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MRI sport-specific pulley imaging

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Abstract

Objective We aim to create a novel MRI methodology that employs sport-specific stress views for imaging finger pulley injuries in the evaluation of post-operative healing effectiveness. The goal is to measure the bone to tendon distance (BTD), which is the current standard for determining pulley injuries.

Materials and methods The athlete was imaged in a crimp-grip stressed position to emulate sport-specific biomechanics. A Gradient Echo technique was modified to maximize the signal to noise ratio and minimize distortion near the bone and tendon, simplifying the determination of the BTD.

Results A stress-crimped hand position is imaged in less than one half-minute to enable diagnostic visualization of a normal proximal phalanx' bone and tendon via measurement of their BTD.

Conclusion This novel stress methodology allows for sport-specific imaging, which is ideal for determining functional compromise of the hand's pulley mechanism. Surgical outcomes may be more sensitively compared when using stress views, and these comparisons may then direct optimal repair technique. Future studies will utilize this technique to attempt early-stage detection of pulley injuries prior to complete rupture.

Keywords Rock climber · A2 pulley · Stress-crimped · Magnetic resonance imaging (MRI) · Sport-specific

Introduction

Finger pulley injuries in athletes and nonathletes have been well documented over the past few decades. A2 pulley injuries of the ring finger are the most common pulley injury, followed by the smaller A4 pulley, although there is debate suggesting the A4 may often rupture first [1]. For a clinician to detect an isolated A2 or A4 pulley injury, imaging is often required [2]. Ultrasound is reportedly 100% sensitive in detecting A2 pulley injuries, but is less specific than MRI [3]. Clinically detected bowstringing deformity of the flexor tendon pair is usually only evident when concurrent A2 and A4 pulley injuries are present (or A1 and A2) [2–4]. Bowstringing results in an increased bone to tendon distance (BTD) [5], and thus increases in BTD are the determining factor in diagnosing pulley injuries with imaging [3, 6]. In a healthy subject the BTD is <2 mm, while with injury, the distance increases [7, 8].

Flexion of the finger significantly increases sensitivity in detecting injuries to the pulley mechanism in climbing athletes, due to the fact that A2 pulley rupture typically involves extreme stress in a flexed position referred to as the 'crimped position', or crimp-grip [1]. The crimped position is defined as the PIP joint in 90° of flexion with the DIP joint in about 10° of extension [9]. Imaging the crimped position under stress is the ideal method to examine the pulley because it emulates the climber's action during injury, and is therefore a sport-specific imaging technique [9].

Aside from Bayer et al.'s assessment of cadavers under stress in the crimped position [6, 10], only one study by Bodner et al. has assessed pulley injuries [5]. It employed 40° of flexion at the PIP joint, slightly removed from the

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climber's more extended slope grip (50–70° flexion at the PIP joint and minimal flexion of the DIP joint [11, 12]), and substantially removed from the crimped position. However, the slope grip is rarely associated with A2 pulley injuries, and is more prone to other types of injuries [11]. The crimp-grip pulley system experiences up to 36× more force than the slope-grip pulley system, with much of that force on the flexor digitorum profundus [13]. In summary, a stress-crimped view is a more sport-specific view for assessing pulley injuries compared with the slope-grip, and should be tested in live patients.

We present a novel MRI technique that allows for imaging in the crimped position under stress in less than 30 s. Stress views will create the possibility of diagnosing earlier-stage pulley injuries and evaluating of post-operative healing effectiveness. The purpose of this study is to demonstrate the feasibility of stress views by MRI in live patients, which has not previously been demonstrated.

Methods

A novel MRI methodology for imaging finger pulley injuries in sport-specific stress views has been developed. Prior to entering the MRI suite, the athlete's grip strength was tested with a Jamar Hydraulic Hand Dynamometer to confirm generation of at least 10 kg/cm² for 1 min. In the MRI suite, the athlete's arm was positioned extended overhead with the hand in a crimped position. The position was voluntarily held without brace or tape. The athlete grasped a glass container with a small lip, as shown in Fig. 1; this position most closely approximates sport-specific stress. All sequences were performed in the same position sequentially with 90-s breaks for recovery between scans.

Three variations of a sagittal 3D coherent gradient echo (GRE) MRI pulse sequence were executed on a 1.5 T (Philips Ingenia, Amsterdam, Netherlands) MRI scanner in attempts to generate optimal signal-to-noise (SNR) and



Fig. 1 Stress-crimped position emulating the sport-specific stress most commonly associated with the A2 pulley injury in climbers

imaging efficiency. All techniques employed the SENSitivity Encoding (SENSE) algorithm [14] for parallel imaging without any further image subsampling, to reduce scan time but maintain image quality. Scan times were given by the minimum possible time needed to achieve sufficient SNR and spatial resolution to permit accurate BTD evaluation. Following are the specific scan parameters, also summarized in Table 1.

Scan 1: Images were acquired of the 3rd (Fig. 2a) and 4th digits in a relaxed-crimped position with flip angle = 15°, repetition time (TR)/echo time (TE) = 30/13.81 ms, 259-s scan time, 19.6-kHz receive bandwidth, 180/178/75 matrix size and 0.4/0.45/1.2-mm voxel size along frequency/phase/slice directions.

Scan 2: Images were acquired of the 3rd (Fig. 2b) and 4th digits in a stress-crimped position with flip angle = 12°, TR/TE = 15.5/9.21 ms, 49.1-s scan time, 19.4-kHz receive bandwidth, 160/133/75 matrix size and 0.50/0.60/1.2-mm voxel size along frequency/phase/slice directions.

Scan 3: Images were acquired of the 3rd digit (Fig. 2c) in a stress-crimped position with flip angle = 12°, TR/TE = 15.5/9.2 ms, 24.6-s scan time, 19.4-kHz receive bandwidth, 160/124/40 matrix size and 0.50/0.65/1.3-mm voxel size along frequency/phase/slice directions.

BTD values were measured near the midpoint of the proximal phalanx, with several measurements over the three images made to permit computation of uncertainty. The green arrows in Fig. 2 indicate the location of measurement.

Results

Figure 2 depicts three images that resulted from the three sequences executed in this study. All three images yield diagnostic image quality sufficient for evaluation of pulley injuries, with clear delineation of the normal bone and tendon of the proximal phalanx. Figure 2b,c employs optimized flip angle and TR/TE in order to bring the scan time below 1 min, with Fig. 2c only requiring 25 s through reduction of the mediolateral field-of-view such that the sagittal views only covered the 3rd digit. These shortened scan times permitted sport-specific stress retention. Figure 2 also shows that the BTB value for this patient was computed to be 1.5 ± 0.1 mm, which is considered normal [7, 8].

Discussion

Sport-specific stress imaging is ideal for identifying and fully characterizing injuries; here this fact is exploited with stress-

Table 1 MRI Protocol specifics for sport-specific pulley imaging

Sequence		1	2	3
Echo type		Coherent gradient	Coherent gradient	Coherent gradient
Field strength [T]		1.5	1.5	1.5
SENSE parallel imaging		Yes	Yes	Yes
Dimensionality		3D	3D	3D
Flip angle [°]		15	12	12
Repetition time/TR [ms]		30	15.5	15.5
Echo time/TE [ms]		13.8	9.2	9.2
Scan time [s]		259	49.1	24.6
Receive bandwidth [kHz]		19.6	19.4	19.4
Frequency encoding	Matrix size	180	160	160
	Resolution [mm]	0.44	0.50	0.50
Phase encoding	Matrix size	178	133	124
	Resolution [mm]	0.45	0.60	0.65
Slices	Matrix size	75	75	40
	Thickness [mm]	1.2	1.2	1.3
	Orientation	Sagittal	Sagittal	Sagittal
Patient setup	Digits imaged	3rd and 4th	3rd and 4th	3rd
	Hand stress	Relaxed	Stressed	Stressed
	Hand position	Crimped	Crimped	Crimped

crimped MRI for pulley-injury imaging. In the injured athlete with equivocal physical and ultrasound exams, the MRI stress views allow for higher sensitivity in detection and characterization of partial and complete tears. Rather than aiming to directly visualize the hand's pulley system, this technique generates images that allow BTD measurement, a direct indicator of pulley injury [3, 5, 6, 15]. Stress views could also allow more thorough and accurate comparisons of treatment effectiveness and outcomes. Both conservative splinting and

surgical techniques could be more effectively compared in trials with stress views, though there is a limit due to the inability to accurately measure grip force in the MRI suite. Finally, stress views may guide return-to-play parameters, which may be particularly valuable in competition.

The described stress-crimped MRI methodology for imaging pulley injuries could be of great value in imaging pulley injuries, as it closely emulates the action of the athlete during injury. Because the actual rupture of the pulley occurs during

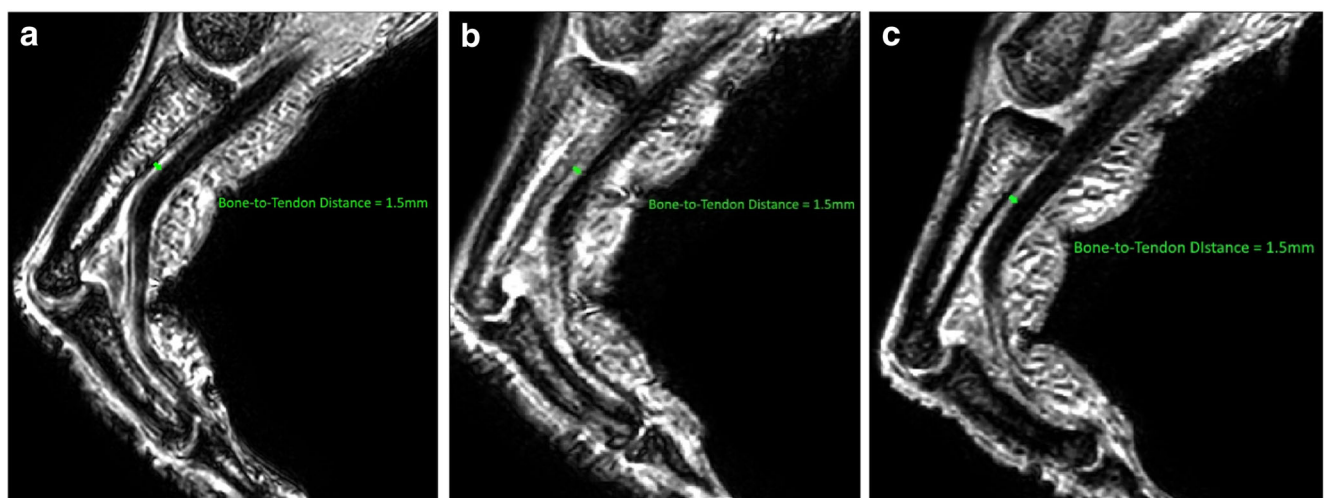


Fig. 2 **a** 259 s relaxed crimped sagittal image of the 3rd digit. Location and value of the bone-to-tendon distance measurement is depicted in green. **b** 49-s stressed crimped sagittal image of the 3rd digit. Location and value of the bone-to-tendon distance measurement is depicted in

green. **c** 25 s stressed crimped sagittal image of the 3rd digit. Location and value of the bone-to-tendon distance measurement is depicted in green

extreme stress, a shorter imaging time that allows for sustained, high stress of the pulley allows for more sport-specific imaging. The stress level achievable in the MRI scans executed in ~30 s of imaging can thus more closely simulate pulley rupture dynamics than standard MRI scans that last several minutes.

The pulse sequence we customized for diagnostic imaging of the pulley mechanism needed to achieve high quality images with minimal artifacts in short scan times. Increasing voxel size, shortening TR, and employing SENSE shortened scan time. The short TR additionally inspired the use of small flip angles near the Ernst angle [16] of the cortex and tendon. These small flip angles yield optimal SNR efficiency, negate the need for gradient spoiling, and suppress stimulated echo artifacts due to the generation of minimal transverse magnetization. The sequence also minimizes image distortion by using short TE and additional phase encoding along the slice direction (3D imaging), potentially improving accuracy in BTM measurements. All MRI pulse sequence modifications are standard parameter changes available on MRI systems from all manufacturers, including the parallel imaging SENSE technique [11].

Future studies that employ further technique refinement will give greater insight into pulley injury healing, both operative and nonoperative. Earlier detection of deficient pulleys may allow for a greater understanding of the pathophysiology, possibly leading to a reduction in the incidence of complete ruptures.

Limitations The technique requires the athlete to hold a stress position for approximately 30 s. We believe this is possible for most athletes, if not all. Should a modification be necessary, less stress exerted during the scan or taping may improve scan quality if pain or strength are limiting factors. Stress views do not have consistently applied stress, therefore limiting comparisons of treatment effectiveness. Finally, this study offers a qualitative assessment of normal pulley function.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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