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REVIEW

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Sonography in Sports Injuries – Subs Bench or Underestimated Veteran?

Sonographie bei Sportverletzungen – Ersatzbank oder unterschätzter Veteran?

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Summary

- **Treatment of sports injuries** needs effective and early diagnostics to provide optimal therapy and return-to-sports with a minimum of delay. Patient history and clinical examination determine order and urgency of further imaging tools.
- **Usually,** sonography (US) is the first-line diagnostic tool to detect muscle-, tendon- and peripheral ligamentous injuries. It gives the opportunity to differentiate acute lesions from chronic overuse injuries. Furthermore, in frequent follow-up examinations after an acute injury it is of great value to monitor the healing process. Advantages, especially towards magnetic resonance imaging (MRI), are early availability (in part already sidelines or in the changing room with portable devices), low costs and the possibility of dynamic examination (e.g. in tendon ruptures or ligament injuries). The latter is one of the most important benefits towards static MRI, as partial lesions can be detected easily. Furthermore, influence of the injuries on function and stability can be evaluated in real-time.
- **Besides, technical advancements** like Contrast-enhanced Ultrasonography (CEUS), Elastography and Ultrasonographic Tissue Characterization (UTC) might improve sonographic sensitivity and expand the range of application in the near future.
- **Although,** magnetic resonance imaging (MRI) is increasingly available and used more and more for primary diagnostics, US remains one of the most important tools in the hands of sports medicine specialists.

KEY WORDS:
Sonography, Ultrasound, Sports Injury, Diagnostics

Zusammenfassung

- **Bei der Behandlung von Sportverletzungen** ist eine effektive und frühzeitige Diagnostik erforderlich, um den Sportler optimal zu behandeln und eine frühe und erfolgreiche Rückkehr in den Sport zu gewährleisten. Aus der Anamnese und klinischen Untersuchung leiten sich Dringlichkeit und Reihenfolge der weiteren apparativen Diagnostik ab. Die Ultraschalldiagnostik stellt hier die erste Instanz dar.
- **Im Bereich** der Muskel-, Sehnen- und peripheren Bandverletzungen ist sie das wichtigste primäre Tool, um akute Verletzungen von chronischen Überlastungszuständen zu differenzieren. Auch in der regelmäßigen Verlaufsuntersuchung nach einer akuten Verletzung ist sie von großem Wert. Die Vorteile des Ultraschalls, insbesondere gegenüber der Kernspintomographie (MRT), liegen in der schnellen Verfügbarkeit (zum Teil bereits am Spielfeldrand bzw. in der Umkleidekabine mit mobilen Geräten), den geringen Kosten und der Möglichkeit der dynamischen Untersuchung (z.B. Sehnenrupturen oder Gelenkinstabilität bei ligamentärer Partialruptur). Letzteres ist eines der entscheidenden Vorzüge gegenüber dem statischen MRT, da hierdurch Partialläsionen einfacher detektiert und die Auswirkung der Läsion auf die Funktion geprüft werden können.
- **Auch neue Entwicklungen** in der Ultraschalltechnik wie die Kontrastmittel-gestützte Sonographie, die Elastographie oder auch die Ultrasonographic Tissue Characterization werden möglicherweise in der nahen Zukunft das Anwendungsspektrum vergrößert bzw. die Sensitivität der Sonographie erhöhen.
- **Obwohl** die Kernspintomographie (MRT) zunehmend Verbreitung findet und häufiger auch als primäres Diagnostikum eingesetzt wird, bleibt die Sonographie das eines der wichtigsten diagnostischen Tools in den Händen des Sportmediziners.

SCHLÜSSELWÖRTER:
Sonographie, Ultraschall, Sportverletzung, Diagnostik

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Introduction

Acute sports injuries as well as chronic lesions mostly regard soft tissue structures as muscles, ligaments and tendons. For this reason, besides patient history and clinical examination sonography and magnetic resonance imaging (MRI) are the most valuable tools to examine those injuries. The fast enhancements in MRI technologies and its broad availability have taken musculosceletal ultrasound a back seat over the past years. Especially in professional sports MRI has become the gold standard in detection of sports injuries. The question comes up if sonography is still needed in the early phase and follow-up of those injuries.

In addition, sonographic technologies have been advanced to improve sensitivity of this diagnostic tool. Furthermore, there are still the advantages of portability, prompt availability and option of dynamic examination. The latter helps the sports medicine specialist not only visualizing structure but also function.

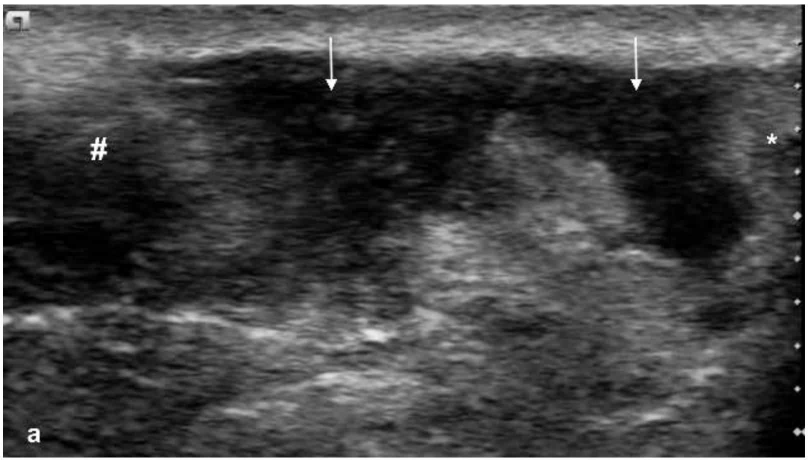

Figure 1

Sonography of an Achilles tendon rupture (longitudinal plane) with dynamic examination to evaluate adaption of the stumps in dorsal extension (a). # proximal stump, * distal stump, white arrows hematoma between ruptured tendon.

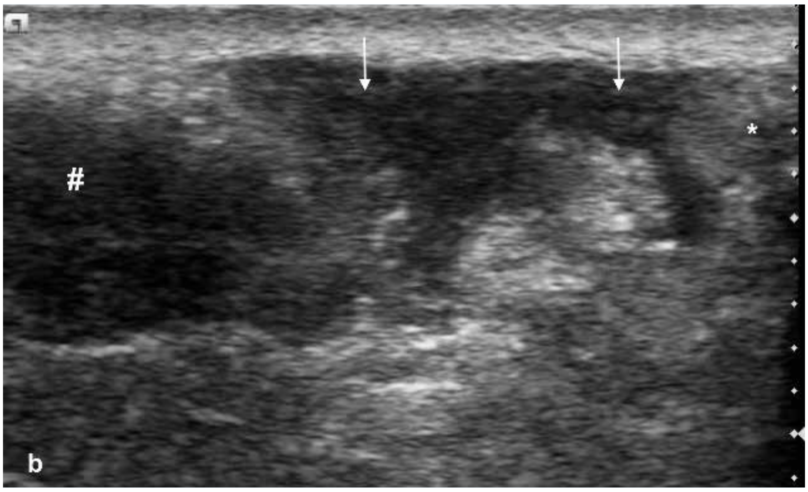

Figure 2

Sonography of an Achilles tendon rupture (longitudinal plane) with dynamic examination to evaluate adaption of the stumps in plantar flexion (b). # proximal stump, * distal stump, white arrows hematoma between ruptured tendon.

Muscle Injuries

Muscle injuries are very common in sports injuries. Depending on sports and proficiency level they account for 10-55% of all sports injuries (18). Especially in professional athletes off times are related to those injuries to a big amount. Caused by incidence the four major muscle groups of the lower limb (Hamstrings, adductors, gastrocnemius, quadriceps) are in focus of research concerning imaging and rehab (11, 28). Causal, direct from indirect mechanism has to be differentiated. Indirect acute trauma with eccentric load to the muscle fibres are most common (18). Those eccentric loads lead to lesions of various extent. Furthermore, structurel lesions have to be differed from ultrastructurel lesions (33). This means, injuries with a macroscopic disruption of muscle fibres have to be distinguished from injuries with increase of muscle tone but without a macroscopic lesion (33). As clinical examination is not always able to do so, imaging like sonography and MRI are needed to initiate correct therapy (20, 21, 27). To decide about therapy and to give statement on return-to sports imaging to evaluate extent of the muscular damage is eminent (1, 6, 28). Muscle lesions with negative sonography or with extent of lesion less than 25% of the muscles cross-sectional-area showed to have a earlier return-to-sports (28).

Using high-frequency linear–array transducers (12-18MHz) with in-plane resolution less than 200 µm, secondary muscle bundle can be visualized as smallest anatomical unit (14, 25). In young athletes muscles give the impression to be more hypoechoic and perimysium is more distant to each other. For that reason, both-sided examination is important (25). Ideal point in time to perform sonography is 2-48h after injury. At that time hematoma gets more hypoechoic and offers perfect contrast to structurel damage to the muscle (35). Most common sonographic classification of muscle lesions is the one by Peetrons (35). Unfortunately, this classification doesn't consider ultrastructurel lesions and doesn't fit to the most important clinical classification of Müller-Wohlfarth et al. (33) in graduating structurel lesions. Hence, an adaption of the Munich consensus classification (33) was done by the GOTS expert meeting recently (12) (table 1).

Besides acute trauma, sonography is of great value in examine post-injury complications. Myositis ossificans can be detected 2 weeks earlier as with conventional x-ray (35). Healing without a scar is common in partial muscle fibre tears. In high grade muscle tears healing process leads to some kind of scar tissue (18). Those scars are detectable as hyper- or isoechoic area with adherence to the fascia without movement in dynamic examination (26). After indirect injury a linear and after direct injury a nodular alteration can be seen (41). Also hernias and recurrent seromas after high-grade lesions are visible in dynamic examination with active muscle contraction (26).

Tendon Injuries

In the diagnostic of tendon pathologies the examiner is commonly confronted with the question to differ tendinopathies from partial or complete ruptures.

In acute tendon ruptures hematoma is a perfect natural contrast agent to circumscribe the stump of the tendon. Other than in muscle lesions sonography is sensitive very early. Also bony avulsions can be detected by the hyperechoic line with dorsal echo extinction at the end of the tendon stump. One major advantage towards MRI is the possibility of dynamic examination. By way of example, in Achilles tendon ruptures approximation of tendon stumps can be proven in maximal plantar flexion (fig. 1 and 2). Furthermore, demarcation of partial ruptures from complete ruptures is possible in extension to visualize dehiscence in the rupture zone.

Tendinopathies show different sonographic changes depending on grading of the disease. In early phase of a peritendinitis a hypoechoic halo can be seen around the tendon. In chronic phase a reduced gliding between tendon and peritendineum can be seen under dynamic examination. Tendinosis shows a hypoechoic zone in the middle of the tendons cross section first and a fusiform thickening mostly in the midportion later on.

Ligament Injuries

Sports injuries of peripheral ligaments are very common and can be treated conservatively in most of the cases. But clarification of the extend of the ligamentous lesion is necessary to manage therapy and make a statement on return-to-sports. Availability of high-frequency transducers with up to 18 MHz make it possible to examine structural damage of even small ligaments e.g. ulnar collateral ligament of thumb basal joint (skier's thumb) (fig. 3 and 4). Furthermore, dynamic examination with sonography gives information about stability, which MRI cannot provide.

25% of all musculoskeletal injuries are ankle sprains (40). Acute lesions of the lateral collateral ligaments and the medial collateral ligament can be detected with high sensitivity and specifity (15, 29, 30). More important is the detection of syndesmotic injuries as surgical treatment can be necessary. MRI has a sensitivity of 93% in detecting those lesions (39) but is not able to show instability of the distal tibiofibular joint. Sonography has only a sensitivity of 66% when it is performed static (32) but can be improved up to 89% when performed dynamically (31). Furthermore, dynamic examination shows instability of the distal tibiofibular joint (fig. 5 and 6). On the contrary, dynamic evaluation of anterior talar shift with stress-sonography in acute ankle sprains showed to be of low value (43). Even with use of local anaestethics, stress-sonography without direct ligament visualization showed only a sensitivity of 27%, while clinical examination showed a sensitivity of 93%. Comparable to stress-radiographs, stress-ultrasound cannot be recommended to detect anterior tibiotalar instability in acute ankle sprains. In the hand of a experienced sonographer slight movements under direct visualization of the ligament can improve detection of a lesion.

This dynamic examination has also been found to be of great value in detection of ulnar collateral ligament lengthening and instability in heavily exposed athletes e.g. baseball pitchers (3, 5).

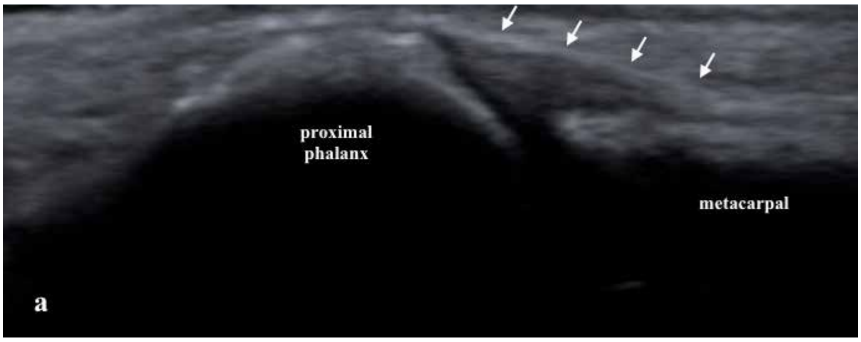

Figure 3
High-resolution US with a 18MHz linear-array transducer of a intact ulnar collateral ligament (white arrow) of a thumb basal joint in longitudinal plane. in neutral position (a).

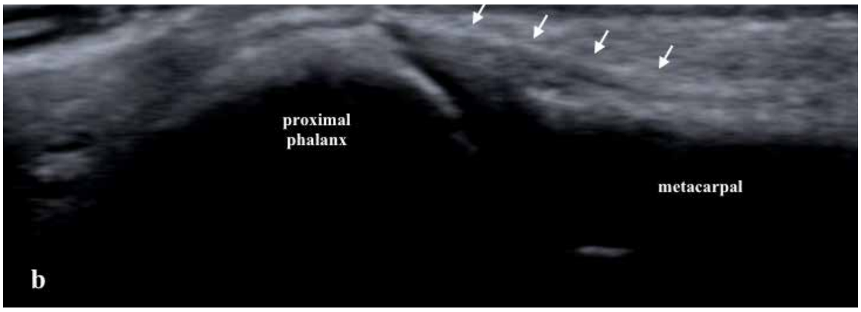

Figure 4
High-resolution US with a 18MHz linear-array transducer of a intact ulnar collateral ligament (white arrow) of a thumb basal joint in longitudinal plane. under stress (b) in radial abduction.

Table 1
Muscle injury classification with adaption of sonographic findings according to the GOTS expert meeting 2016 (12) modified from (33).

			MRI	US
A. Indirect muscle disorder/ injury	**Ultrastructural muscle disorder**	**Type 1: Overexertion-related muscle disorder**		
		Type 1A: Fatigue-induced	negative	negative
		Type 1B: Delayed-onset muscle soreness (DOMS)	Edema in high-resolution MRI	negative or slight edema
		Type 2: Neuromuscular muscle disorder		
		Type 2A: Spine-related	negative or edema	negative or slight edema
		Type 2B: Muscle-related	negative or edema	negative or slight edema
	Structural muscle injury	**Type 3: Partial muscle tear**		
		Type 3A: Minor partial tear	Intramuscular hematoma, rarely fiber disruption	Elongated fiber structure, intramuscular hematoma, rarely fiber disruption
		Type 3B: Moderate partial tear	Fiber disruption, fascia disruption, intra- and/or intermuscular hematoma	Fiber disruption, separation under compression, intra- and/or intermuscular hematoma
		Type 4: (Sub)total muscle tear		
		Type 4A: Subtotal tear and Tendinous avulsion	Extensive disruption of fiber structure with fascia disruption, intra- and intermuscular hematoma	Extensive disruption of fiber structure with fascia disruption, intra- and intermuscular hematoma
		Type 4B: Complete tear and Tendinous avulsion	Complete muscle disruption, retraction, intra- and intermuscular hematoma	Complete muscle disruption, retraction, intra- and intermuscular hematoma
B. Direct muscle injury		**Contusion**		Variable value from edema, intra- and intermuscular hematoma up to fiber disruption
		Laceration		Sharp fiber disruption with fascia disruption, Complete muscle disruption, intra- and intermuscular hematoma

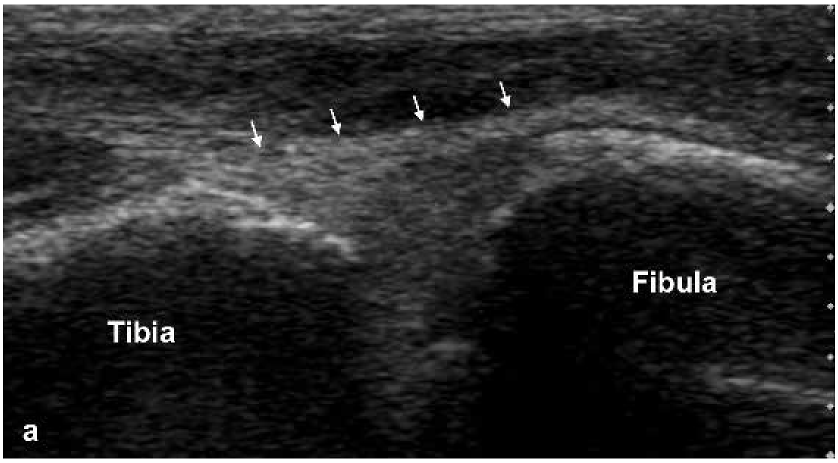

Figure 5

Sonography in horizontal plane of the anterior interosseous tibiofibular ligament (AITFL) (white arrows) in intact situation (a).

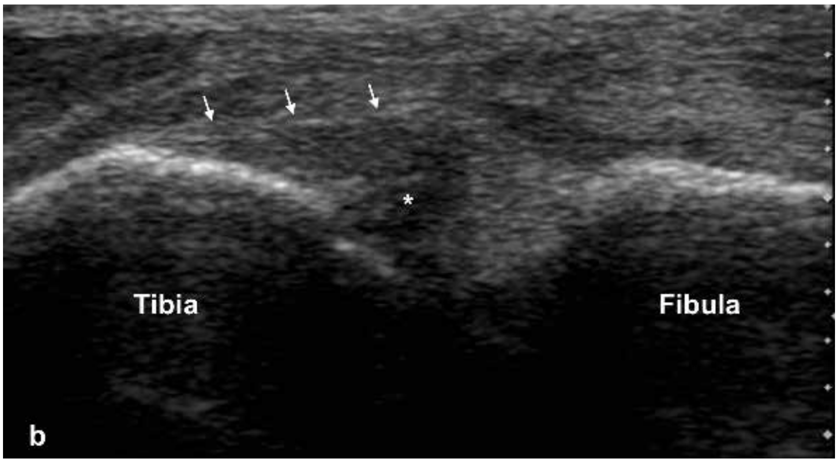

Figure 6

Sonography in horizontal plane of the anterior interosseous tibiofibular ligament (AITFL) (white arrows) with fibular sided tear and interosseous hematoma (b) (*).

Advanced Techniques

Further developments have improved sonography in the last decade a lot as this imaging tool is still important in other branches as cardiology, gynecology or gastroenterology. Also sports medicine and orthopedics have taken advantage of these developments (table 2).

Powerdoppler-sonography is able to detect small vessels with low blood flow. In Tendinopathies neovascularization can be detected anterior to and inside the tendon.

This phenomenon is best investigated for the Achilles tendon (37). Clinical relevance of those neo-vessels is not clarified yet (13, 24, 37). On one hand neovascularization were found in 47-64% of symptomatic tendinopathies (16), on the other hand 29% of asymptomatic patients showed them also (37). Also activity showed influence on the extent of these changes and were announced to be a prognostic factor for development of a tendinopathy in asymptomatic runners (16). A own recent study showed that this neovascularization in symptomatic Achilles tendinopathies was not correlated with pain and function and was additionally not influenced by exccentric heavy load training (44).

In muscle lesions this technique is able to detect small lesions especially in the repair phase when myotubes are developed (19, 34). This effect can be improved by application of an i.v. contrast agent within the meaning of CEUS (Contrast-enhanced ultrasonography). The contrast agent is made of microbubbles which can be detected as hyperechoic microstructures by application of focused ultrasonographic frequencies. First case reports showed CEUS to be of advantages in detection of minor lesions and ultrastructural lesions (17, 38). Further investigations are needed to validate this technique and make it applicable.

3D-sonography is not of value in muscle and tendon pathologies(38). It can improve visualization of large muscle lesion but in those cases MRI should be the imaging modality of choice.

Elastography is another new technique, which was developed for liver diagnostics. This technique makes it possible to detect and compare stiffness of different tissues. It has to be noted, that there are different methods to obtain this information depending on type of stress application and detection of tissue displacement. In strain elastography (synonym: compression elastography, real-time elastography) axial soft tissue displacement forced by manual compression is measured semi-quantitative. By external manual application of tissue pressure with the hand-held transducer, axial echo reflection on tissue before and after compression is compared. In image construction strain changes relatively to the surrounding tissue is displayed. This potentially equalizes the disadvantages of this technique like correct probe alignement and differences by different manual pressure and different tissue depths (10). Shear wave elastography measures shear waves of the ultrasound waves when interacting with tissue. The velocity of those waves, dispreading perpendicular to the ultrasound pulse, is detected and colour-coded. This makes this technique more objective than strain elastography. Disadvantage of this method is a minimum of tissue depth, as shear waves need a defined depth to be produced (10). A third method is called transient elastography. Similar to shear wave elastography, the velocity of shear waves in the tissue gets measured. To produce those waves a vibrating short-tone burst is used. This could avoid reflections and interference between the tissues (10). To date, in musculoskeletal imaging strain elastography is predominantly used. In a first descriptive publication on muscle injuries acute haemorrhage was shown to be more “elastic” in comparison to the surrounding muscle tissue. In healing of muscle injuries fibrosis showed to be of higher stiffness than the normal muscle tissue (4). Without further studies, a beneficial application in muscle imaging can not be seen at the moment. However, in detection of tendinopathies an advantage towards B-mode sonography was seen. Strain Elastography showed a sensitivity and specifity of 100% in comparison to histology (23). Shear-wave elastography showed also a specifity of 91,5% comparing patients with mid-portion tendinopathy to those with normal Achilles tendons. However, sensitivity was only 66,7% (2). As mentioned above, achilles tendon might be to superficial to generate enough shear waves. Furthermore, there is a current disagreement among the studies whether a tendinopathy shows increase (7, 8, 22) or decrease of elasticity (36).

Primarily developed in veterinary medicine for evaluation of horse tendons Ultrasonographic tissue characterization (UTC) is a method to quantify the tendon structure. By longitudinal displacement of the US transducer along the tendon structure-related echoes and interfering echoes are differentiated. Computerized analysis of these echoes leads to a colour-scaled image of the examined tendon. Preliminary studies to this technique in human achilles tendons showed structural changes in symptomatic tendinopathies in comparison to healthy controls (9, 42).

Table 2

Possible fields of application of advanced ultrasound techniques.

US TECHNIQUE	POSSIBLE FIELD OF APPLICATION
Powerdoppler US	Tendinopathies (prognostic factor)
	Tendon and ligament healing
Contrast-enhanced US (CEUS)	Minor muscle lesions
3D sonography	No recent field of application in musculosceletal US
Elastography	Early detection of Tendinopathies
	Quantification of tendinopathies
	Quantification of scar tissue after muscle injuries
Ultrasonographic tissue characterization (UTC)	Early detection of Tendinopathies
	Quantification of tendinopathies
	Quantification of scar tissue after muscle injuries

Conclusion

Musculosceletal ultrasound remains the first-line imaging tool in detection of sports injuries. It gives the opportunity of early differentiation between slight and severe soft tissue injuries to the physician. Furthermore, frequent follow-up examinations to manage rehabilitation and control healing, as well as dynamic examination to analyze function are important issues. With the upcoming advanced techniques US might extent its application spectrum in the near future. Especially in examination of tendinopathies and minor muscle lesions CEUS, elastography and UTC seem to be of great potential. Due to its advantages every physician dealing with professional as well as recreational athletes should be trained in musculoskeletal ultrasound.

Conflict of Interest

The authors have no conflict of interest.

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