[ Imaging ]

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# Sports Ultrasound: Applications Beyond the Musculoskeletal System

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**Background:** Traditionally, ultrasound has been used to evaluate musculoskeletal injuries in athletes; however, ultrasound applications extend well beyond musculoskeletal conditions, many of which are pertinent to athletes.

**Evidence Acquisition:** Articles were identified in PubMed using the search terms *ultrasound, echocardiogram, preparticipation physical examination, glycogen, focused assessment with sonography of trauma, optic nerve*, and *vocal cord dysfunction*. No date restrictions were placed on the literature search.

**Study Design:** Clinical review.

**Level of Evidence:** Level 4.

**Results:** Several potential applications of nonmusculoskeletal ultrasound in sports medicine are presented, including extended Focused Assessment with Sonography for Trauma (eFAST), limited echocardiographic screening during preparticipation physical examinations, assessment of muscle glycogen stores, optic nerve sheath diameter measurements in athletes with increased intracranial pressure, and assessment of vocal cord dysfunction in athletes.

**Conclusion:** Ultrasound can potentially be used to assist athletes with monitoring their muscle glycogen stores and the diagnosis of multiple nonmusculoskeletal conditions within sports medicine.

**Keywords:** ultrasonography; sports medicine; diagnostic imaging

Traditionally, diagnostic ultrasound (US) has been used in sports medicine to evaluate musculoskeletal injuries to subcutaneous tissue, fascia, muscle, tendons, joints, bones, ligaments, and nerves.[52,53] Diagnostic US has many advantages over other imaging modalities, including point of care access, equipment portability, lower cost of equipment, decreased expense for the patient, patient comfort, and lack of ionizing radiation.[43,52,53] US also allows the health care provider to image structures as they move, thus allowing the recognition of pathology that could not be clearly depicted with static images. Furthermore, the dynamic nature of this imaging modality enables US to be used to guide interventional procedures.[19]

Although the ability of US to evaluate musculoskeletal conditions is exceptional, the utility of diagnostic US in sports medicine extends well beyond the musculoskeletal realm.

## EXTENDED FOCUSED ASSESSMENT WITH SONOGRAPHY FOR TRAUMA (EFAST)

The use of US in the setting of blunt thoracoabdominal trauma was first described by Kristensen et al[30] in 1971. However, it was not adopted for trauma until the 1990s with the development of Focused Assessment with Sonography in Trauma (FAST) in 1995,[46] which is a rapid 4-view examination for hemoperitoneum and hemopericardium.[4,44-47] The FAST examination is now a component of the Advanced Trauma Life Support (ATLS) algorithm.[4] Approximately 200 mL of free fluid is required to identify free intraperitoneal fluid. At this degree of free fluid, the sensitivity of the FAST examination for abdominal trauma ranges from 42% to 98% and the specificity from 95% to 100%.[7,8,11,16,20,27,31,35,36,42,49,64] The eFAST, or extended FAST

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examination, further evaluates for pneumothorax or hemothorax. The sensitivity and specificity for pneumothorax with US is 86% to 98% and 97% to 100%, respectively, whereas the same for supine anteroposterior chest radiographs is 28% to 75% and 99% to 100%, respectively.[1-3,60]

eFAST is currently used predominantly in the emergency department setting. The eFAST examination could be used to evaluate athletes with suspected thoracoabdominal trauma to improve the triage process. Sports-related thoracoabdominal trauma (pneumothorax,[15] kidney,[59] spleen,[6] or liver injury[6] or pericardial effusion[9]) can be identified by US. The same ski and snowboard injuries can be efficiently and accurately evaluated with US.[18,49] US may play a role in the prehospital evaluation of athletes with thoracoabdominal trauma.

A description of how to perform the eFAST examination along with supporting figures can be found in Appendix 1 (available at http://sph.sagepub.com/content/suppl).

## LIMITED ECHOCARDIOGRAPHIC ASSESSMENT FOR STRUCTURAL CARDIAC ABNORMALITIES DURING THE PREPARTICIPATION PHYSICAL EXAMINATION

The conditions that predispose athletes to structural cardiac abnormalities (SCDs) are rare, with the most common cause of SCD—hypertrophic cardiomyopathy (HCM)—in 0.1% to 0.2% of the population.[29] Structural cardiac abnormalities are responsible for 84% of all SCDS, 44% of which stem from HCM and left ventricular hypertrophy (LVH).[19,32] Acquired diseases and conduction-related conditions are responsible for the remainder of SCDs.[32]

Screening for conditions that predispose athletes to SCD is possible; however, the most effective and cost-efficient screening method to detect these conditions is subject of significant debate. The American Heart Association (AHA) argues for the use of history and physical (H&P) examination in the United States, while in Europe, a focused H&P and electrocardiogram (ECG) is the recommended practice.[12,32] Unfortunately, both the H&P and ECG have significant limitations as screening methods. Although cost conservative in comparison with ECG, the AHA's recommended H&P examination generates a high number of false negative and false positive results, putting athletes with detectable cardiac abnormalities at risk for SCD and subjecting athletes to lengthy cardiac work-ups and time away from sport, respectively.[23]

The availability of portable US has led to the development of the Early Screening for Cardiac Abnormalities with Preparticipation Echocardiography (ESCAPE) protocol.[63] Preliminary studies[61-63] sought to determine the accuracy of limited echocardiograms performed by physicians compared with experienced echocardiographers. Four end-diastolic measurements were obtained: interventricular septal thickness (IVSd), left ventricular internal diameter (LVIDd), left ventricular posterior wall thickness (LVPWd),[61,62] and aortic root diameter.[61,63] These studies established that physicians could reliably obtain these echocardiographic measurements. The ESCAPE protocol produced promising accuracy and reliability results: 65 National Collegiate Athletic Association (NCAA) Division 1 collegiate athletes received preparticipation physical examinations on the 2007 12-element AHA recommendations, a 12-lead ECG (2010 European Society of Cardiology criteria), and a limited echocardiogram performed by a physician and a cardiologist to assess for HCM and aortic root dilatation.[61] There was no statistically significant difference between the echocardiographic measurements obtained by the physician and those obtained by the cardiologist, indicating a high degree of interrater reliability. The limited ECG would have reduced the referral rate to cardiology by 33% when compared with the combination of H&P and ECG. The ESCAPE protocol can reduce the false-positive rates associated with H&P and ECG and may broaden the spectrum of diseases that can be detected during the preparticipation physical examination.[61]

Figure 1. Transducer and patient position (right lateral decubitus) to obtain a parasternal long-axis view during a limited echocardiogram.

A limited echocardiogram can be performed with a low-frequency (eg, 5-2 MHz) phased array transducer. Images are obtained via the parasternal long-axis view with the patient in the right lateral decubitus position (Figure 1). The IVSd, LVIDd, and LVPWd measurements are all obtained at the end of diastole. The IVSd is obtained approximately 1 cm caudal to the aortic outflow tract (Figure 2). The LVPWd is measured from the

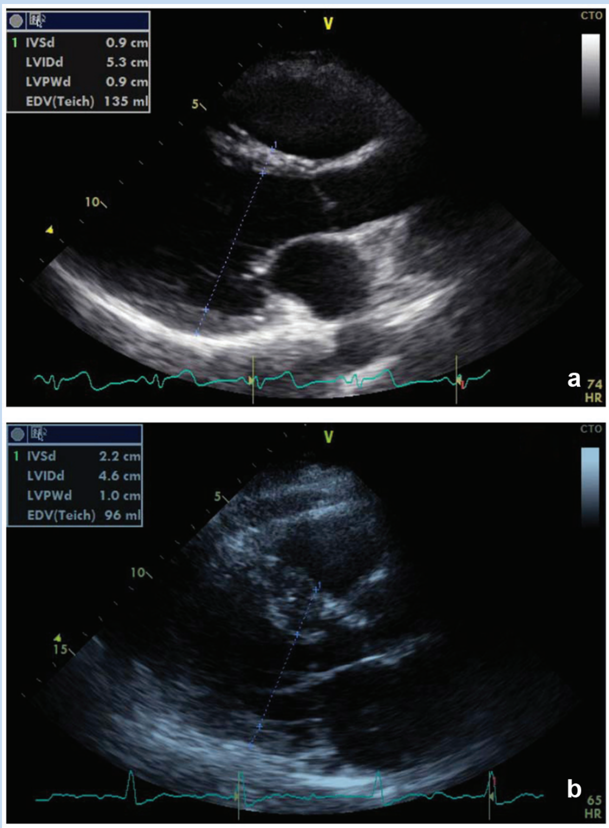


Figure 2. Echocardiographic measurements of the interventricular septal thickness (IVSd) in (a) a normal athlete and (b) an athlete with hypertrophic cardiomyopathy. Top of image, right ventricle; bottom of image, left ventricular posterior wall; left side of image, left ventricular cavity; right side of image, aortic and mitral valves. LVPWd, left ventricular posterior wall diameter distance; LVIDd, left ventricular internal diameter distance.

superficial aspect of the epicardium to the deep edge of the endocardium (Figure 2). The aortic root diameter is measured from the inner edge to the inner edge at the sinuses of Valsalva.

## ASSESSMENT OF MUSCLE GLYCOGEN STORES WITH US

Eighty percent of glycogen is stored in skeletal muscle.[26] Glycogen depletion results in fatigue, reduced performance,[10,13,14,25,33,34,48] and increased overtraining risk.[50,51,54]

Muscle biopsies are the gold standard test to determine skeletal muscle glycogen stores. While appropriate in the research setting, this is an impractical way of determining glycogen stores for an athlete on a regular basis. An ideal test would be portable, inexpensive, and noninvasive.

Two studies have evaluated the ability of diagnostic US to assess the pre- and postexercise muscle glycogen stores in the rectus femoris (RF) and vastus lateralis (VL) muscles of competitive cyclists.[26,41] A LOGIQ-e (General Electric) US machine with a 12-MHz linear array transducer was used for the studies. The midportion (halfway between the anterior superior iliac spine and superior pole of the patella) of the RF and VL muscles were scanned in the short- and long-axes before and immediately after exercise (Figure 1 in Appendix 2, available at http://sph.sagepub.com/content/suppl). An indelible marker was used to mark the skin where image acquisition was performed to ensure images were taken from the same location pre- and postexercise. Pre- and postexercise muscle biopsies were also performed and analyzed for glycogen content. Athletes consumed a high carbohydrate diet (8 g carbohydrate/kg of body weight) for 3 days prior to the exercise test, avoided exercise for 48 hours prior to the test, and exercised no longer than 2 hours per day at a moderate intensity for the prior 7 days. The exercise test involved riding at an intensity of 2 to 3 g/min of carbohydrate metabolism for 90 minutes on a cycloergometer (Lode Excalibur Sport; Lode).

Following image acquisition, the US images were processed and analyzed using the MuscleSound application (MuscleSound, LLC). A description of this process along with supporting figures can be found in Appendix 2. The pre- and postexercise glycogen scores produced by the MuscleSound analysis were found to be highly correlated with those of the muscle biopsies (preexercise, $r = 0.93$, $P < 0.001$; postexercise, $r = 0.94$, $P < 0.001$). The correlation between the pre- and postexercise difference in muscle glycogen content calculated by the MuscleSound US image evaluation and the muscle biopsy were also highly correlated ($r = 0.81$, $P < 0.001$). It should be noted that both of these studies were funded by MuscleSound LLC. This should be taken into consideration when interpreting their results.

## OPTIC NERVE SHEATH DIAMETER MEASUREMENTS IN ATHLETES WITH SUSPECTED INCREASED INTRACRANIAL PRESSURE

Evaluation of the optic nerve sheath diameter (ONSD) is an easy-to-learn[56] and accurate way to evaluate intracranial pressures from a multitude of etiologies.[5,17] The optic nerve is surrounded by cerebrospinal fluid and dura mater, which forms the optic nerve sheath. The intracranial subarachnoid space connects to the optic nerve sheath, and therefore its diameter is influenced by cerebrospinal fluid pressure variations, particularly at the retrobulbar segment.[21,24] ONSD has been correlated with intracranial pressures through studies that directly measure intrathecal and intracranial pressures.[22,37] A description of how to assess the ONSD with ultrasound along with supporting figures can be found in Appendix 3 (available at http://sph.sagepub.com/content/suppl).

In addition to identifying signs of increased intracranial pressure, a diagnostic US evaluation of the eye can also reveal

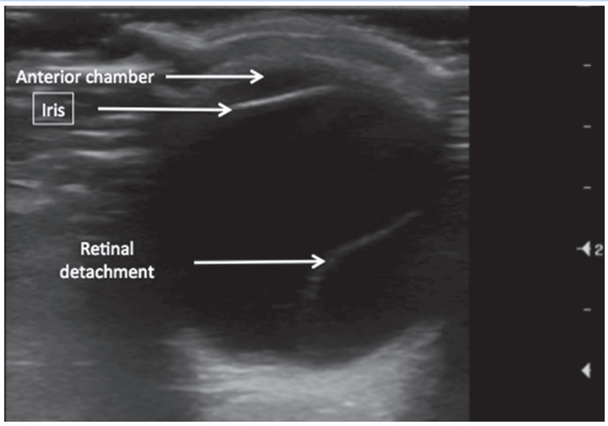


Figure 3. Diagnostic ultrasound image revealing a retinal detachment. The detached retina is seen as a linear, hyperechoic structure within the anechoic vitreous body and is tethered to the globe. Top of image, superficial; bottom of image, deep; left side of image, medial; right side of image, lateral.

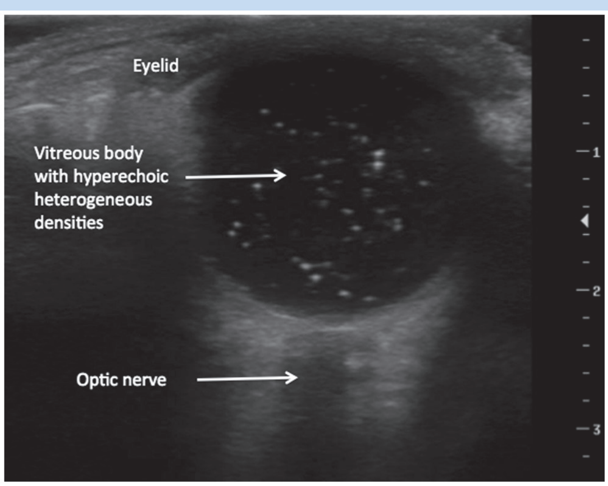


Figure 4. Diagnostic ultrasound image of a vitreous hemorrhage. The vitreous hemorrhage appears as hyperechoic, heterogeneous densities within the anechoic vitreous body. Having the patient move his eyes horizontally will produce a "swirl sign," and the densities will swirl within the globe. Top of image, superficial; bottom of image, deep; left side of image, medial; right side of image, lateral.

several other potential injuries found in athletes. A retinal detachment is seen as a linear hyperechoic structure (Figure 3) within the anechoic vitreous body (humor), and a vitreous hemorrhage appears as diffuse hyperechoic structures within the anechoic vitreous body (Figure 4). A traumatic lens dislocation appears as a hyperechoic lens dislocated from the ciliary body (Figure 5).

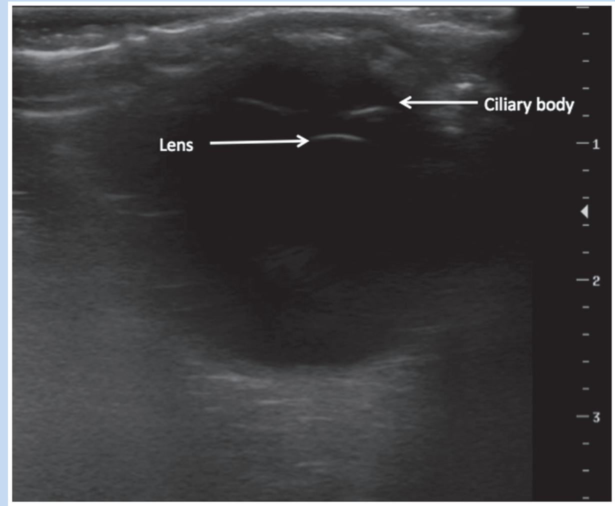


Figure 5. Diagnostic ultrasound image of a lens dislocation. In this image, the hyperechoic lens is dislocated posterior to the ciliary body. Top of image, superficial; bottom of image, deep; left side of image, medial; right side of image, lateral.

## SONOGRAPHIC EVALUATION FOR VOCAL CORD DYSFUNCTION

Vocal cord dysfunction (VCD) involves closure of the vocal cords while inspiring, thus causing wheezing, stridor, dyspnea, and exercise intolerance.[38] The pathophysiology of VCD is poorly understood.[55] It is most common in elite female athletes 20 to 40 years of age.[38,39] Psychological stress or anxiety increases symptoms of VCD.[38,39] VCD is frequently misdiagnosed as asthma.[40] Unfortunately, typical asthma treatments, such as inhaled β-agonists, are ineffective for VCD.[40]

VCD is suggested when the inspiratory portion of a pulmonary function test's flow volume loop is flattened.[38] However, the gold standard diagnostic test for VCD is video laryngoscopy.[57] This is typically performed during or immediately following an exercise test meant to provoke VCD.[57] Unfortunately, video laryngoscopy is an invasive procedure in which a video laryngoscope is introduced through the patient's nose and advanced to their nasopharynx such that the vocal cords can be visualized.

A potential alternative to video laryngoscopy is sports US (Figure 6). US has been used to successfully evaluate vocal cord masses and abnormal vocal cord movements associated with vocal cord paralysis.[58] Hu et al[28] demonstrated good intra- and interrater reliability (0.723-0.943 and 0.736-0.903 intraclass correlation coefficients, respectively) measurements of the length, width, and thickness of the true and false vocal cords. To date, there have not been any published studies evaluating the ability of sports US to accurately and reproducibly diagnose VCD in athletes.

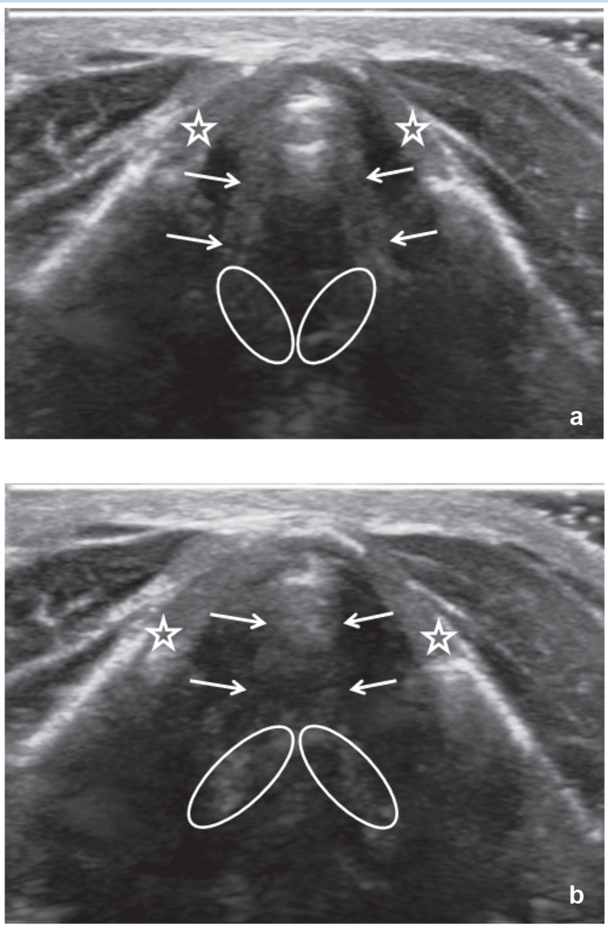


Figure 6. Ultrasound image of vocal cords during inspiration with the ultrasound probe placed over the anterior aspect of the subject's neck. (a) Normal, abducted position of vocal cords. (b) Paradoxical, adducted position of vocal cords. Arrows, vocal cords; ovals, arytenoid cartilage; stars, thyroid cartilage. Top of image, superficial; bottom of image, deep; left side of image, left side of subject; right side of image, right side of subject. Used with permission of the Mayo Foundation for Medical Education and Research.

## CONCLUSION

Diagnostic US is a commonly used imaging modality in sports medicine. Although traditionally used to evaluate musculoskeletal conditions, diagnostic US in sports medicine has utility for multiple nonmusculoskeletal conditions.

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