

## RECTUS FEMORIS MECHANICS IN RUGBY KICKING

Neil Bezodis<sup>1</sup>, Stephanie Lazarczuk<sup>1,2</sup>, Jurdan Mendiguchia<sup>3</sup>, Thomas Love<sup>1</sup>

A-STEM Research Centre, Swansea University, UK<sup>1</sup>

SHAS, St Mary's University, Twickenham, UK<sup>2</sup>

ZENTRUM Rehab and Performance Center, Spain<sup>3</sup>

This study aimed to quantify rectus femoris muscle-tendon unit length and excitation during different types of rugby kick. Seven male rugby players completed a series of kicks during which kinematic and muscle excitation data were collected. Between 0.2 and 0.1 s prior to ball contact in all kick types, the rectus femoris lengthened rapidly whilst muscle excitation also rapidly increased, identifying eccentric action as a possible mechanism for muscle strain injury. Peak rectus femoris muscle excitations occurred later in the kicks with a primary height demand, and differences in the timing of peak muscle excitation existed between different regions of the rectus femoris muscle. This study provides information which can be used to inform the specificity of physical preparation and rehabilitation protocols for rugby kickers.

**KEY WORDS:** injury, kick, muscle, performance, quadriceps, Rugby Union.

**INTRODUCTION:** There is a negative association between the number of player days that a professional Rugby Union (hereafter 'rugby') team lose to injury and their success (Williams et al., 2016). As kicking directly contributes to 45% of all of the points scored in rugby (Quarrie & Hopkins, 2015) and indirectly contributes to further points (i.e. tries) through gaining territorial and tactical advantages, it is therefore important that the players who frequently kick within a team remain injury free to enhance the likelihood of team success. Whilst injury incidence during the act of kicking is relatively low compared with other rugby match actions such as tackling and being tackled (Lazarczuk et al., 2017), not all players kick, and some of those who do perform only one or two kicks per match. Kicking injury propensity during rugby matches is 0.62 injuries per 1000 kicks (corresponding to one kicking injury every 23 matches; Lazarczuk et al., 2018), with the most common location of kicking injury being the kicking leg thigh (Lazarczuk et al., 2017). The most common injury diagnosis is a rectus femoris (RF) muscle strain (Lazarczuk et al., 2017), a diagnosis which is also highly prevalent in other sports involving kicking (Mendiguchia et al., 2012).

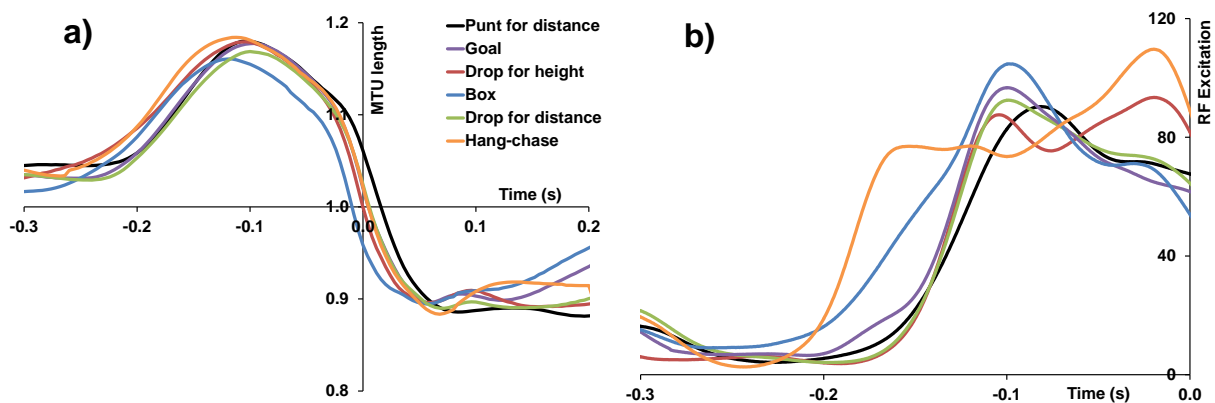
Muscle strain injuries typically occur during forced lengthening or eccentric muscle actions (Whiting & Zernicke, 2008), but RF lengths and excitations during kicking are not known. Furthermore, different regions of the RF have been shown to have different functional roles during isometric contraction and whilst walking at different speeds (Watanabe et al., 2012; 2014), and thus consideration of the region-specific nature of RF excitation during a ballistic action such as kicking is warranted. As a variety of different kick types are performed in rugby, with kick type and volume varying greatly between playing positions (Lazarczuk et al., 2018), understanding RF kinematics and excitation during different kick types would provide valuable position-specific information to assist coaching and medical staff in the management of potential RF muscle strain injuries. We therefore aimed to quantify RF muscle-tendon unit (MTU) length and excitation during different types of rugby kick with a view to understanding the relative demands of different kick types, including exploration of the region-specific nature of RF excitation.

**METHODS:** Seven professional and semi-professional male rugby players (Mean  $\pm$  SD: age = 23  $\pm$  3 years; 1.81  $\pm$  0.04 m; 88.6  $\pm$  6.0 kg) who regularly kicked in matches provided written informed consent to participate in this study which was approved by the local Research Ethics Committee. All data were collected on 3G artificial turf in a large indoor hall during pre-season, with all kickers wearing their own moulded rubber boots. Each kicker performed a series of kick types which they would typically perform in matches and training: punt for distance (n = 7 kickers), goal kicks (n = 5), drop kick for height (n = 4), box kick (n = 2), drop kick for distance (7) and hang-chase (n = 3).

Reflective markers were attached to the lower body of each kicker (anatomical markers for defining segment endpoints plus additional tracking clusters of four markers per thigh, shank and foot). During each kick, the motion of the pelvis markers and the thigh, shank and foot tracking markers was recorded at 250 Hz by a 12-camera Vicon T20-S system. Synchronously-recorded electromyography (EMG) electrodes (Delsys, Trigno, 2000 Hz) were also attached to the RF muscle of the kicking leg at 33%, 50% and 67% of the distance between the anterior inferior iliac spine and the superior margin of the patella. Two high-speed cameras (Sony FX1000, 200 Hz) were synchronised to the marker and EMG data to the nearest millisecond, and used to track three-dimensional ball motion.

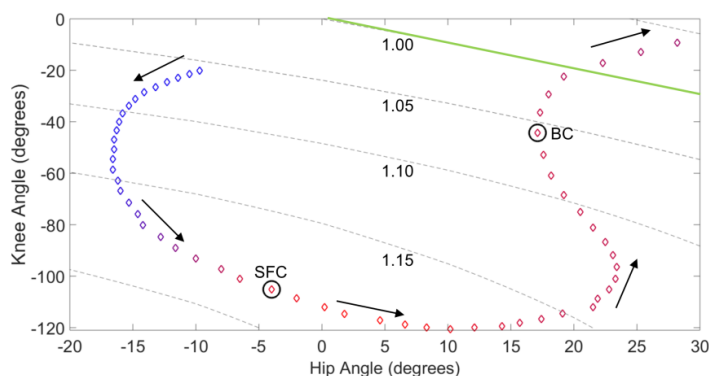
For each kicker, one kick of each type which they performed was selected based on the performance (ball launch) data, and was used for all subsequent analysis. Ball contact was visually identified from the high-speed camera clips and set as time = 0.0 s in the raw kinematic and EMG data. The kinematic data were reconstructed in OpenSim (v. 3.3) using inverse kinematics with a modified 7-segment version of the Delp et al. (1990) model. This models the RF via a wrapping point on the distal femur at knee flexion angles greater than  $-83.65^\circ$ . RF MTU lengths were expressed relative to quiet standing (as a length of 1.0) and exported alongside hip and knee flexion angles. The EMG data were processed by removing DC bias, high-pass filtering (30 Hz), full wave rectification, and creation of a linear envelope via low-pass filtering (10 Hz). Composite EMG time-histories for each kick type were created by expressing the processed continuous EMG data as a percentage of the peak magnitude achieved during the punt for distance kick for each individual kicker, before averaging all kicks of a given type to provide a mean RF excitation signal based on all of the kickers who completed that kick type. Peak muscle excitations during the final 0.25 s prior to ball contact were identified from the processed EMG data, and for each kicker they were expressed as a percentage of the corresponding peak excitation during the punt for distance kick.

**RESULTS:** Based on the mean time-histories for each of the kick types (Figure 1a), the RF MTU was longer than its resting length for the 0.3 s prior to ball contact for all kick types aside from the box kick (Figure 1a). RF MTU length peaked around 0.1 s before ball contact (i.e. near support foot contact), at lengths ranging from 1.15 to 1.20 of resting length. The box kick demonstrated the lowest mean peak RF MTU length, whilst the hang-chase kick demonstrated the greatest mean peak RF MTU length. Peak muscle excitation magnitudes (from the central electrode) ranged between 101 and 118% of the punt for distance kick magnitudes. However, whilst four of the kick types demonstrated peak excitation around 0.1 s before ball contact (close to the time of peak RF MTU length), RF excitation peaked just prior to ball contact in the drop kick for height and hang-chase (Figure 1b).



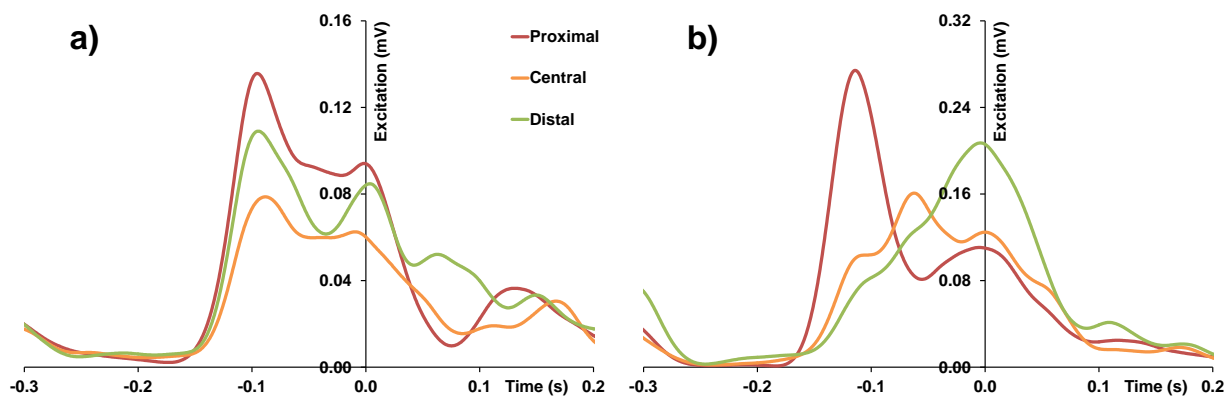
**Figure 1. Rectus femoris a) MTU lengths and b) excitations (from the central electrode) during each of the six kick types (mean curves from all kicks of each type; ball contact = time zero).**

The length of the RF MTU (Figure 1a) is a function of the hip and knee flexion angles. The RF was at its longest and most excited around the time when the knee was at its peak flexion angle (e.g. Figure 2). When the hip was at its peak flexion angle, RF muscle excitation was relatively low and the MTU was at around 1.10-1.15 of its resting length because the knee was in approximately  $50^\circ$  to  $60^\circ$  of flexion (e.g. Figure 2).



**Figure 2.** Length and excitation of the RF as a function of hip and knee flexion angles for an example kick (Kicker 4, punt for distance). The contours correspond to the RF MTU length (relative to resting (1.00); green line). The colour of the data points correspond to the magnitude of excitation of the central RF electrode (blue = zero excitation, red = maximum excitation, colour graded linearly between). SFC = support foot contact; BC = ball contact.

Muscle excitation magnitudes peaked at different times between different regions of the RF. In some kicks (e.g. Figure 3a) there appeared to be simultaneous peak excitation across the three regions of the RF muscle, whereas in other kicks (e.g. Figure 3b) the regions appeared to reach peak excitation in a proximal-to-distal fashion (Figure 3b).



**Figure 3.** Example trials with two different within-rectus femoris EMG patterns: a) synchronous peak values near support foot contact (Kicker 4, punt for distance), b) proximal-to-distal timing in peak values (Kicker 7, goal kick).

**DISCUSSION:** The RF MTU length changes are broadly similar between different kick types, lengthening between 0.2 and 0.1 seconds prior to ball contact, and reaching peak lengths (~1.2 times resting length) around 0.1 s prior to ball contact. This is after the hip has started to flex from its peak extension (~15-25° of extension at around 0.2 s prior to ball contact) but near the time of peak knee flexion (~115-120° at around 0.1 s prior to ball contact; e.g. Figure 2), reflective of the fact that the RF MTU length is affected more by the knee than the hip (Hawkins & Hull, 1990). Box kicks induce the least strain because of earlier hip flexion and smaller peak knee flexion magnitudes. In contrast, hang-chase kicks induce the greatest strain because of earlier (but not greater) knee flexion which therefore coincides with greater hip extension angles. These findings are pertinent as full-backs have the highest propensity for kicking injury of all playing positions amongst the backs, and they perform the highest proportion of hang-chase kicks, whereas scrum-halves have the lowest propensity for kicking injury and perform the highest proportion of box kicks (Lazarczuk et al., 2018).

The increases in RF excitation were most rapid (i.e. steepest; Figure 1b) from -0.2 to -0.1 s, which coincided with the most rapid MTU lengthening (Figure 1a) for all kick types, suggesting that this was predominantly eccentric action rather than forced lengthening. This identifies a possible mechanism for the relatively high prevalence of RF strains amongst the injuries sustained during kicking in rugby (Lazarczuk et al., 2017; Whiting & Zernicke, 2008). The two kicks with a height demand (hang-chase and drop kick for height) demonstrated a

different RF excitation pattern from the other four kicks, having a later peak which occurred just prior to ball contact. Given previous evidence that different regions of the RF muscle have different functional roles during isometric contractions and walking (Watanabe et al., 2012; 2014), this could be due to different regional excitation within the RF given the existence of proximal-to-distal excitation patterns within some of the kicks (e.g. Figure 3b), but further analysis is required to support this extension to ballistic movements.

We have modelled the RF as a single structure, and assessed muscle excitation at three different regions along it. Whilst it must be acknowledged that the RF has two insertions (direct and indirect), that we have only measured muscle excitation at distinct locations, and that we have a low number of samples of certain kick types, our data provide preliminary evidence which could help to direct and inform the understanding of different types of RF injury and prognosis (Balius et al., 2009). Future analysis is required to explore this further and to investigate whether differential RF excitation may be a function of the individual kicker and/or kick type, with a view to better understanding different RF injury locations.

**CONCLUSION:** The RF muscle acts at relatively long lengths throughout the majority of the kicking action prior to ball contact. Muscle excitation is at its greatest around the time when the RF MTU is at its longest, although a region-specific excitation nature within the RF may exist. The greater peak MTU lengths and contributing hip and knee joint kinematics in some kick types may have important implications for RF muscle strain injuries. This study provides information which can be used by coaching and medical staff to help inform the mechanical specificity of conditioning and training exercises used to prepare kickers' RF muscles for the demands of rugby kicking.

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