High resolution ultrasound for imaging complications of muscle injury: Is there an additional role for elastography?

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Abstract

Muscle healing after injury occurs within a period of weeks following a three-phase physiological process. Disruption of the normal healing process may lead to a number of complications, including excessive scar formation, myositis ossificans, muscle atrophy, muscle cysts and hernias. Complications of muscle injury are important because they may be symptomatic, are associated with high risk of re-injury and compromise muscle performance, thus delaying return to sporting activity and requiring special treatment. High-resolution ultrasound imaging equipped with high-frequency probes and advanced B-mode and Doppler technology has emerged as a promising modality for the diagnosis, grading and follow-up of muscle injury. Ultrasound allows imaging of minimal scar formation, early detection of myositis ossificans and cysts, and dynamic evaluation of small muscle hernias. Ultrasound imaging combined with strain and shear wave elastography can also provide information on the mechanical properties of intact and diseased muscle tissue, thus allowing assessment of muscle biomechanics in the clinical setting. This article reviews the histology and ultrasound appearance of normal and abnormal muscle healing with an emphasis on the sonographic appearances of muscle injury complications. It also discusses pitfalls, provides tips for an less experienced sonographer and presents the possible role of strain elastography in the diagnosis of complications, such as scar tissue.

Introduction

Muscle injury is very common during sports and is a result of various mechanisms which range from delayed onset muscle soreness (DOMS), which is practically a symptom with no long-term consequences, to severe shearing injuries, including muscle strain, muscle contusions and lacerations[1,2]. Severe muscle injuries have a significant impact on the management of an athlete, because they can affect the timing of return to sporting activity, the biomechanical performance of the muscle and the possibility of recurrent injury[1–3].

High-resolution ultrasound imaging is extensively used in the workup of muscle injuries. With the advent of the latest generation high-resolution ultrasound scanners equipped with high-frequency probes and advanced B-mode and Doppler technology, muscle tissue can be imaged in exquisite detail allowing the depiction of subtle abnormalities. The sensitivity of high-resolution ultrasound can be comparable to that of MRI in the acute setting (between 2–48 hours) with lower sensitivity in DOMS and hyperacute stages (less than 2 hours from injury)[4–8]. Ultrasound can be used as a cheap and easily
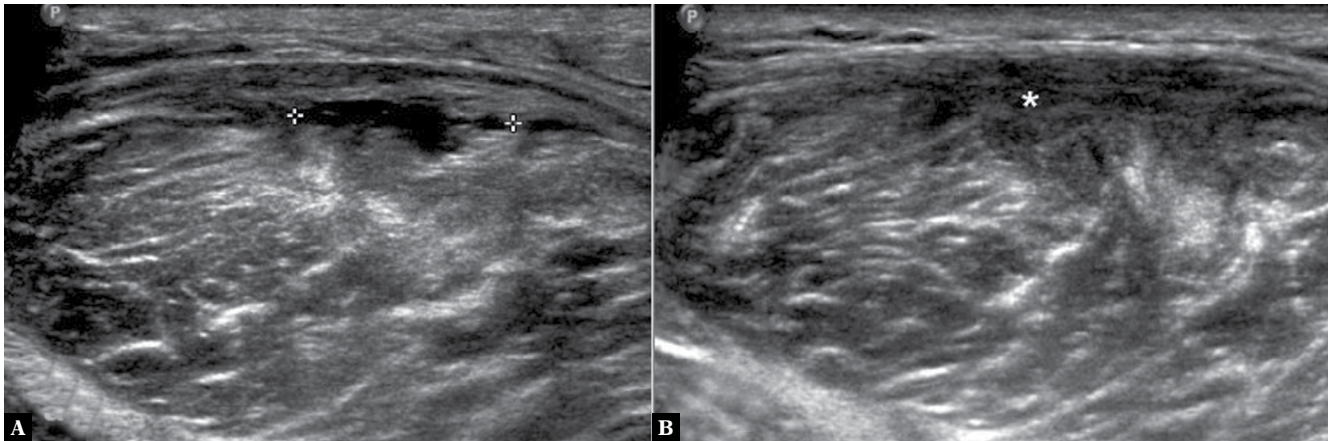
Fig. 1. *Ultrasound appearance of normal healing of a grade II muscle injury (partial tear) at the rectus femoris muscle near the superficial aponeurosis. There is a hypoechoic area filled with fluid (calipers) 3 days after injury* **(A)**. *Three weeks later, the gap has filled with mildly hypoechoic tissue (asterisk)* **(B)**

accessible modality to evaluate the location, extent and severity of a muscle injury, can provide information that predict the prognosis of muscle injury and guide appropriate rehabilitation or surgical treatment[3–7]. Moreover, ultrasound has the unique advantages of contralateral comparison and dynamic imaging during movement or muscle contraction to appreciate subtle changes[4–8]. In the subacute and chronic stages, ultrasound can be of value to follow up injured muscle during the healing process and identify complications that may require special treatment[4–8].

In addition to morphological features, ultrasound imaging combined with strain and shear wave elastography can also provide information on the mechanical properties of intact and diseased muscle tissue, thus allowing assessment of muscle biomechanics in the clinical setting[9–16]. Strain elastography has been used to assess both normal muscle during exercise and muscle pathologies, including muscular dystrophy, myositis and pain syndromes[2,13]. However, there are only scarce data in the literature regarding the role of elastography in assessing muscle injury and its complications, based either on experimental animal studies using shear wave elastography[17,18] or studies using strain elastography in the clinical setting[14–16].

This article reviews the role of ultrasound in post-injury muscle repair as well as sonographic appearances of complications occurring during abnormal healing. It also illustrates the possible role of strain elastography in the diagnosis of muscle injury complications in the clinical setting.

Histology and ultrasound appearances of muscle healing

Muscle healing after shear injury follows a repair rather than a regeneration process, including three phases[2], which directly correlate with ultrasound findings.

During the destructive phase within a couple of hours from injury, the ruptured myofibers contract to seal the torn ends, and the stump is filled by hematoma. During the repair phase, satellite cells begin to differentiate into myoblasts, and fibroblasts begin to produce collagen. Within 5–6 days, the necrotized ruptured myofiber is replaced by the regenerating myofiber, and within 3 days after the injury neovascularization develops. During the remodeling phase, myotubes fuse with the surviving parts of fibers and form new musculotendinous junctions. Finally, the regenerated fiber contains a small amount of well-organized scar tissue. At 10 days after injury, scar maturation is complete; however, it takes weeks to months to return to pre-injury muscle strength[2,6]. The physiological process of muscle healing is enhanced by short-time immobilization at first, which allows the granulation tissue to become strong enough, and later by gradual physical activity, which intensifies the regeneration phase by inducing angiogenesis and correct orientation of myofibers[2].

The ultrasound features of normal muscle repair reflect the above physiological procedures[1,6]. In cases of mild (grade I) injury that appears as an echogenic area in the muscle, normal healing typically presents as a decrease in the size of the lesion and return to normal echotexture. In the case of more severe injury (Grade II and III), the hypoechoic areas corresponding to fluid collections gradually decrease in size and isoechoic or echogenic tissue corresponding to scar tissue gradually fills the gap (Fig. 1). This is evident at the site of the tear at 6 weeks[6]. However, small residual areas of injury, evident on MRI as high signal in fluid sensitive sequences, may not be evident on US due to its lower contrast resolution compared to MRI[8].

Complications of muscle injury

Complications of muscle injury are a result of disruption of the normal healing process. They include excessive scar formation, myositis ossificans, muscle atrophy, muscle cyst and muscle hernia.
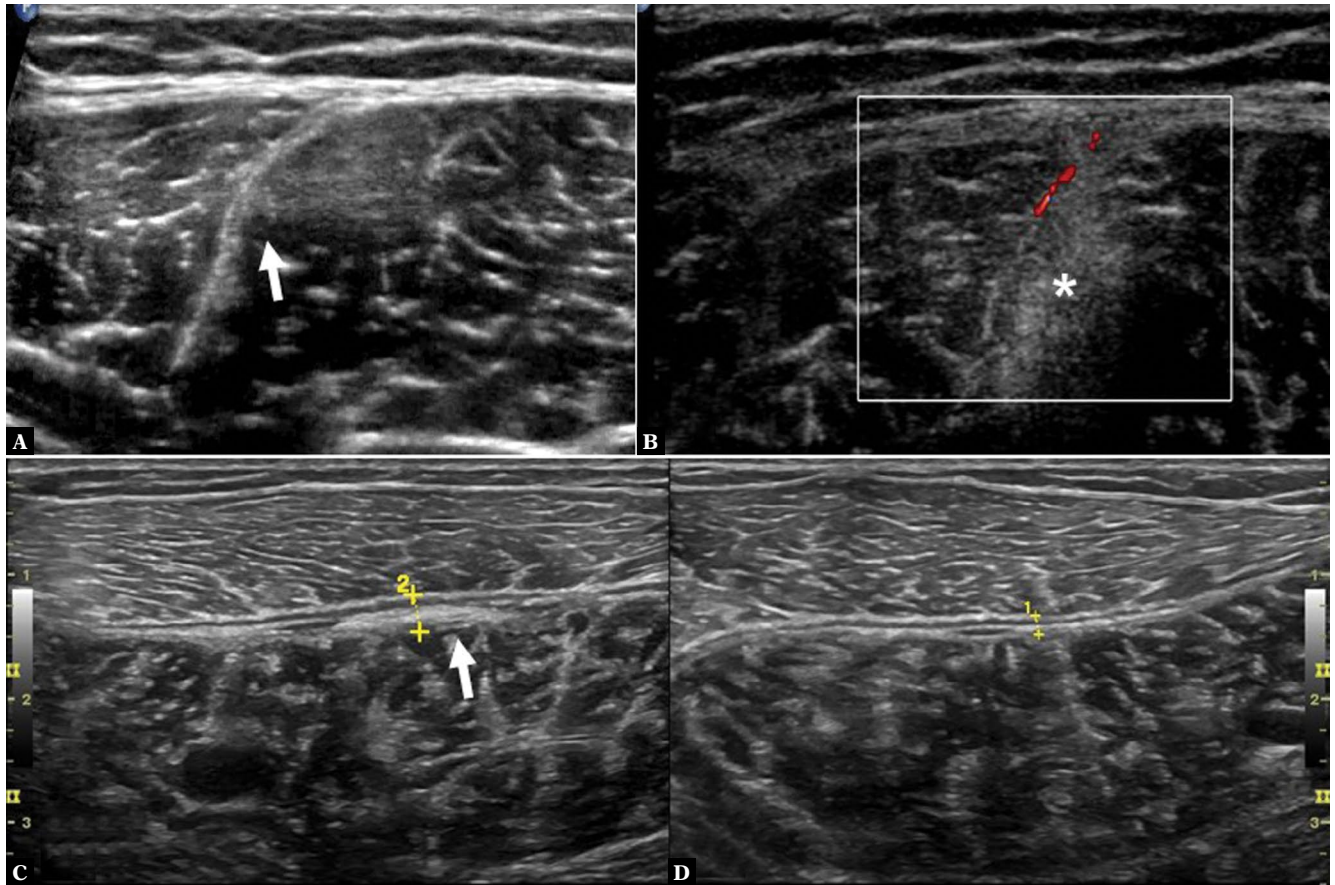
Fig. 2. *Ultrasound appearances of scar tissue. Axial US image of the normal* **(A)** *and symptomatic* **(B)** *rectus femoris muscle of a 25-year-old football player one month after injury. There is significant thickening of the central aponeurosis with associated echogenic scar tissue (asterisk on* **B***) with subtle neovascularity on Doppler imaging. Comparison to the asymptomatic side (arrow in* **A***) highlights the difference in thickness and echogenicity. Longitudinal US image of the symptomatic* **(C)** *and contralateral asymptomatic* **(D)** *medial gastrocnemius muscle of a 22-years-old football player. There is subtle echogenic thickening of the aponeurosis of the muscle (white arrow) compared to the asymptomatic side, indicating the presence of minimal scar tissue*

Excessive scar formation

Excessive permanent scar tissue is formed if mobilization is begun immediately after the injury[4–8]. Excessive scar is a significant complication and should be meticulously searched for during follow-up of muscle injury. It is particularly important for elite athletes, as it can be symptomatic, causing pain and tenderness aggravated with muscle stretching. It also compromises muscle performance and is considered to predispose to re-rupture at the site of the original trauma[3,6]. The typical US appearance of scar tissue is that of an echogenic homogeneous or inhomogeneous irregular area which may be surrounded by a hypoechoic halo[4–6] (Fig. 2A). The hypoechoic area may be associated with significant posterior shadowing, which is an artifact caused by the presence of irregularly oriented dense fibrous tissue. When present, this artifact may mask the typical appearance of the scar (Fig. 3A). However, in the clinical practice, the detection of small echogenic areas of scar tissue may be particularly challenging especially for a less experienced sonographer, as they may resemble the echogenic dots and lines which are part of the normal US appearance of a muscle. Occasionally, minimal amount of scar tissue may be depicted as irregular thickening of the muscle fascia or aponeurosis, which can only be appreciated when compared to the contralateral asymptomatic side (Fig. 2B, 2C). In challenging cases, the depiction of the scar tissue can be facilitated by asking the patient to point out with their finger where the pain is located, by contralateral comparison and by specifically looking at the areas where scar is expected (that is the musculotendinous junction and the muscle-fascia boundary). Dynamic testing may be useful to reveal differences in contraction of the muscle at the areas of scarring. Anisotropy may be helpful to confirm the suspected area when in doubt as scar tissue is usually less anisotropic than normal muscle due to the more irregular orientation of scar tissue compared to the well-organized parallel-oriented muscle fibers. Practically, this means that by tilting the transducer, the hypoechoic changes induced by the muscle are more pronounced that those caused by scar tissue[19] Subtle neovascularity may occasionally be found in early stages of scar formation (Fig. 2).

Elastography may potentially have a role in the depiction of subtle scars. Laboratory research has shown that fibrotic scar tissue has reduced elasticity[20]. Using commercially
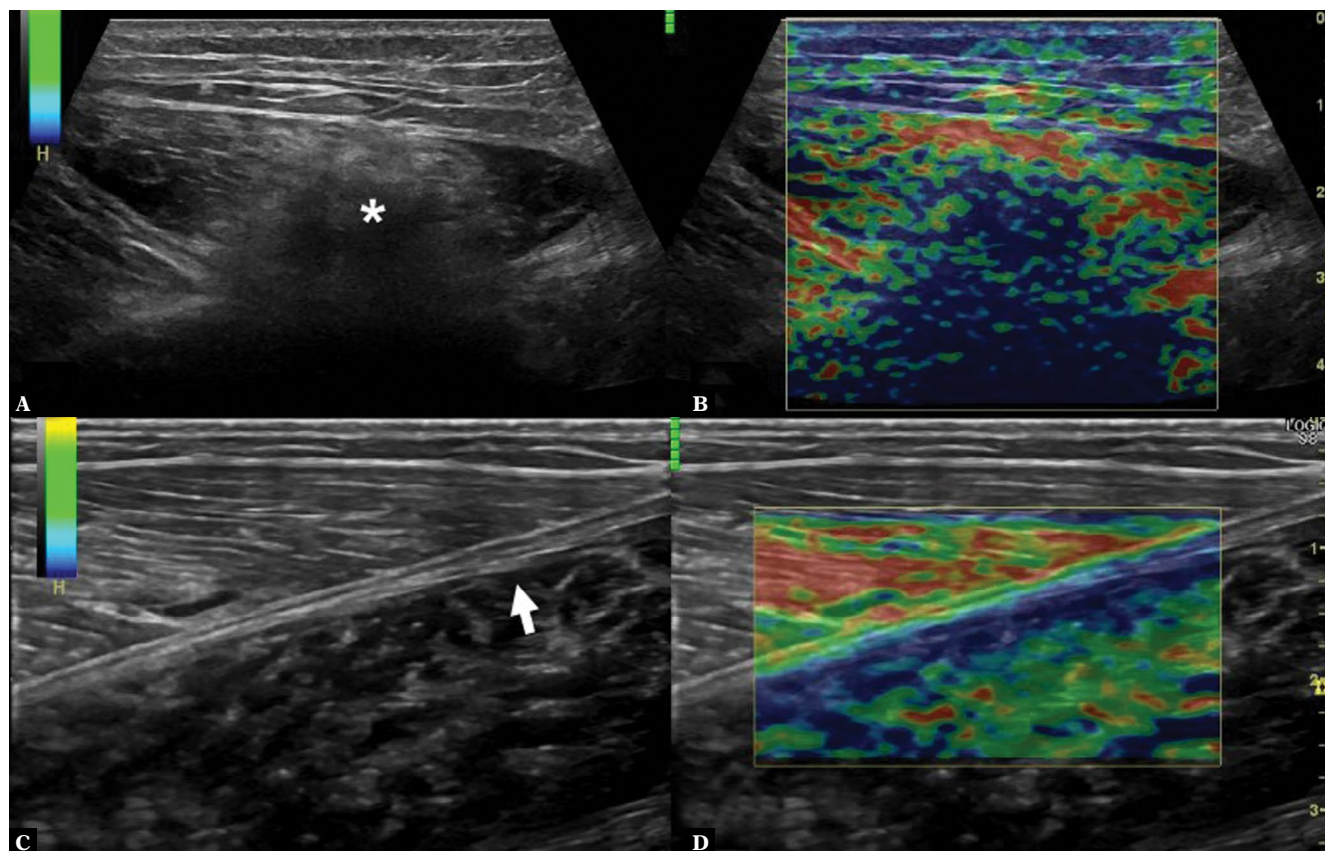
Fig. 3. *Real-time strain elastography of scar tissue. Axial US* **(A)** *and strain elastography* **(B)** *images of rectus femoris muscle of a 33-year--old football player with significant echogenic scar tissue at the central aponeurosis (asterisk on* **A***) with associated significant acoustic shadowing. The corresponding elastogram shows reduced strain (blue) at the area of scar tissue compared to the normal appearance of the remaining muscle (mosaic pattern of green and red). Longitudinal US image of the symptomatic medial gastroc-nemius muscle of a 22-years-old football player. There is subtle echogenic thickening of the aponeurosis of the muscle (white arrow) indicating the presence of minimal scar tissue. The corresponding elastogram shows reduced strain (blue) along the musculo-apo-neurotic junction*

available shear elastography systems, this result has been confirmed in post-radiation neck fibrosis[21]. There is only limited data about the use of ultrasound elastography in the clinical setting in muscle injury and posttraumatic muscle scarring, with only a few papers addressing strain elastography properties of scar tissue[14] and muscle tears in tennis leg[15]. The strain elastogram of normal skeletal muscle shows an inhomogeneous mosaic pattern of blue, green and red colors[12,14,15,22,23]. It is reported that in the case of muscle injury, elastography shows loss of the typical elasticity pattern at areas where B mode ultrasound shows normal appearances[14]. It has been shown that acute injury leads to an increase in muscle elasticity probably due to hematoma, presenting as a rather homogeneous red area that a few weeks later becomes stiffer (blue) as the hematoma disappears, and there is formation of scar tissue[14,15] (Fig. 3). It is therefore suggested that muscle lesions with good prognosis show a soft elastic ribbed appearance, whereas fibrosis causes an area of increased stiffness, which may be larger than the echogenic scar area in B-mode and may occasionally contain soft areas, depending on lesion length and time from injury[14]. Although the published data only include studies and pictorial essays, the findings suggest that strain elastography could be used as a potential tool to follow up

muscle healing and detect the presence of early or subtle scar tissue.

Posttraumatic myositis ossificans

Myositis ossificans is a form of focal posttraumatic intramuscular ossification commonly involving the proximal part of the limbs, the intercostal spaces and the gluteal muscles. History of trauma may be totally absent in 40% of cases, or only minor injury may be occasionally reported by the patient. It may present as a painful tender lump or may be completely asymptomatic. The characteristic calcifications in X-rays take about 6–8 weeks to fully mature, they then decrease in size by 6 months and gradually disappear [4–6,24–26]. The typical US appearance at the early stage (2–4 weeks), includes a hypoechoic soft tissue mass with preservation of fibers containing hyperechoic central areas and increased vascularity[24–26]. Fluid levels may be occasionally present, due to hemorrhage. At the subacute stage (<6 months), coarse calcifications gradually form in sheets from the periphery of the lesion extending along the shaft of the long bones[24]. Occasionally linear calcifications along fibers may develop[24]. The mature lesion (>6 months)
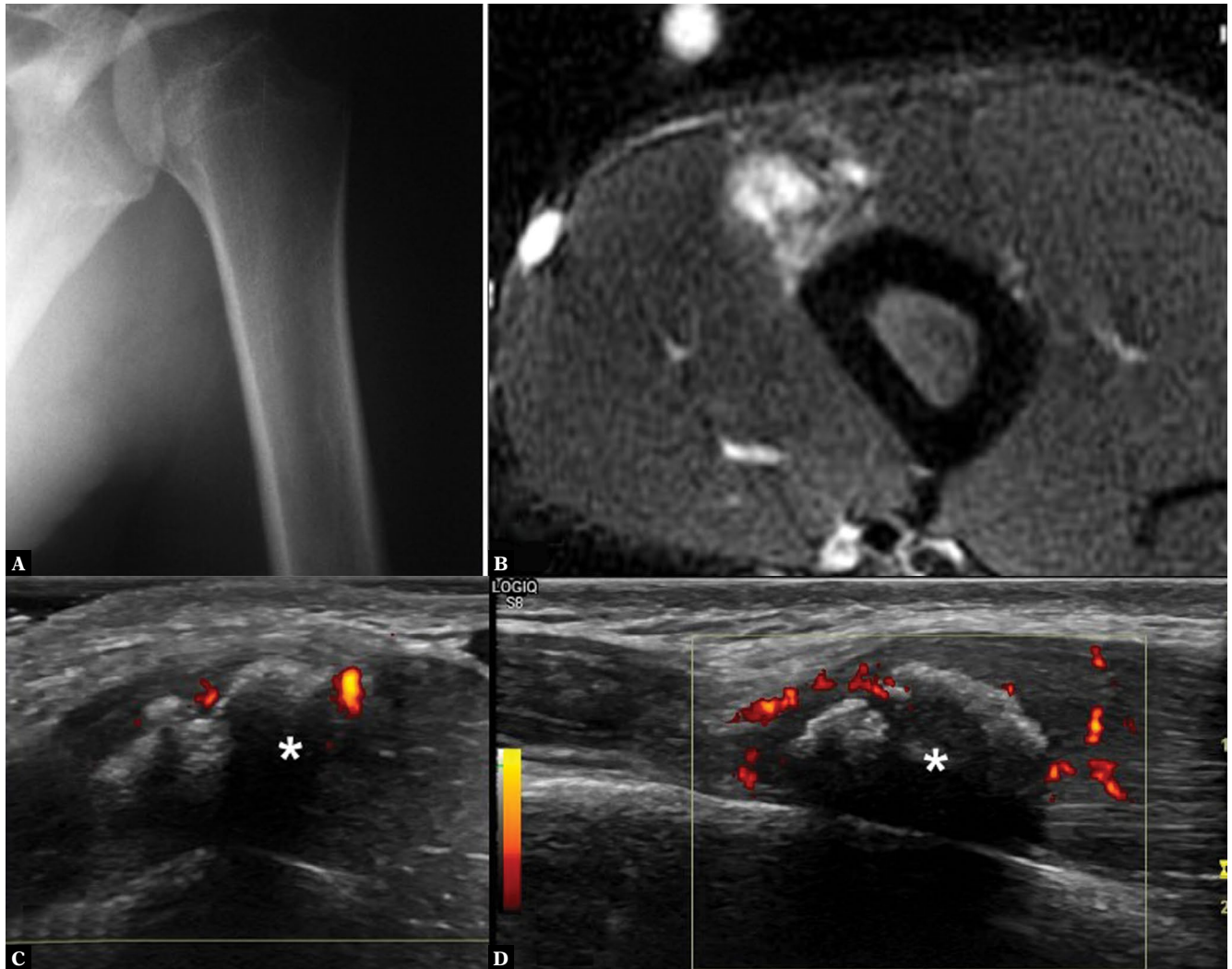
Fig. 4. *Myositis ossificans in a 17-year-old boy with a tender palpable mass at the middle of the arm that gradually appeared within 2 weeks. X-ray of the humeral bone was unremarkable* **(A)**. *Axial T2 fat-saturated MR image* **(B)** *shows an inhomogeneous intramuscular lesion close to the humeral periosteum with scarce low signal foci and an intact humeral diaphysis. Axial* **(C)** *and longitudinal US images* **(D)** *clearly depict the presence of intramuscular calcifications (asterisk) in a laminar pattern parallel to the diaphysis with associated neovascularity, typical of myositis ossificans. Upon enquiring, a history of blunt trauma during a football match was finally recalled 3 weeks prior to the examination*

consists of densely calcified material, similar to the appearance in plain X-rays, which becomes more irregular as the calcification gradually resolves[24].

Ultrasound is particularly useful at the very early stages (less than 10 days) when radiographs are normal and MRI only shows non-specific myositis or a heterogeneous mass, with areas of low signal intensity material, that may be mistaken for a sarcoma[24–26]. The key to the differential diagnosis is the depiction of typical peripheral zonal calcifications that differentiate myositis ossificans from juxtacortical sarcoma. Ultrasound plays a crucial role in establishing the accurate diagnosis in the early stage, as it allows the faint intralesional calcifications to be depicted as early as 2 weeks before they become evident on X-rays[24–26] (Fig. 4). When there is still a doubt, US follow-up in 3 to 4 weeks may help to confirm the diagnosis.

Muscle hernia

Muscle herniation is a complication caused by penetrating or blunt direct muscle trauma resulting in a focal defect in the myofascial sheath around a muscle (epimysium)[27–30]. Small areas of superficial muscle may occasionally or constantly protrude through the defect leading to a muscle hernia (Video 1 – available at www.jultrason.pl). Muscle hernias are more common at the lower limb, typically affecting the anterolateral tibial muscles, and can present either as tender palpable lumps that can change in size depending on the physical activity or as episodes of sudden excruciating pain during muscle contraction[27–30] (Fig. 5A).

Ultrasound is an ideal imaging test to confirm a suspected muscle hernia due to high resolution, dynamic examination technique and interaction with the patient[27–30]. Ultrasound
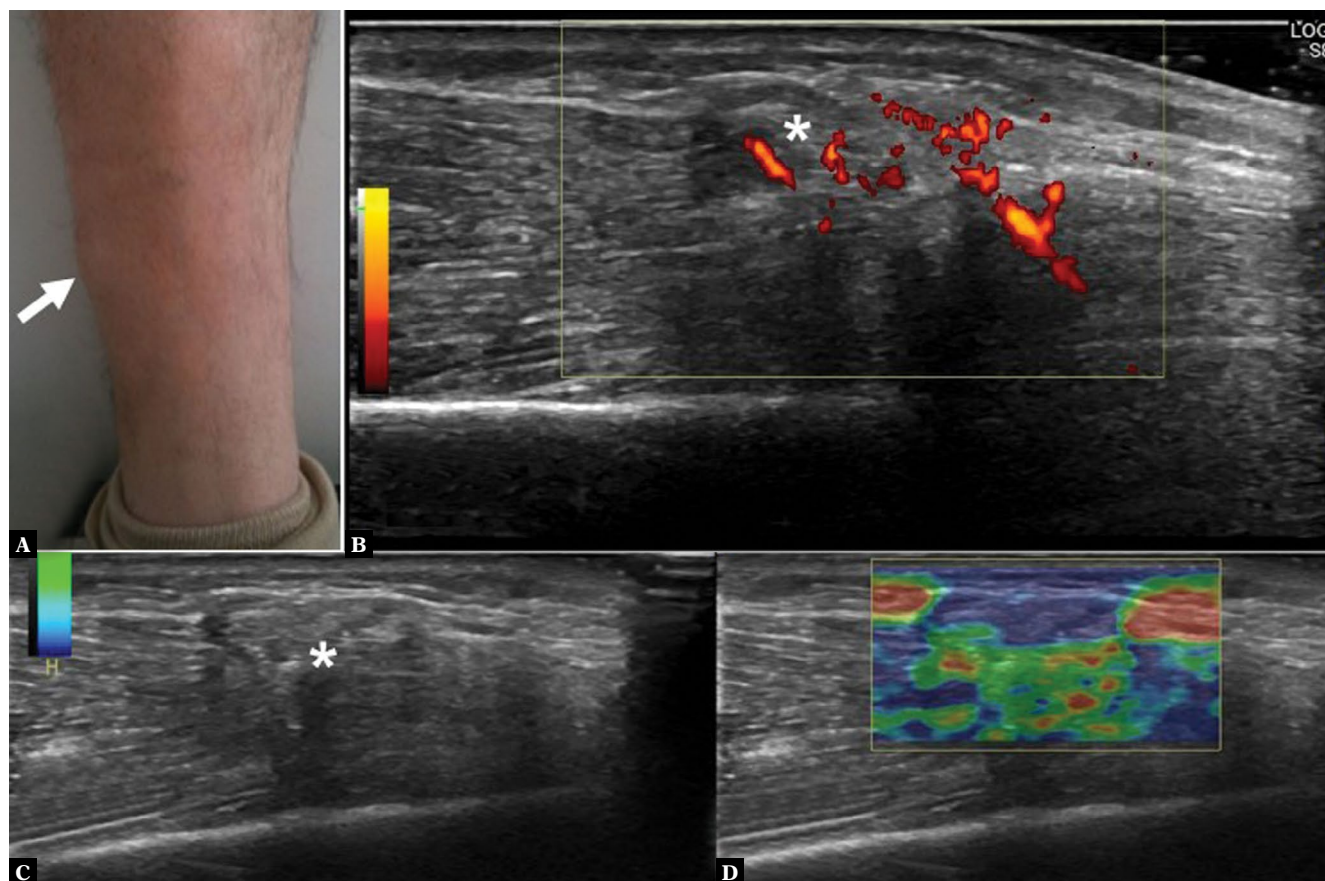
Fig. 5. *Muscle hernia in a 40-year-old man with a tender palpable mass at the tibia following blunt trauma with a rock, more painful after walking (arrow in **A**). There is protrusion of muscle fibers through a defect in the epimysium with associated neovascularity probably due to venous congestion **(B)**. Real time strain elastography including B-mode image **(C)** and the corresponding elastogram **(D)** show the presence of reduced strain (blue corresponds to high stiffness) at the area of the muscle hernia, highlighting the protrusion/ entrapment of tissue at the area of herniation. Dynamic examination of this case is shown in Video 1 (available at www.jultrason.pl)*

typically shows normal-appearing or hypoechoic muscle tissue protruding through a fascia defect in the subcutaneous tissue (Fig. 5B,C). Doppler imaging may show the presence of increased vascularity at the area of the muscle hernia due to venous congestion (Fig. 5B). Dynamic maneuvers with contraction of the affected muscle (e.g. after walking, standing or dorsiflexion of the foot) are particularly helpful to reveal minimal herniations that may not be evident at rest (Video 1, Video 2 – available at www. jultrason.pl). Care must be taken during ultrasound examination to apply only minimal pressure with the transducer as excess pressure may reduce the muscle hernia and mask it. The role of elastography has not been assessed in the literature; however, our experience suggests that in cases of doubt, strain elastography may confirm the diagnosis by revealing changes in the mosaic pattern of normal muscle with homogeneously increased stiffness at the area of the herniated muscle (Fig. 5D).

Muscular cysts and muscular atrophy

Intramuscular cysts are complications resulting from an incomplete resorption of a hematoma, leading to a thin-walled fluid-filled intramuscular area[31,32]. They are pseudocysts, as their walls are lined only with collagen and may contain blood clots, fibrin, amorphous debris, cholesterol clefts, hemosiderin deposits, cellular scar tissue and occasionally dystrophic calcifications[32]. They are often referred to as calcific myonecrosis, chronic expanding hematoma or ancient hematoma. Posttraumatic muscular cysts may be asymptomatic or may cause disruption of the normal muscle function because of biomechanical changes during contraction. Ultrasound shows a cystic area with thin or indistinct walls which may contain either clear fluid or echogenic inhomogeneous material resulting in a pseudosolid appearance (Fig. 6). Posttraumatic intramuscular cysts may clinically and sonographically mimic aggressive soft tissue neoplasms and the discrimination is often based on a definite history of trauma, lesion follow-up and occasionally additional imaging[31,32]. Strain and shear wave elastography have been evaluated as additional tools in the differential diagnosis of benign cysts or pseudocystic lesions from sarcomas with promising results in preliminary studies[33–35]. Ultrasound-guided aspiration may reduce symptoms and help avoid surgical excision.
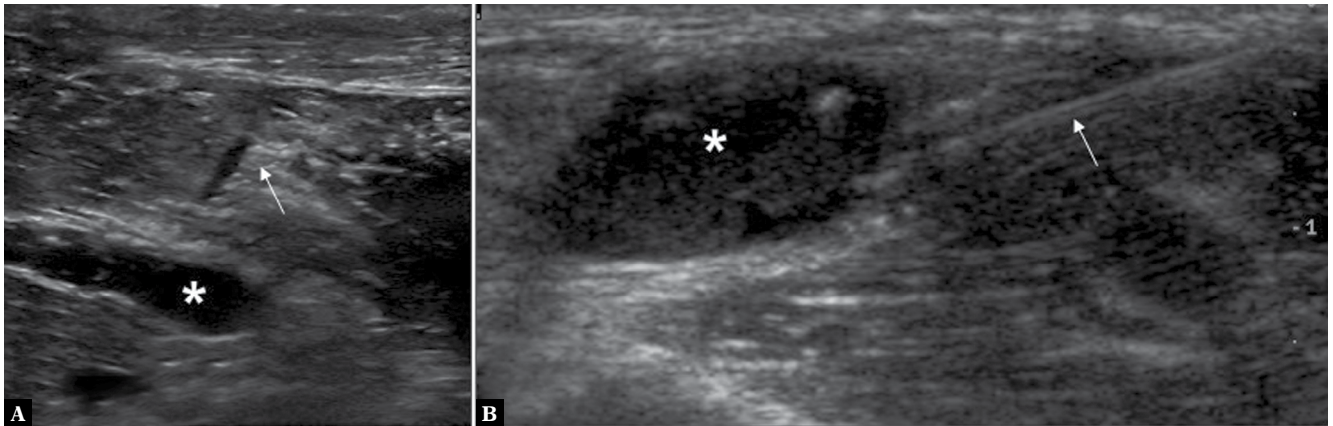
Fig. 6. *Intramuscular cyst/seroma in 45-year-old woman 3 months after blunt trauma* **(A)**. *There is an intramuscular fluid-filled area containing anechoic fluid (asterisk in* **A**). *There is also a small muscle tear perpendicular to the muscle fibers (arrow). US-guided aspiration using an 18G needle (arrow) of the residual hypoechoic hematoma containing echogenic material in a 50-year-old male* **(B)**

Muscle atrophy may be the final result of muscle injury in cases of high grade muscular injury and large hematomas in combination with insufficient rehabilitation[5]. Ultrasound typically shows loss of muscle bulk and increased echogenicity of the atrophic muscle (Fig. 7), more easily appreciated in the axial views and in comparison to the contralateral unaffected side; however, even semi-quantitative US techniques are less accurate and reproducible than MRI in diagnosing and grading the loss of volume and fatty infiltration of the muscle[5,36].

Elastography has been recently assessed as an alternative US-based method to assess muscle atrophy and fatty content mainly in the rotator cuff muscles[37–39]. Shear wave elastography seems to be a feasible and promising tool in the quantitative assessment of the degree of muscle atrophy provided that there is not much overlying soft tissue[37]. In a study of supraspinatus muscle atrophy, there was a decrease in the shear wave velocity with increasing fat content corresponding to softening of the muscle at the early stages of atrophy with subsequent stiffening of the muscle at the final stage of fatty infiltration[38]. However, all data are based on preliminary studies and more work is needed to be able to use elastography for detecting posttraumatic atrophy in the clinical practice.

Conclusion

Complications of muscle injury are a result of disruption of the normal healing process. They include excessive scar formation, myositis ossificans, muscle atrophy, muscle cyst and muscle hernia. Ultrasound is ideal to follow up muscle injury and depict complications, as it is widely available, quick and allows dynamic and contralateral scanning that facilitates the depiction of minimal lesions. Dynamic ultrasound with Doppler imaging allows an early accurate diagnosis of myositis ossificans, is the modality of choice for muscle hernias and allows the diagnosis and guided aspiration of muscle cysts and seromas. In cases of excessive scar formation, ultrasound can easily depict the typical echogenic appearance. However, in cases of minimal scars, meticulous scanning techniques may be employed. Ultrasound is less sensitive that MRI to assess muscle fatty infiltration and atrophy secondary to chronic injury. Strain
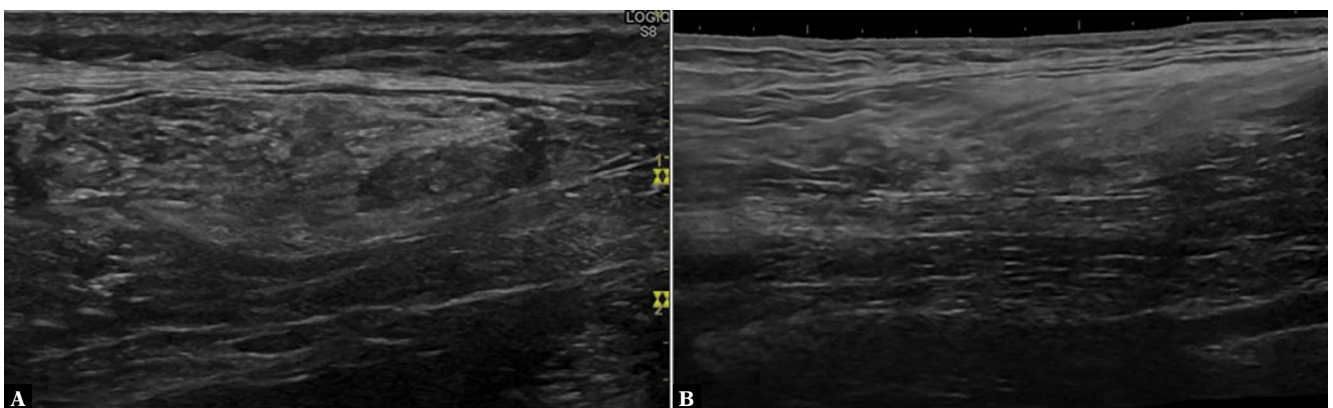

Fig. 7. *Muscle atrophy. Axial* **(A)** *and longitudinal* **(B)** *images of muscle atrophy secondary to chronic injury that led to muscle wasting. There is increased echogenicity of the atrophic muscle corresponding to fatty infiltration*

elastography is a promising technique to assess changes in muscle elasticity associated with impaired healing and the formation of scar tissue. However, as the published evidence is still scarce, more research is needed to establish the role of elastography in the follow-up of muscle injury.

Conflict of interest

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