5. Fornage BD. Achilles tendon: US examination. Radiology 1986 Jun; 159 (3): 759-64
6. Gondolph-Zink B, Scheiderer W, Eisenlauer G. Sonography of Achilles tendon changes in athletes. Sportverletz Sportschaden 1987 Jun; 1 (2): 96-9
7. Jerosch VJ, Castro WH, Sons HU. Possibilities for using sonography in sports injuries of the shoulder joint. Sportverletz Sportschaden 1989 Jun; 3 (2): 74-80
8. Kälebo P, Swärd L, Karlsson J, et al. Ultrasonography in the detection of partial patellar ligament ruptures (jumper's knee). Skeletal Radiol 1991; 20 (4): 285-9
9. Sipilä S, Suominen H. Ultrasound imaging of the quadriceps muscle in elderly athletes and untrained men. Muscle Nerve 1991 Jun; 14 (6): 527-33
10. Aspelin P, Ekberg O, Thorsson O, et al. Ultrasound examination of soft tissue injury of the lower limb in athletes. Am J Sports Med 1992 Sep-Oct; 20 (5): 601-3
11. Gabriel H, Kindermann W. Ultrasound of the abdomen in endurance athletes. Eur J Appl Physiol Occup Physiol 1996; 73 (1-2): 191-3
12. Brahm H, Ström H, Piehl-Aulin K, et al. Bone metabolism in endurance trained athletes: a comparison to population-based controls based on DXA, SXA, quantitative ultrasound, and biochemical markers. Calcif Tissue Int 1997 Dec; 61 (6): 448-54
13. Foldes AJ, Danziger A, Constantini N, et al. Reduced ultrasound velocity in tibial bone of young ballet dancers. Int J Sports Med 1997 May; 18 (4): 296-9

Adis © 2012 Springer International Publishing AG. All rights reserved.

14. Orchard JW, Read JW, Neophyton J, et al. Groin pain associated with ultrasound finding of inguinal canal posterior wall deficiency in Australian Rules footballers. Br J Sports Med 1998 Jun; 32 (2): 134-9
15. He W, Xiang DY, Dai JP. Sonography in the 29th Olympic and Paralympic Games: a retrospective analysis. Clin Imaging 2011 Mar-Apr; 35 (2): 143-7
16. Urhausen A, Kindermann W. Echocardiographic findings in strength- and endurance-trained athletes. Sports Med 1992 Apr; 13 (4): 270-84
17. Cohen A, Diebold B, Raffoul H, et al. Evaluation by Doppler echocardiography of systolic and diastolic functions of the left ventricle of the athlete's heart. Arch Mal Coeur Vaiss 1989 Aug; 82 (2): 55-62
18. Fagard R, Van den Broeke C, Amery A. Left ventricular dynamics during exercise in elite marathon runners. J Am Coll Cardiol 1989 Jul; 14 (1): 112-8
19. Pelliccia A, Kinoshita N, Pisicchio C, et al. Long-term clinical consequences of intense, uninterrupted endurance training in olympic athletes. J Am Coll Cardiol 2010 Apr 13; 55 (15): 1619-25
20. Caselli S, Di Paolo FM, Pisicchio C, et al. Three-dimensional echocardiographic characterization of left ventricular remodeling in Olympic athletes. Am J Cardiol 2011 Jul 1; 108 (1): 141-7
21. Galderisi M, Lomoriello VS, Santoro A, et al. Differences of myocardial systolic deformation and correlates of diastolic function in competitive rowers and young hypertensives: a speckle-tracking echocardiography study. J Am Soc Echocardiogr 2010 Nov; 23 (11): 1190-8
22. Butz T, van Buuren F, Mellwig KP, et al. Two-dimensional strain analysis of the global and regional myocardial function for the differentiation of pathologic and physiologic left ventricular hypertrophy: a study in athletes and in patients with hypertrophic cardiomyopathy. Int J Cardiovasc Imaging 2011 Jan; 27 (1): 91-100
23. Indermühle A, Vogel R, Rutz T, et al. Myocardial contrast echocardiography for the distinction of hypertrophic cardiomyopathy from athlete's heart and hypertensive heart disease. Swiss Med Wkly 2009 Nov 28; 139 (47-48): 691-8
24. Caselli S, Pelliccia A, Maron M, et al. Differentiation of hypertrophic cardiomyopathy from other forms of left ventricular hypertrophy by means of three-dimensional echocardiography. Am J Cardiol 2008 Sep 1; 102 (5): 616-20
25. D'Andrea A, Riegler L, Cocchia R, et al. Left atrial volume index in highly trained athletes. Am Heart J 2010 Jun; 159 (6): 1155-61
26. Scharhag J, Thünenkötter T, Urhausen A, et al. Echocardiography of the right ventricle in athlete's heart and hearts of normal size compared to magnetic resonance imaging: which measurements should be applied in athletes? Int J Sports Med 2010 Jan; 31 (1): 58-64
27. Poh KK, Ton-Nu TT, Neilan TG, et al. Myocardial adaptation and efficiency in response to intensive physical training in elite speedskaters. Int J Cardiol 2008 Jun 6; 126 (3): 346-51
28. Oomah SR, Mousavi N, Bhullar N, et al. The role of three-dimensional echocardiography in the assessment of right ventricular dysfunction after a half marathon: comparison with cardiac magnetic resonance imaging. J Am Soc Echocardiogr 2011 Feb; 24 (2): 207-13
29. Hanssen H, Keithahn A, Hertel G, et al. Magnetic resonance imaging of myocardial injury and ventricular torsion after marathon running. Clin Sci (Lond) 2011 Feb; 120 (4): 143-52
30. Neilan TG, Januzzi JL, Lee-Lewandrowski E, et al. Myocardial injury and ventricular dysfunction related to training levels among nonelite participants in the Boston marathon. Circulation 2006 Nov 28; 114 (22): 2325-33
31. Pelliccia A, Di Paolo FM, De Blasiis E, et al. Prevalence and clinical significance of aortic root dilation in highly trained competitive athletes. Circulation 2010 Aug 17; 122 (7): 698-706
32. D'Andrea A, Cocchia R, Riegler L, et al. Aortic root dimensions in elite athletes. Am J Cardiol 2010 Jun 1; 105 (11): 1629-34
33. Babaee Bigi MA, Aslani A. Aortic root size and prevalence of aortic regurgitation in elite strength trained athletes. Am J Cardiol 2007 Aug 1; 100 (3): 528-30
34. D'Andrea A, Naeije R, D'Alto M, et al. Range in pulmonary artery systolic pressure among highly trained athletes. Chest 2011 Apr; 139 (4): 788-94
35. La Gerche A, MacIsaac AI, Burns AT, et al. Pulmonary transit of agitated contrast is associated with enhanced pulmonary vascular reserve and right ventricular function during exercise. J Appl Physiol 2010 Nov; 109 (5): 1307-17
36. Reynolds A. Imaging the injured shoulder. Radiol Technol 2012 Jan; 83 (3): 261-82
37. Ocguder DA, Tosun O, Bektaser B, et al. Ultrasonographic evaluation of the shoulder in asymptomatic overhead athletes. Acta Orthop Belg 2010 Aug; 76 (4): 456-61
38. Wu CH, Wang YC, Wang HK, et al. Evaluating displacement of the coracoacromial ligament in painful shoulders of overhead athletes through dynamic ultrasonographic examination. Arch Phys Med Rehabil 2010 Feb; 91 (2): 278-82
39. Whiteley RJ, Adams RD, Nicholson LL, et al. Reduced humeral torsion predicts throwing-related injury in adolescent baseballers. J Sci Med Sport 2010 Jul; 13 (4): 392-6
40. Thomas SJ, Swanik C, Higginson JS, et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. J Shoulder Elbow Surg 2011 Jul; 20 (5): 708-16
41. Jobe CM, Coen MJ, Screnar P. Evaluation of impingement syndromes in the overhead-throwing athlete. J Athl Train 2000 Jul; 35: 293-9
42. Silva RT, Hartmann LG, de Souza Laurino CF, et al. Clinical and ultrasonographic correlation between scapular dyskinesia and subacromial space measurement among junior elite tennis players. Br J Sports Med 2010 May; 44 (6): 407-10
43. Tran N, Chow K. Ultrasonography of the elbow. Semin Musculoskelet Radiol 2007 Jun; 11 (2): 105-16
44. Lee MH, Cha JG, Jin W, et al. Utility of sonographic measurement of the common tensor tendon in patients with lateral epicondylitis. AJR Am J Roentgenol 2011 Jun; 196 (6): 1363-7
45. Clarke AW, Ahmad M, Curtis M, et al. Lateral elbow tendinopathy: correlation of ultrasound findings with

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pain and functional disability. Am J Sports Med 2010 Jun; 38 (6): 1209-14
46. Mishra A, Pavelko T. Treatment of chronic elbow tendinosis with buffered platelet-rich plasma. Am J Sports Med 2006 Nov; 34 (11): 1774-8
47. Mishra A, Collado H, Fredericson M. Platelet-rich plasma compared with corticosteroid injection for chronic lateral elbow tendinosis. PM R 2009 Apr; 1 (4): 366-70
48. Gard K, Ebaugh D. The use of acetic Acid iontophoresis in the management of a soft tissue injury. N Am J Sports Phys Ther 2010 Dec; 5 (4): 220-6
49. Luz KR, Furtado R, Mitraud SV, et al. Interobserver reliability in ultrasound assessment of rheumatoid wrist joints. Acta Reumatol Port 2011 Jul-Sep; 36 (3): 245-50
50. Ohrndorf S, Hensch A, Naumann L, et al. Contrast-enhanced ultrasonography is more sensitive than grayscale and power doppler ultrasonography compared to MRI in therapy monitoring of rheumatoid arthritis patients. Ultraschall Med 2011 Dec; 32 Suppl. 2: E38-44
51. Filippucci E, Gabba A, Di Geso L, et al. Hand tendon involvement in rheumatoid arthritis: an ultrasound study. Semin Arthritis Rheum 2012; 41 (6): 752-60
52. Créteur V, Madani A, Brasseur JL. Pronator quadratus imaging. Diagn Interv Imaging 2012 Jan; 93 (1): 22-9
53. Chen SF, Lu CH, Huang CR, et al. Ultrasonographic median nerve cross-section areas measured by 8-point "inching test" for idiopathic carpal tunnel syndrome: a correlation of nerve conduction study severity and duration of clinical symptoms. BMC Med Imaging 2011 Dec 21; 11 (1): 22
54. Hunderfund AN, Boon AJ, Mandrekar JN, et al. Sonography in carpal tunnel syndrome. Muscle Nerve 2011 Oct; 44 (4): 485-91
55. Choi SJ, Ahn JH, Lee YJ, et al. de Quervain disease: US identification of anatomic variations in the first extensor compartment with an emphasis on subcompartmentalization. Radiology 2011 Aug; 260 (2): 480-6
56. Finnoff J, Lavallee ME, Smith J. Musculoskeletal ultrasound education for sports medicine fellows: a suggested/potential curriculum by the American Medical Society for Sports Medicine. Br J Sports Med 2010 Dec; 44 (16): 1144-8
57. Pedret C, Balius R, Barceló P, et al. Isolated tears of the gracilis muscle. Am J Sports Med 2011 May; 39 (5): 1077-80
58. Malliaropoulos N, Papacostas E, Kiritsi O, et al. Posterior thigh muscle injuries in elite track and field athletes. Am J Sports Med 2010 Sep; 38 (9): 1813-9
59. Morvan G, Vuillemin V, Guerini H, et al. Recent advances in imaging of hip and knee prostheses. Bull Acad Natl Med 2011 Mar; 195 (3): 613-26
60. Minardi JJ, Lander OM. Septic Hip Arthritis: Diagnosis and arthrocentesis using bedside ultrasound. J Emerg Med. Epub 2012 Jan 26
61. Yoong P, Guirguis R, Darrah R, et al. Evaluation of ultrasound-guided diagnostic local anaesthetic hip joint injection for osteoarthritis. Skeletal Radiol. Epub 2011 Nov 10
62. Shankar H. Ultrasound-guided hip joint injections: a new scanning routine for easy methodical training. Pain Pract 2012 Jan; 12 (1): 80-1
63. Sánchez M, Guadilla J, Fiz N, et al. Ultrasound-guided platelet-rich plasma injections for the treatment of osteoarthritis of the hip. Rheumatology (Oxford) 2012 Jan; 51 (1): 144-50
64. Cook JL, Purdam CR. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. Br J Sports Med 2009 Jun; 43: 409-16
65. Malliaras P, Purdam C, Maffulli N, et al. Temporal sequence of grayscale ultrasound changes and their relationship with neovascularity and pain in the patellar tendon. Br J Sports Med 2010 Oct; 44: 944-7
66. Malliaras P, Cook J. Changes in anteroposterior patellar tendon diameter support a continuum of pathological changes. Br J Sports Med 2011 Oct; 45 (13): 1048-51
67. Koenig MJ, Torp-Pedersen S, Boesen MI, et al. Doppler ultrasonography of the anterior knee tendons in elite badminton players: colour fraction before and after match. Br J Sports Med 2010 Feb; 44 (2): 134-9
68. Warden SJ, Kiss ZS, Malara FA, et al. Comparative accuracy of magnetic resonance imaging and ultrasonography in confirming clinically diagnosed patellar tendinopathy. Am J Sports Med 2007 Mar; 35 (3): 427-36
69. Pfirrmann CW, Jost B, Pirkl C, et al. Quadriceps tendinosis and patellar tendinosis in professional beach volleyball players: sonographic findings in correlation with clinical symptoms. Eur Radiol 2008 Aug; 18 (8): 1703-9
70. Child S, Bryant AL, Clark RA, et al. Mechanical properties of the Achilles tendon aponeurosis are altered in athletes with Achilles tendinopathy. Am J Sports Med 2010; 38 (9): 1885-93
71. Archambault JM, Wiley JP, Bray RC, et al. Can sonography predict outcome in patients with achillodynia? J Clin Ultrasound 1998; 26: 335-9
72. Hirschmuller A, Konstantinidis L, Frey V, et al. Prognostic value of Achilles tendon Doppler sonography in asymptomatic runners. Med Sci Sports Exerc. Epub 2011 Jun 29
73. Emerson C, Morrissey D, Perry M, et al. Ultrasonographically detected changes in Achilles tendons and self reported symptoms in elite gymnasts compared with controls: an observational study. Man Ther 2010 Feb; 15 (1): 37-42
74. Sconfienza LM, Silvestri E, Cimmino MA. Sonoelastography in the evaluation of painful Achilles tendon in amateur athletes. Clin Exp Rheumatol 2010 May-Jun; 28 (3): 373-8
75. Genovese E, Ronga M, Recaldini C, et al. Analysis of achilles tendon vascularity with second-generation contrast-enhanced ultrasound. J Clin Ultrasound 2011 Mar-Apr; 39 (3): 141-5
76. Hosey RG, Mattacola CG, Kriss V, et al. Ultrasound assessment of spleen size in collegiate athletes. Br J Sports Med 2006 Mar; 40 (3): 251-4
77. Hosey RG, Kriss V, Uhl TL, et al. Ultrasonographic evaluation of splenic enlargement in athletes with acute infectious mononucleosis. Br J Sports Med 2008; 42: 974-7
78. McCorkle R, Thomas B, Suffaletto H, et al. Normative spleen size in tall healthy athletes: implications for safe return to contact sports after infectious mononucleosis. Clin J Sport Med 2010 Nov; 20: 413-5

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79. O'Connor TE, Skinner LJ, Kiely P, et al. Return to contact sports following infectious mononucleosis: the role of serial ultrasonography. Ear Nose Throat J 2011 Aug; 90 (8): E21-4
80. Morelli V, Smith V. Groin injuries in athletes. Am Fam Physician 2001 Oct 15; 64: 1405-14
81. Jansen JA, Mens JM, Backx FJ, et al. Treatment of long-standing groin pain in athletes: a systematic review. Scand J Med Sci Sports 2008 Jun; 18: 263-74
82. Jansen JA, Mens JM, Backx FJ, et al. Diagnostics in athletes with long-standing groin pain. Scand J Med Sci Sports 2008 Dec; 18 (6): 679-90
83. Jansen J, Weir A, Dénis R, et al. Resting thickness of transversus abdominis is decreased in athletes with long-standing adduction-related groin pain. Man Ther 2010 Apr; 15 (2): 200-5
84. Jansen JA, Poot B, Mens JM, et al. The effect of experimental groin pain on abdominal muscle thickness. Clin J Pain 2010 May; 26 (4): 300-5
85. ter Steege RW, Van der Palen J, Kolkman JJ. Prevalence of gastrointestinal complaints in runners competing in a long-distance run: an internet-based observational study in 1281 subjects. Scand J Gastroenterol 2008; 43 (12): 1477-82
86. Peters HP, Bos M, Seebregts L, et al. Gastrointestinal symptoms in long-distance runners, cyclists, and triathletes: prevalence, medication, and etiology. Am J Gastroenterol 1999 Jun; 94 (6): 1570-81
87. Gil SM, Yazaki E, Evans DF. Aetiology of running-related gastrointestinal dysfunction. How far is the finishing line? Sports Med 1998 Dec; 26 (6): 365-78
88. Perko MJ. Duplex ultrasound for assessment of superior mesenteric artery blood flow. Eur J Vasc Endovasc Surg 2001 Feb; 21 (2): 106-17
89. Wright H, Collins M, Villiers RD, et al. Are splanchnic hemodynamics related to the development of gastrointestinal symptoms in ironman triathletes? A prospective cohort study. Clin J Sport Med 2011 Jul; 21 (4): 337-43
90. Tao K, Davenport M. Deep venous thromboembolism in a triathlete. J Emerg Med 2010 Apr; 38 (3): 351-3
91. Yim ES, Friedberg RP. Lower extremity deep vein thrombosis following an intense calf workout. Curr Sports Med Rep 2012 Nov-Dec. In press
92. Orlik J, McVey J. Deep vein thrombosis and bilateral pulmonary embolism following minor trauma to the popliteal fossa: could this have been avoided? CJEM 2011 Mar; 13 (2): 122-6
93. Tuna H, Birtane M, Ekuklu G, et al. Does quantitative tibial ultrasound predict low bone mineral density defined by dual energy X-ray absorptiometry? Yonsei Med J 2008 Jun 30; 49 (3): 436-42
94. Mack-Shipman LR, O'Grady DM, Erickson JM, et al. Heel ultrasonography is not a good screening tool for bone loss after kidney and pancreas transplantation. Clin Transplant 2004 Oct; 18 (5): 613-8
95. Nicholson PH, Bouxsein ML. Effect of temperature on ultrasonic properties of the calcaneus in situ. Osteoporos Int 2002 Nov; 13 (11): 888-92
96. Krieg MA, Cornuz J, Hartl F, et al. Quality controls for two heel bone ultrasounds used in the Swiss Evaluation of the Methods of Measurement of Osteoporotic Fracture Risk Study. J Clin Densitom 2002 Winter; 5 (4): 335-41
97. Moayyeri A, Adams JE, Adler RA, et al. Quantitative ultrasound of the heel and fracture risk assessment: an updated meta-analysis. Osteoporos Int 2012 Jan; 23 (1): 143-53
98. Moore SA, Moore M, Klentrou P, et al. Maturity status in male child and adolescent athletes. J Sports Med Phys Fitness 2010 Dec; 50 (4): 486-93
99. Falk B, Braid S, Moore M, et al. Bone properties in child and adolescent male hockey and soccer players. J Sci Med Sport 2010 Jul; 13 (4): 387-91
100. Madić D, Obradović B, Smajić M, et al. Status of bone mineral content and body composition in boys engaged in intensive physical activity. Vojnosanit Pregl 2010 May; 67 (5): 386-90
101. Garbella E, Catapano G, Pratali L, et al. Pulmonary edema in healthy subjects in extreme conditions. Pulm Med. Epub 2011 June 22
102. Pingitore A, Garbella E, Piaggi P, et al. Early subclinical increase in pulmonary water content in athletes performing sustained heavy exercise at sea level: ultrasound lung comet-tail evidence. Am J Physiol Heart Circ Physiol 2011 Nov; 301 (5): H2161-7
103. Sarvazyan A, Tatarinov A, Sarvazyan N. Ultrasonic assessment of tissue hydration status. Ultrasonics 2005 Aug; 43 (8): 661-71
104. Utter AC, McAnulty SR, Sarvazyan A, et al. Evaluation of ultrasound velocity to assess the hydration status of wrestlers. J Strength Cond Res 2010 Jun; 24 (6): 1451-7
105. Sivan M, Brown J, Brennan S, et al. A one-stop approach to the management of soft tissue and degenerative musculoskeletal conditions using clinic-based ultrasonography. Musculoskeletal Care 2011; 9 (2): 63-8

Correspondence: Dr *Eugene Sun Yim*, MD, MPH, 319 Longwood Ave, Boston, MA 02115, USA.
E-mail: eyim@bidmc.harvard.edu

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