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THE FORCES EXERTED ON PROXIMAL MYOTENDINOUS JUNCTION OF THE BICEPS FEMORIS LONG HEAD MUSCLE DURING HIGH-SPEED RUNNING

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INTRODUCTION

Hamstring strain injury is one of the most common injuries in sports involving sprinting such as track and field, soccer, and rugby [1]. The biceps femoris long head muscle (BFLH) is injured most frequently among the bilateral hamstring muscles [1]. In addition, hamstring strain injuries are most frequently observed at the proximal myotendinous junction (MTJ) of BFLH [2].

The bilateral hamstring muscles generate the peak muscle force with the peak musculotendon strain during the late swing phase of running [3]. Previous studies indicated that the hamstring muscles activity and force increases as sprinting speed increases [3]. Therefore, the hamstring muscles are more susceptible to strain injuries during the late swing phase of high-speed running [3]. Fiorentino et al. [4] reported that muscle fiber strains are larger along the proximal aponeurosis area or around the proximal MTJ in BFLH. However, the forces exerted on the proximal MTJ in BFLH during the late swing phase of high-speed running are not clear.

The goals of this study were (i) to generate a special muscle model with multiple Hill-type muscle fibers, and (ii) to use this model for predicting the forces exerted on the proximal MTJ of BFLH during the late swing phase of high-speed running.

METHODS

Ten male soccer players (age 22.2±0.4years, 64.6±3.9kg, 170.3±5.9cm) performed three sprinting trials at 85% and 100% of their maximal speed. These trials were recorded using a three-dimensional motion analysis system (Vicon, 250Hz) and force platforms (Kistler, 1.5kHz). The late swing phase was defined from the maximal knee flexion to the foot strike, and normalized as 100% phase time.

A three-dimensional musculoskeletal model of the right leg with muscle models was used to compute the musculotendon dynamics during high-speed running. BFLH was modeled as the special muscle model (Fig. 1), which is based on the Hill-type muscle model with multiple muscle fibers, to predict the forces exerted on the proximal MTJ. The other muscles were modeled as a Hill-type muscle model, where a single muscle fiber was in series with an elastic tendon, include the force-length-velocity properties of muscles and force-length properties of tendon. Muscle excitation-to-activation dynamics in all muscle models were represented by a first-order differential equation [5]. The parameters of the Hill-type muscle model such as original and insertion points, optimal fiber length, pennation angle at optimal fiber length, and maximum isometric force were determined by reference to Gati2392model of OpenSim3.3, and scaled to the subjects' anthropometry.

The number of muscle fibers in the special muscle model was set at five (Fig. 1). Each muscle fiber was represented as a passive element (PE) in parallel with an active contractile element (CE), which include the force-length-velocity properties of muscles. Free tendon and aponeurosis were represented as a non-linear elastic element. We assumed that the strain in free tendon and aponeurosis was 0.04 when muscle generated maximum isometric force. According to some previous studies, the pennation angle of BFLH would be 7deg-23deg because of large individual differences.

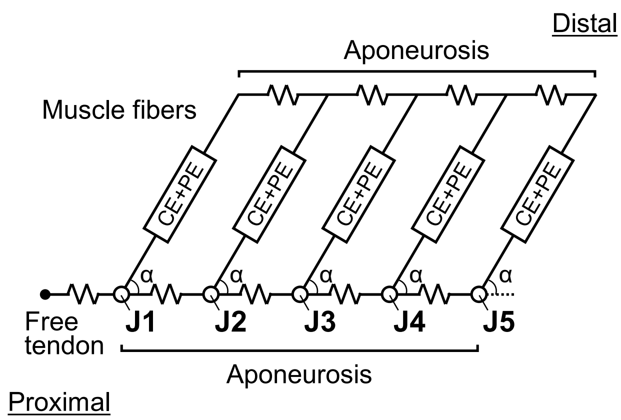

Fig 1: The special muscle model with five muscle fibers. Each junction (J1-J5) was defined as the proximal MTJ.

Therefore, the pennation angle at optimal fiber length was set at several values from 15deg to 23deg. The pennation angle of each muscle fiber was assumed as the same value. We calculated muscle forces at each pennation angle to determine the effects of the pennation angle on the musculotendon dynamics. Other muscle parameters of BFLH such as original and insertion points, optimal fiber length, and maximum isometric force were determined by reference to Gati2392model of OpenSim3.3 and scaled to the subjects' anthropometry. The value of the maximum isometric force divided by the number of muscle fiber, which was five in this study, was used in each muscle fiber. We defined junctions between aponeurosis and muscle fiber as the proximal MTJ in the special muscle model (Fig. 1). The forces exerted on the proximal MTJ (J1-J5) of BFLH were calculated as the sum of muscle fiber force and aponeurosis force by using the special muscle model. We also analyzed each muscle fiber force and each proximal aponeurosis strain.

To compare the peak values of each aponeurosis strain and the forces exerted on the MTJ at the individual junction, we performed a two-way repeated measures ANOVA at each sprint speed. Turkey's post hoc analysis was conducted if the ANOVA showed statically significant main or interaction effects. Student's paired t-test was used to compare the sprint speed (85% and 100% sprint speed). Statistical significance was set at p<0.05.

RESULTS AND DISCUSSION

The force exerted on J1 was significantly larger than other MTJ (J2-J5) at 85% and 100% sprint speed (p<0.01) (Fig. 2). Peak strain of the aponeurosis located near the free tendon was significantly greater than the others (p<0.01). The forces exerted on the MTJ (J1-J5) and peak aponeurosis strain increased significantly as sprinting speed increased (p<0.01). These results suggested that the MTJ and aponeurosis located near the free tendon were the most vulnerable tissues in BFLH strain injuries during high-speed running.

Smaller pennation angle led to increasing the forces exerted on all the MTJ (p<0.05) (Fig. 3). Peak values of aponeurosis strain and muscle force also increased as pennation angle decreased. In both the special muscle model and the Hill-type muscle model, smaller pennation angle is more efficient in converting muscle fiber force to muscle force. Therefore, smaller pennation angle was related to increasing the forces exerted on the MTJ and aponeurosis strain. This present study indicated that the smaller pennation angle of BFLH could be one of the most important architecture at the high risk of strain injuries.

CONCLUSIONS

The special muscle model which includes multiple muscle fibers could predict the forces exerted on the MTJ and the musculotendon dynamics such as each muscle fiber force and each aponeurosis strain during high-speed running. This study indicated that the peak values of the aponeurosis strain and the force exerted on the MTJ of BFLH were larger at J1 located near the free tendon. In addition, smaller pennation angle led to increasing the force exerted on the MTJ.

REFERENCES

1. Woods C, et al. Br J Sports Med 38: 36-41, 2004.
2. Askling CM, et al. Am J Sports Med 35: 197-206, 2007.
3. Chumanov ES, et al. J Biomech 40: 3553-3562, 2007.
4. Fiorentino NM, et al. J Biomech 47: 3325-3333, 2014.
5. Thelen DG, J Biomech Eng 125: 70-77, 2003.

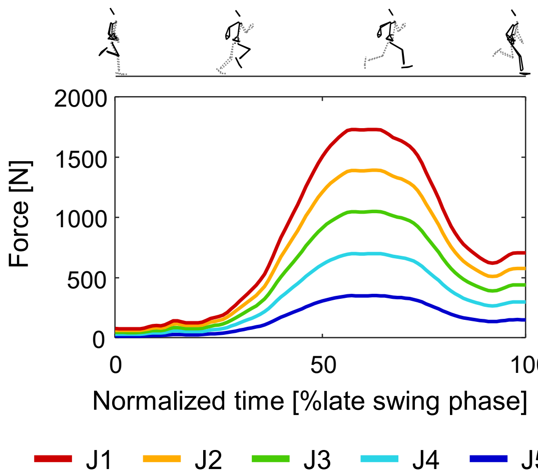

Fig 2: The forces exerted on the MTJ (J1-J5) of BFLH during the late swing phase of maximal running.

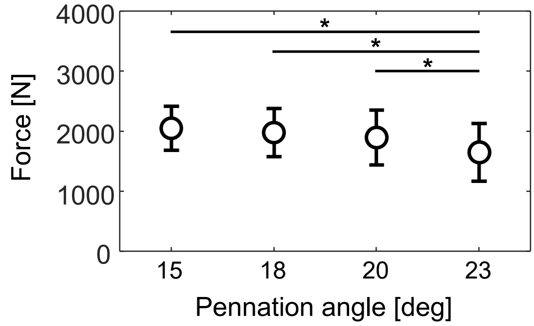

Fig 3: Peak values of the force exerted on J1 at several pennation angles (15deg-23deg) during the late swing phase of maximal running (*: p<0.05).