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Sonographic evaluation of digital annular pulley tears

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Abstract *Objective.* To evaluate the sonographic (US) appearance of digital annular pulley (DAP) tears in high-level rock climbers.
Design and patients. We performed a retrospective analysis of the US examinations of 16 high-level rock climbers with clinical signs of DAP lesions. MRI and surgical evaluation were performed in five and three patients respectively. The normal US and MRI appearances of DAP were evaluated in 40 and three normal fingers respectively.
Results. Nine of 16 patients presented a DAP tear. In eight subjects (seven with complete tears involving the fourth finger and one the fifth finger), US diagnosis was based on the indirect sign of volar bowstringing of the flexor tendons. Injured pulleys were not appreciated by US. Tears concerned the A2 and A3 in six patients and the A3 and A4 in two patients. A2 pulley thickening and hypoechogenicity compatible with a partial tear was demonstrated in one patient. MRI and surgical data correlated well with the US findings. Four patients had tenosynovitis of the flexor tendons but no evidence of pulley disruption. US examinations of three patients were normal. In the healthy subjects US demonstrated DAP in 16 of 40 digits.
Conclusion. US can diagnose DAP tears and correlates with the MRI and surgical data. Because of its low cost and non-invasiveness we suggest US as the first imaging modality in the evaluation of injuries of the digital pulley.

Key words Trauma · Hand · Sonography · Ultrasound · Annular pulleys · MRI

Introduction

The flexor tendons of the fingers run in osteofibrous canals formed by the palmar aspect of the phalanges and the fibrous tendon sheath made by the digital annular (A1 to A5) and cruciform (C1 to C3) pulleys (DAP) (Fig. 1A). The A2 and the A4 DAP, located at the cranial third of the proximal phalanx (PP) and intermediate phalanx (IP), are the broader and functionally the most important DAP [1]. The main function of pulleys is to stabilize the flexor tendons during finger flexion, thus avoiding ulnar and radial displacement or palmar bowstringing. Displacement of the tendons lowers their mechanical efficiency and reduces digital performance [2].

Tears of the DAP are the most frequent injuries of climbers. Chronic lesions result in flexion contracture of the proximal interphalangeal joint and reduction of digital performance [1, 2, 3]. Although clinical examination in acute lesions is limited by soft tissue swelling and pain, early diagnosis and accurate assessment of the degree of DAP tear is essential in choosing between conservative treatment and surgery and can prevent fibrous sequelae [2]. MRI and CT have been proposed for evaluation of DAP [4, 5], but US is more available, less ex-

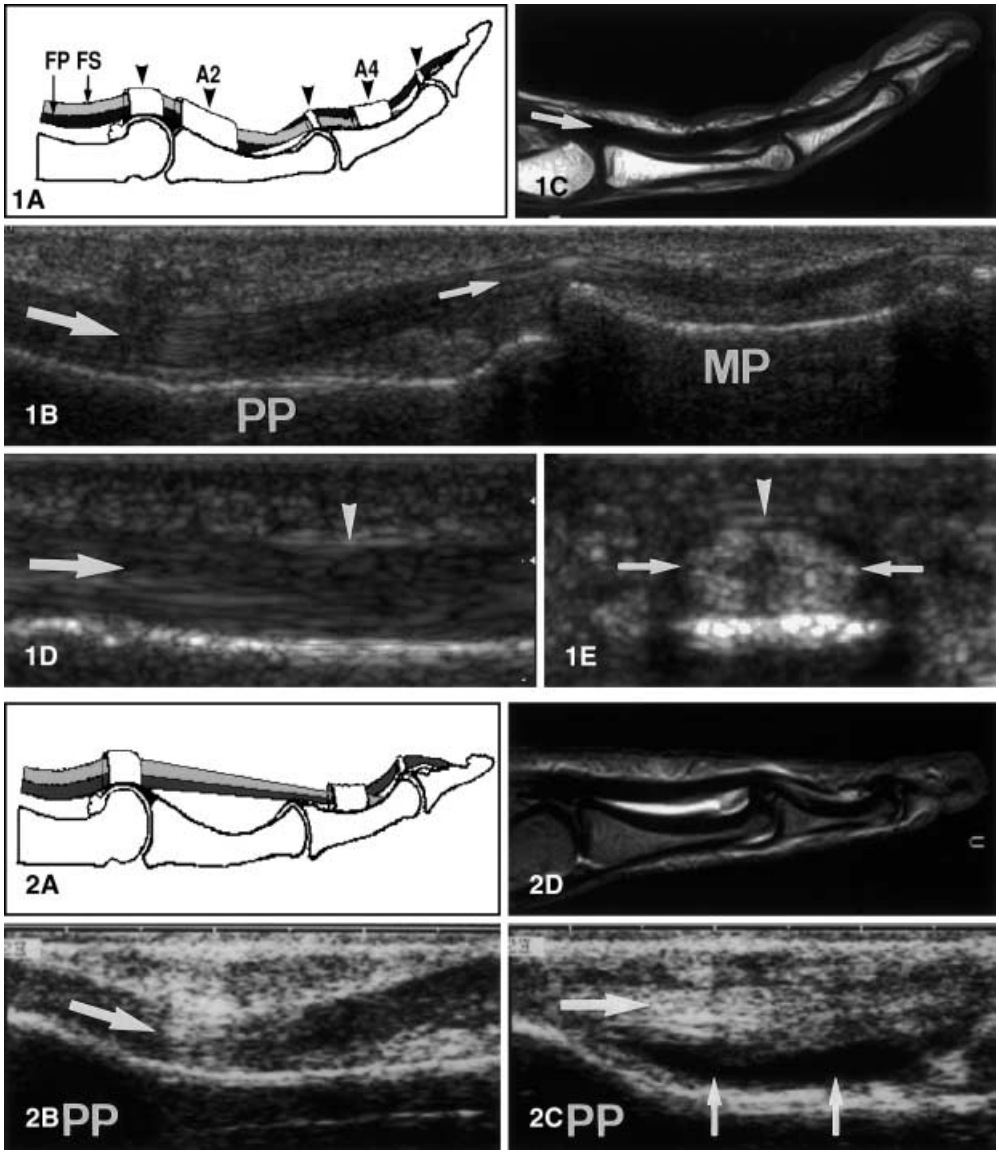

Fig. 1A–E US of the normal flexor mechanism. *PP* proximal phalanx, *MP* middle phalanx, *arrows* flexor tendons (*FS* flexor superficialis tendon, *FP* flexor profundus tendon), *arrowheads* DAP (*A2* A2 DAP, *A4* A4 DAP). **A** Drawing of the flexor mechanism shows the flexor superficialis and profundus tendons as well as the DAP. Cruciform pulleys (not shown) are located between DAP. **B, C** Split-off longitudinal sonogram (**B**) and sagittal T1-weighted MR image (**C**) show the flexor tendons, which are retained against the phalanges by the DAP. **D, E** Longitudinal (**D**) and transverse (**E**) sonograms obtained at the level of the A2 DAP show the pulley as a hyperechoic linear structure overlying the flexor tendons

Fig. 2A–D Complete tear of the A2 and A3 DAP. *Large arrows* flexor tendons, *small arrows* bowstringing of the tendons and localized effusion. **A** Drawing shows bowstringing of the tendons localized at the level of the proximal phalanx. **B, C** Longitudinal sonograms of a normal finger (**B**) and of a patient (**C**) with a surgically proved complete A2 DAP tear. In **B** the flexor tendons are closely retained against the proximal portion of the proximal phalanx. In **C** disruption of the A2 DAP causes bowstringing of the flexor tendons and a local effusion. **D** Corresponding sagittal T2-weighted MR image of the same patient confirms tendon displacement and a localized fluid collection

pensive and non-invasive. A retrospective review of the US examinations of 16 climbers with clinically suspected acute DAP tears is presented.

Material and methods

We retrospectively reviewed the imaging studies of 16 high-level male rock climbers aged between 22 and 37 years (mean 27 years) who had injured their hands during climbing. All patients were examined by a rheumatologist with a special interest in climbing. The fingers affected were the fourth and the fifth in 14 and two patients respectively. Patients reported a history of localized pain following powerful flexion of the fingers during climbing. Physical examination showed localized pain and swelling along the palmar surface of the involved finger compatible with DAP lesions in all patients.

All patients were evaluated with plain radiographs (anteroposterior and lateral views) and with US. US was performed with equipment (AU-4 Idea, Esaote, Genoa, Italy; HDI-3000, ATL, Bothell, Wash.) working with broadband (frequency band 12–5, 10–13,) linear array transducers. Longitudinal and axial sonograms were obtained over the palmar aspect of the finger with the dorsum of the hand resting on the table. No stand-off pad was deployed. Sonograms were obtained with the finger extended and flexed. Dynamic US included scanning during passive and active flexion. In addition the tendons were examined during resisted flexion by asking the patient to maintain the finger flexed at 45° while the examiner tried to extend it by gently pushing the fingertip.

MRI was performed on five patients with a US diagnosis of DAP disruption using a 2-T unit (Prestige, Elscint, Haifa, Israel). The patient was prone within the MRI gantry with the arm elevated, the hand resting on a flat board with the fingers flexed at approximately 45°. A 12 cm surface coil or a dedicated extremity coil were used. Scout sequences were obtained in the coronal plane to identify the optimal sagittal plane for evaluating the affected finger. Two averages were obtained. Slice thickness was 3 or 4 mm with 10% gap interslice. FOV was 12 cm. The imaging

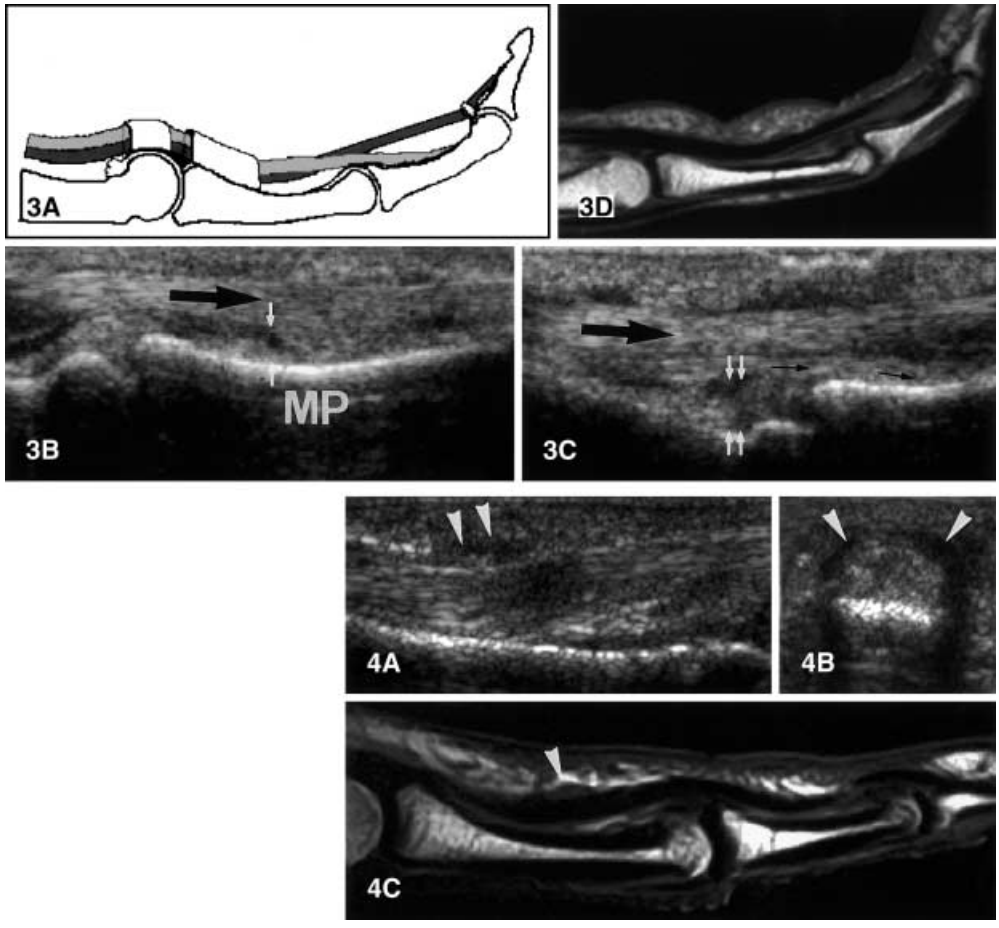

Fig. 3A–D Complete tear of the A3 DAP and A4 DAP. *Large arrows* flexor profundus tendon, *small black arrows* flexor superficialis tendon, *small white arrows* bowstringing of the tendons. **A** Drawing shows bowstringing of the tendons localized at the level of the middle phalanx and proximal interphalangeal joint. **B, C** Longitudinal sonograms at rest (**B**) and during resisted flexion (**C**). In **B** the flexor tendons are not in contact with the proximal portion of the middle phalanx. In **C** an increase in tendon bowstringing at the level of the proximal interphalangeal joint as well as the proximal portion of the middle phalanx is evident. **D** Corresponding sagittal T1-weighted MR image confirms tendon bowstringing at the level of the A3 and A4 DAP

Fig. 4A–C Partial tear of the A2 DAP. *Arrowheads* A2 DAP. **A, B** Longitudinal (**A**) and transverse (**B**) sonograms obtained at the level of the A2 DAP show thickening and irregular hypoechogenicity of the pulley related to a partial tear. No tendon bowstringing or fluid collection is evident. **C** Corresponding sagittal T1-weighted MR image confirms the US findings

protocol consisted of T1-weighted spin-echo (SE), T2-weighted fast spin-echo (FSE) sequences (TR/TE=550/20, 2000/86, respectively) and STIR sequences obtained in the sagittal plane, and proton density and T2-weighted FSE sequences (2000/20–86) obtained in the axial plane. In three patients the injured finger and the adjacent one were imaged taped together to assess normal MRI anatomy. Because of movement artefacts images obtained during resisted flexion were of poor quality and were obtained only in two patients.

Both US and MRI studies were obtained within 2–7 days from the climbing trauma (mean 5 days). The normal US appearance of the flexor tendons and DAP of 40 fingers (20 fourth fingers and 20 third fingers) in 20 normal subjects (age- and sex-matched to the patients) was evaluated.

Six patients were treated conservatively. Three patients underwent surgical repair of the torn DAP.

Results

Normal findings

In the 40 normal fingers US imaged the details of the normal anatomy of the digital flexor system (Fig. 1). The flexor tendons are depicted as hyperechoic fibrillary structures coursing along the bone cortex and volar joint capsule. The flexor superficialis (FS) and flexor profundus (FP) tendons can be identified on an anatomical basis. Moreover dynamic examination during passive flexion of the distal phalanx, which produce selective movement of the FP, provides differentiation between the two tendons. All sonograms, including dynamic studies and those obtained with resisted flexion, showed the tendons in close contact with the volar aspect of the phalanges at the level of the A2 and A4 DAP (Fig. 1B). Passive and active movements of the fingers showed smooth gliding of the tendons within the digital tunnel. A2 DAP were depicted in a minority of the control group (16/40 fingers) as a thin (0.3–0.5 mm) hyperechoic line located at the volar aspect of the tendons at the level of proximal phalanx (Fig. 1D, E). Identification of the A2 DAP, however, was based only on the knowledge of their anatomical location since there was no cadaveric correlation and no other imaging modalities can show the pulleys. The A4 DAP was never consistently depicted by US. Although DAP were detectable in a minority of patients their anatomical and functional integrity could easily be assessed by the lack of palmar dislocation of the flexor tendons on static and dynamic sonograms. MRI of normal fingers demonstrated the flexor tendons but was unable to show the normal DAP (Fig. 1C).

Pathological findings

Standard radiographs showed no evidence of fracture or cortical avulsion. Eight patients presented bowstringing of the flexor tendons related to injury of the DAP. In six patients the bowstringing was maximal at the level of the proximal phalanx and was consistent with A2 and A3 ADP lesions (Fig. 2). In two patients a tear of the A3 and A4 DAP led to bowstringing at the level of the middle phalanx (Fig. 3). Although palmar subluxation of the tendons was evident in extension, it was more apparent during passive flexion and further increased in resisted flexion (Fig. 3B, C). In all patients the flexor tendons were normal. A hypoechoic fluid collection surrounding the tendons, more evident between the volar aspect of the tendons and the phalanges, was depicted in all cases and corresponded to acute tenosynovitis. In one patient the A2 DAP appeared thickened, hypoechoic and irregular (Fig. 4). No tendon bowstringing was noted in this patient and the US appearance suggested a partial tear. Seven patients did not show tendon bowstringing or pulley abnormalities on US but four of these demonstrated a tenosynovial effusion while the remaining three showed no significant abnormalities.

In the five patients examined with both techniques, the MRI findings correlated well with the US appearances. In four cases MRI showed a localized bowstringing of the flexor tendons which confirmed a complete tear (Figs. 2D, 3D) (four A2 and A3 DAP and one A3 and A4 DAP). All patients presented normal tendons surrounded by a synovial sheath effusion which appeared as an area of high signal intensity on T2-weighted FSE and STIR sequences. No joint effusions could be detected. In the fifth patient, thickening and signal changes of the A2 DAP (low signal on T1-weighted images and high signal on T2-weighted images) were compatible with a partial tear (Fig. 4C).

Discussion

Interest in rock climbing has grown rapidly since the introduction of artificial walls. Climbing is associated with high stress and repetitive microtrauma, involving mainly the upper extremity, which account for a variety of hand disorders including tendon injuries, DAP disruptions, joint contractures, ligament injuries and carpal tunnel syndrome. Pulley tears are among the most frequent lesions in elite climbers (50%) [6] and are the result of local trauma during different grip techniques. In the crimped technique powerful flexion of the fingers with metacarpophalangeal joint extension, proximal interphalangeal joint flexion and distal interphalangeal joint extension can lead to excessive forces from the flexor tendons on the A2 and A3 DAP and consequent rupture. Partial tears are not associated with tendon bowstringing and seem not to predispose to degenerative changes.

Treatment of partial lesions involves the avoidance of climbing and the wearing of a finger tape-bandage or a ring splint for 2–3 months. Untreated complete tears can lead to flexion contractures of the proximal interphalangeal joint, secondary osteoarthritis and reduced functional performance. There is controversy regarding the surgical management of complete tears. Taping of the affected finger and non-steroidal anti-inflammatory drugs (NSAIDs) [7] as well as surgical reconstruction of the pulleys [8] were reported to be successful and allowed most patients to return to the same level of climbing activity. Factors which can affect the choice of treatment include the age and the climbing level of the patient as well as the number of pulleys involved. Older, medium-level patients can be treated conservatively if they agree to reduce their activity. More recently, surgery has been proposed in all high-level climbers with complete tears [9].Whatever the type of therapy, early diagnosis is required to prevent flexion contracture [10]. In acute cases, because of local swelling and pain which limit physical examination, the differential diagnosis between DAP lesions and post-traumatic tenosynovitis or sprains of the proximal interphalangeal joints and between partial and complete DAP tears can be difficult clinically. Imaging is helpful in differentiating various acute disorders which can affect rock climbers and in distinguishing between partial and complete DAP tears [4,5].

Although in normal conditions DAP are barely detected by US, diagnosis of their disruption can be made indirectly, by demonstrating bowstringing of the flexor tendons which is maximal at the level of the PP and IP in tears of the A2 or A4 DAP respectively. Both MRI and CT have been proposed for evaluation of DAP [4, 5] but, as in our study, the diagnosis was based on indirect signs. In our study US consistently assessed the integrity of the DAP in healthy subjects and correlated well with the MRI findings. The US assessment of DAP tears has received little attention in the radiological literature [11, 12]. In the five cases studied data correlate with a previous report which demonstrated that US is as valuable as MRI in diagnosing complete tears of DAP [12]. In this study both methods showed a sensitivity and specificity of 100% in a group of 14 patients with surgically confirmed DAP tears. The US hallmark of a DAP tear is the demonstration of volar subluxation of the tendons. Longitudinal static sonograms obtained with the fingers flexed at 45° adequately showed tendon bowstringing in all patients presenting a complete disruption. Transverse sonograms added no significant information. Sonograms obtained during resisted flexion of the finger enhanced the subluxation of tendons and confirmed the data from the static examination . The synovial effusions due to tenosynovitis can be explained by the fact that US was performed a few days after the injury. The synovial effusion, because of contrast between the anechoic fluid and the hyperechoic tendons, was helpful in the assessment

of the position of the flexor tendons. Volar subluxation of the base of the intermediate phalanx, observed in tears of the A2 DAP, can be explained by the forces transmitted by the volar dislocated flexor tendons. This finding confirms the role of an intact flexor apparatus in preventing malalignment of the phalanges and may in part explain the development of early osteoarthritis seen in climbers with a previous history of DAP lesions.

Patients who at US showed normal findings or tenosynovitis and the patient with a DAP partial tear were treated conservatively. Because of the high level and need to continue sporting activity three patients with a complete rupture received surgical therapy. The remaining five patients who refused surgery were treated by rest and NSAIDs.

Dynamic US scans in all our acute patients showed smooth gliding of the flexor tendons and were useful in the assessment of the tendons. Theoretically, in chronic cases, fibrous adhesions of the tendons could be evaluated at US by demonstrating reduced tendon gliding as well as movement of the paratendinous tissues during active finger motion. Demonstration of fibrous adhesions can help the clinician in the differential diagnosis of reduced flexion due to para-articular or articular abnormalities.

MRI is able to diagnose DAP tears by demonstrating the displacement of the flexor tendons, surrounded by an effusion in acute cases, but normal and injured DAP cannot be demonstrated . Images obtained under flexor tendons stress (isometric contraction of flexor muscles) were useless due to movement artefacts; moreover the position of the patient during the examination was uncomfortable.

Compared with MRI and CT, US is less expensive, non-invasive and allows dynamic evaluation. An additional advantage of US compared with CT is the detection of a synovial sheath effusion. US can rule out other diseases such as tenosynovitis of flexor tendons or joint diseases, appreciate the numbers of pulleys disrupted and may be able to differentiate partial from complete tears if high-quality equipment is used. Because of its low cost and non-invasiveness we suggest US as the first imaging modality in the evaluation of digital pulley tears.

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