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Case report

Use of Ultrasound to Monitor Biceps Femoris Mechanical Adaptations after Injury in a Professional Soccer Player

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Abstract
This study examined the use of ultrasound to monitor changes in the long head of the biceps femoris (BF) architecture of aprofessional soccer player with acute first-time hamstring strain. The player followed a 14 session physiotherapy treatment until return to sport. The pennation angle and aponeurosis strain of the long head of the biceps femoris (BF) were monitored at 6 occasions (up until 1 year) after injury. The size of the scar / hematoma was reduced by 63.56% (length) and 67.9% (width) after the intervention and it was almost non-traceable one year after injury. The pennation angle of the fascicles underneath the scar showed a decline of 51.4% at the end of the intervention while an increase of 109.2% of the fascicles which were closer to deep aponeurosis was observed. In contrast, pennation angle of fascicles located away from the injury site were relatively unaffected. The treatment intervention resulted in a 57.9% to 77.3% decline of maximum strain per unit of MVC moment and remained similar one year after the intervention. This study provided an example of the potential use of ultrasound-based parameters to link the mechanical adaptations of the injured muscle to specific therapeutic intervention.

Key words: Ultrasound imaging, tissue mechanics, therapeutic exercise, muscle physiology / performance, EMG, Biomechanics/lower extremity

Introduction

Hamstring muscle injuries are very frequent in sports and they are characterized by a high re-injury rate (30%) (Opar et al., 2012). A potential reason for recurrent muscle injuries is the premature return to full activity (Mueller-Wohlfahrt et al., 2013).

Structural damage of the muscle after injury has been quantified either using magnetic resonance imaging (MRI) (Askling et al., 2007)or ultrasound (US) (Malliaropoulos et al., 2010). Although evidence relating the size of the scar and re-injury rate is conflicting (Askling et al., 2007; De Smet and Best, 2000; Koulouris and Connell, 2003), quantification of the extent and location of injury is still considered important in designing appropriate rehabilitation programs (Heiderscheit et al., 2010).

US is currently used to examine architecture and mechanical properties of the hamstrings in vivo (Kellis et al., 2009). One can assume that the presence of the scar after a strain alters geometry of muscle and tendon tissues, at least near the injury area. This could have an effect on muscle force transmission paths (Huijing, 2003) and tendon compliance while it may increase loading of fibers adjacent to the injured area thus increasing the potential for re-injury (Silder et al., 2010). Although the effects of acute hamstring strain on localized strains have been investigated, changes in muscle and tendon architecture have not been clarified yet.

Aetiology of hamstring injury is complex and multifactorial in nature (Mueller-Wohlfahrt et al., 2013; Opar et al., 2012). US is frequently used to examine injury effects on morphology (Malliaropoulos et al., 2010) but it has not been used to monitor changes in muscle - tendon properties after injury. Therefore, in this case study, we explored the use of US to quantify changes in long head of biceps femoris (BF) muscle architecture and tendon strain after acute hamstring injury.

Case report

A 23-year old professional soccer player (body mass = 77.5 kg; height = 1.85 m) was followed for one year after BF injury. Symptoms included local tenderness and pain, more noticeable under stretch (straight leg raise > 45°). The clinical diagnosis based on US and MRI evaluation was BF injury (strain) of the right leg. This injury was classified as a structural injury with moderate partial tear (disruption more than the diameter of a fascicle) (Mueller-Wohlfahrt et al., 2013) and it was not a re-injury. The player was injured during the second half of an official game while sprinting. The local Ethics Committee approved the investigation and the participant gave written informed consent to participate.

The intervention protocol consisted of three phases. Phase 1 included non-steroidal anti-inflammatory medication for the first 5 days along with a standard physiotherapy treatment consisting of ice, crutches, rest, ultrasound and laser and isometric contractions involving the pelvis-lumbar region. Our treatment goal for the patient, at this phase, was to facilitate muscle healing and to regain pain-free, full range of motion and submaximal isometric contraction. Phase 2 included a combination of physical therapy modalities (heat, ultrasound and thermal bands) and trunk stability and moderate intensity strengthening (isometric, concentric and eccentric short-range) exercises, mild stretches (approximately 6-8 exercises / per session, four times a week, intensity increasing from 2 X 6 reps to 4 x 12 repetitions). The overall duration of this phase was 2 weeks and ended when the patient

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could perform an MVC test without pain. Finally, phase 3 exercises included various type of cutting maneuvers, eccentric hamstring and balance exercises of increasing demand as well as advanced trunk stability exercises. The patient returned to sport when he could perform advanced sport-specific exercises without pain and the strength differences between the two limbs were less than 5%.

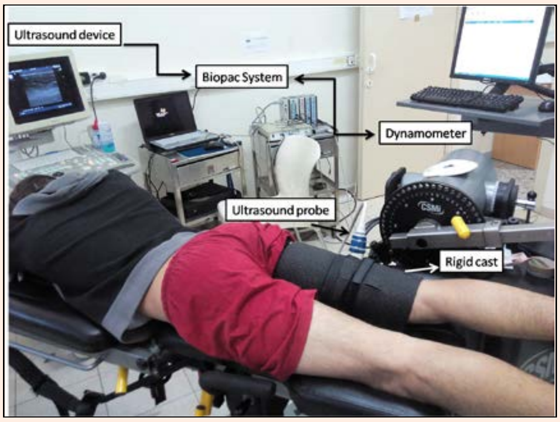


Figure 1.Example images from the experimental set up. After the injury location was identified, the probe was stabilized and secured with a customized rigid cast. The dynamometer and ultrasound data were fed to a Biopac unit for simultaneous display of their all data (Please note that participant is not secured on the dynamometer chair for illustration purposes).

Outcome measures were taken at six occasions: 3, 7, 14, 21, 28 days and 1 year after injury. Particularly, the patient was stabilized on the chair of a Cybex (HumacNorm, CSMI, MA) dynamometer in the prone position with a hip flexion angle of 0° (Figure 1). The axis of rotation of the dynamometer was carefully aligned with the lateral femoral condyle. A twin – axis goniometer (Model TSD 130B, Biopac Systems, Inc., Goleta, CA) was used to record knee angular position (0° = full knee extension). An ultrasonic apparatus (SSD-3500, ALOKA, Japan) was used with an electronic linear array probe of 10 MHz wave frequency. All signals were fed through BNC connectors (Models CLB 102 and CLB107, Biopac Systems, Inc., Goleta, CA) to a 12-bit analog-to-digital converter sampling at a rate of 1000 Hz per channel using the Acknowledge (version 3.9.1, Biopac Systems, Inc., Goleta, CA) software. The video capturing module of this software allowed simultaneous recording of the ultrasound video images at a rate of 30 Hz.

The scanning head of the probe was coated with transmission gel to obtain acoustic coupling. The US probe moved sequentially along muscle length (from the superior to the inferior border) until the ischial tuberosity at least 5 times. From the recorded US video images, the scar was identified and markers were then placed on the skin, to indicate its position along muscle length and to ensure its consistent identification in repeated scans (Figure 1). To exclude any joint rotation effects, US images were also recorded during a passive knee joint motion (from ~10° of knee flexion to ~3° hyper-extension) immediately after the MVC trial.

Initially the scar was identified on the captured US image (Figure 2) at rest. Using a video-based software (Max Traq Lite version 2.09, Innovision Systems, Inc., Columbiaville, Michingan. U.S.A) four points were digitized onthe US image andthe length andwidth were measured. Furthermore, three fascicles were selected from two regionsbased on their position relative to the scar:

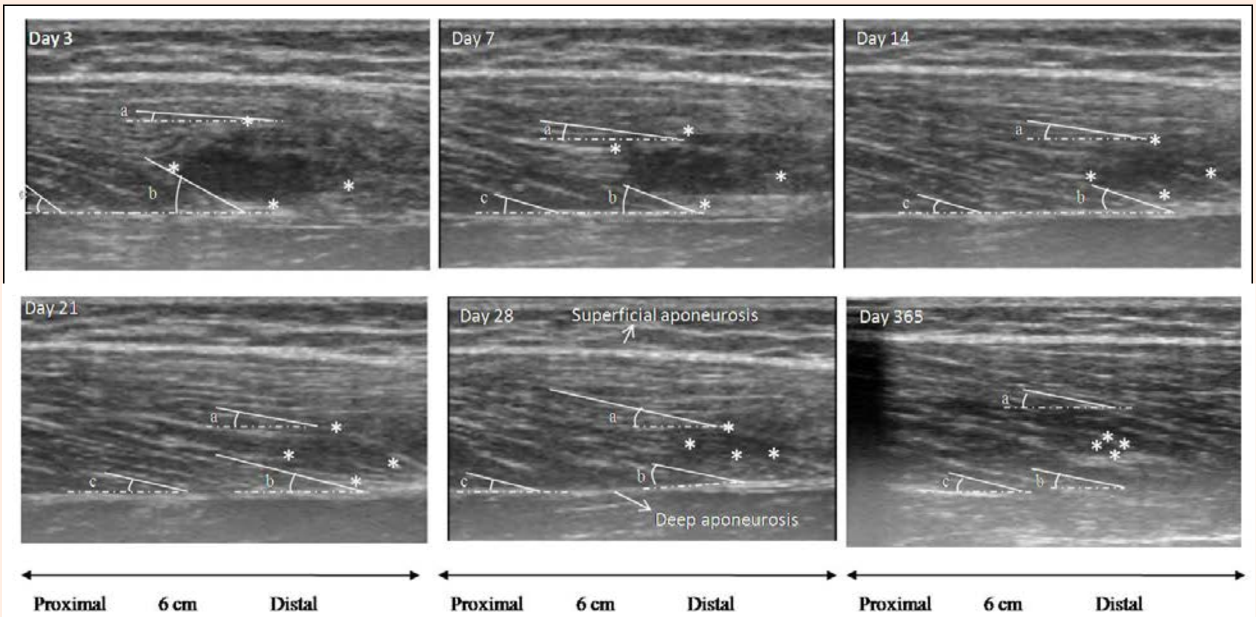


Figure 2. Scar tissue image obtained at each measurement session until 1 year after acute injury. The hematoma / scar was defined by four markers (indicated as asterisks). The pennation angles formed between a superficial (a), a deep (b) and a typical (c) fascicle and the deep aponeurosis are illustrated in each ultrasound image (Please note that the illustrated markers and lines identified in this image may slightly differ compared with those quantified by the video-based analysis software due to differences in image resolution and digitizing accuracy process).

Table 1.Maximum BF strain (%), maximum knee flexion moment of force (Nm) and maximum BF strain per unit of recorded knee flexion moment of force at 6 occasions after injury.

Days after injury	Maximum strain (%)			Moment of force (Nm)			Strain / moment of force		
	0°	45°	90°	0°	45°	90°	0°	45°	90°
3	4.63	7.90	11.52	45.41	31.91	28.81	0.10	0.25	0.40
7	6.98	8.07	12.59	80.01	54.83	50.33	0.09	0.15	0.25
14	6.97	8.19	12.93	131.32	109.44	107.74	0.05	0.07	0.12
21	8.54	8.60	15.83	182.81	141.53	138.42	0.05	0.06	0.11
28	7.92	9.42	14.63	184.53	167.61	155.73	0.04	0.06	0.09
365	8.13	9.21	12.99	199.55	175.21	160.22	0.04	0.05	0.08

one fascicle from the region superficially to the scar, the second fascicle from the region "underneath" the scar closer to the deep aponeurosis and, a third fascicle (referred to as "typical" fascicle) from the deeper region located as far as possible from the scar. For each of these fascicles, two points were digitized along their length and their angle relative to the deeper aponeurosis was calculated (Figure 2). For the ruptured fascicle, the angle between the fascicle and a line perpendicular to deep aponeurosis was considered as the pennation angle.

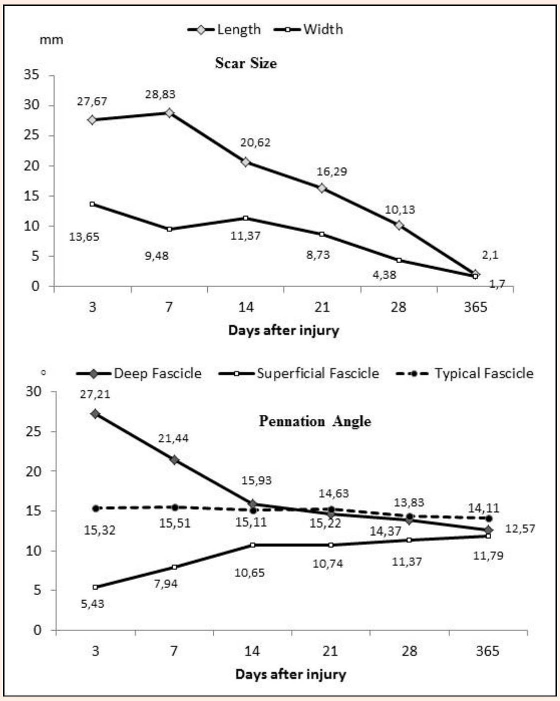
To quantify tendon / aponeurosis strain, a marker was placed on the dermal surface under the pad as a reference point to ascertain that the probe did not slide on the dermal surface and to act as a fixed reference from which manual measures of elongation could be made. A 5-sec isometric maximum voluntary contraction (MVC) was initially performed followed by three 10-s ramp isometric flexion contractions guided by an audiovisual signal. Particularly, the participant was instructed to gradually increase the level of effort every 1 sec until MVC. To achieve this, the moment curve was displayed on a screen notifying the participant to increase the level of effort, every 10% MVC. The procedure was repeated separately for each of three knee flexion angular positions: 0° (full extension), 45° and 90°. The sequence of tests was randomized across angular positions.

To quantify strain, the intersection point between a selected fascicle and the deep aponeurosis was digitized in each US video sequence and its displacement was measured. This displacement was then corrected for any joint position effects by removing the displacement of the point measured during the passive joint test. Strain was then calculated by dividing the displacement by the resting length. Resting length was measured using a flexible measurable tape at 40° of knee flexion (where the passive moment is almost zero) as the curved path from the BF distal origin (lateral aspect of fibula) to the aponeurosis / tendon marker measured along the skin surface (Kellis et al., 2009) and it was equal to 244.5 mm. To express the changes in strain relative to the changes in MVC moment across the 6 testing sessions, in each occasion, the strain was divided by the recorded MVC moment.

Results

The player reported no re-injury one year after the first incident.

Figure 2 presents the progression of scar tissue properties and pennation angle at rest at 6 different measurement sessions. The scar was easily identifiable in the first three sessions, but it was difficult to locate on day 28. The decline in scar size was 63.56% and 67.9% for scar length and width, respectively (Figure 3). Traces of the scar were found one year after injury (Figure 3). The pennation angle of the fascicles underneath the scar showed a decrease of 51.4% at the end of the intervention which was maintained until 1 year after injury (Figure 3). In contrast, the pennation angle of the fascicles above the scar was 90.2% smaller than the one measured in the deeper region of the muscle and showed a 109.4% increase from day 3 to day 28 which was almost maintained 1 year after injury. The pennation angle of the typical fascicle (unaffected region) showed minor changes during the examination period.



Figures 3.Scar dimensions (upper graph) and pennation angle of superficial, deeper and "typical" fascicles of the biceps femoris (lower graph) during the intervention period.

The maximum tendon/ aponeurosis strain increased by 71.06% (at 0°), 19.24% (at 45°) and 27.01% (at 90°) from day 3 to day 28 and remained relatively unchanged until one year after injury (Table 1). The knee flexion moment of force increased 3.5 times after the intervention (Table 1). The maximum strain divided by the recorded MVC moment showed a marked decrease ranging from 57.9% to 77.3% at day 28 and it remained unchanged until the retesting session a year after injury.

Discussion

The presence of the scar caused an alteration of architectural arrangement of the BF muscle in this player (Figure 2). Due to differences in pennation, superficial fascicles would display a higher excursion than deeper fascicles immediately after injury (Lieber and Friden, 2000). This implies that there may be marked differences in the working range of force – length curves between the fascicles near the hematoma at least within the first 2 weeks following injury. In theory this would have two implications: first, an unequal force distribution along the scar which may cause a shift of the hemmorage from high to low pressure areas and, second, an unequal force transmission along the muscle-tendon unit upon contraction. To our knowledge, there are no studies reporting changes in architectural arrangement of an injured BF during a physiotherapy intervention. Strength training generally induces muscle hypertrophy as evidenced by increases in pennation angle and muscle cross-sectional area (Farup et al., 2012). Potier et al. (2009) reported non-significant changes in fascicle length and pennation angle of BF after 8 weeks of eccentric training in healthy individuals. This is in agreement with the present study where minor changes in pennation angle of fascicle from an unaffected area were found. The variable responses in pennation angle of fascicles near the scar observed in this study suggest that muscular adaptations to rehabilitation are mostly guided by the need to recover altered muscle morphology due to hamstring injury rather than to increase fascicle angle.

The decrease in tendon / aponeurosis strain per unit of MVC moment implies a corresponding increase in its stiffness during this physical therapy treatment program (Table 1). It has been proposed that fibrous scar formation is usually due to sarcolemma damage during injury which may increase the relative stiffness of the muscle-tendon unit (Purslow, 2002). This is also in line with Silder et al. (2008) who found that patients with a previous hamstring injury display a higher muscle fiber strain and an enlarged proximal tendon / aponeurosis, and, hence a greater tissue stiffness. A more compliant tendon immediately after injury allows the tendon to lengthen upon stretch, thereby keeping fascicle shortening velocity low and optimizing the power–velocity relationship (Fletcher et al., 2010). In contrast, a stiffer tendon serves to better increase force transfer during movements where pre-stretch is unlikely (Biewener and Roberts, 2000). However, this decrease of the tendon-aponeurosis compliance may lead to increased strain in nearby muscle tissue, potentially increasing the risk for subsequent injury (Silder et al., 2008).

If the healing process of the ruptured muscle area decreases tendinous compliance, then a question is raised about the effectiveness of any physiotherapy intervention program after hamstring injury with regards to hamstring tendon / aponeurosis properties. Currently it is not very clear which types of exercise intervention are more beneficial for enhancing tendinous tissue compliance. Previous research findings in healthy individuals are conflicting as some studies reported increases in whole muscle stiffness (Klinge et al., 1997) or tendon / aponeurosis stiffness (Albracht and Arampatzis, 2013) while others found insignificant changes (Fletcher et al., 2010). The present treatment protocol included stretching, strengthening and trunk stabilization exercises. Although this program resulted in full restoration of strength, it is not clear whether the increase in tendon stiffness may increase the potential for re-injury. Nevertheless, the particular soccer player examined in the present study reported no re-injury one year after the event. Further studies are necessary to investigate long term mechanical adaptations to therapeutic interventions after hamstring injury.

The aforementioned mechanical responses to hamstring injury are highly specific to the muscle (BF) and the type of injury (sprint type, structural, middle tear) of a single soccer player. No generalization, therefore, can be made based on the present findings. Further, strain measurements are highly specific to the aponeurosis and fascicle segments near the injured area. Monitoring of tendon, fascicle and aponeurosis properties during contraction would be desirable but it requires the use of at least three separate US probes. Finally, measures of tissue stiffness, such as Young's modulus, were not calculated in this study.

Conclusion

Monitoring muscle-tendon architecture using ultrasonography in a soccer player with a moderate BF tear showed a gradual recovery of fascicle orientation and scar size and an increase in tendon strain one year after injury. This is an example of potential use of ultrasound-based parameters to link the mechanical adaptations of the injured muscle to specific therapeutic interventions and specific injury type.

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Key points

- Changes in fascicle orientation after biceps femoris mild tear were reduced after a 28 day intervention and remained similar one year after injury.
- Tendon/aponeurosis strain per unit of moment of force decreased during the course of the therapeutic intervention.
- Future studies could utilize ultrasonography to monitor mechanical responses after various types of hamstring injury and interventions in order to improve criteria for a safe return to sport.

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