THE RELATIONSHIP BETWEEN HAMSTRING FLEXIBILITY AND MAXIMAL STRAINS OF HAMSTRING MUSCLE-TENDON UNITS IN SPRINTING: INDICATION TO HAMSTRING STRAIN INJURY

Hui Liu[1], Xianglin Wan[1], William E Garrett[2], Bing Yu[3]

Biomechanics Laboratory, Beijing Sport University, Beijing, China[1]
Duke University Sports Medicine Center, Durham, NC, USA[2]
Center for Human Movement Science, The University of North Carolina at Chapel Hill, Chapel Hill, NC, USA[3]

The purpose of this study was to determine the relationship between hamstring flexibility and maximal strain in sprinting. Ten male and 10 female reactional athletes participated this study. Hamstring flexibility, isokinetic strength data, three-dimensional kinematic data in a hamstring isokinetic test, and kinematic data in a sprinting test were collected for each participant. The optimal hamstring muscle lengths and maximal strains of hamstring muscle-tendon units in sprinting were determined for each participant. Maximal strains of hamstring muscle-tendon units were negatively correlated to hamstring flexibility. Maximal strains of biceps long head and semitendinosus muscle-tendon units were significantly greater than that of semimembranosus. Hamstring flexibility is a factor that significantly affect maximal strain of hamstring muscle-tendon units in sprinting.

KEY WORDS: Muscle strain, injury, muscle optimal length, risk factors.

INTRODUCTION: Hamstring strain injury is one of the most common injuries in track and field, soccer, Australian football, rugby, American football involving high-speed running, jumping and kicking, accounting for up to 29% of all injuries in these sports. Athletes who sustained hamstring strain injury typically need 2 to 8 weeks to recover from the injury and get back to the pre-injury level of activity, which result in significant time and financial loses. Athletes who sustained hamstring muscle strain injuries have a high re-injury rate of 12-31%.Although tremendous efforts have been made to prevent hamstring strain injury and improve the rehabilitation of the injury in the last three decades, the injury rate and re-injury rate, however, remain unchanged (Opar et al, 2014), which indicate an urgent need of studies on hamstring strain injury prevention and rehabilitation.

To effectively prevent hamstring strain injury and improve the rehabilitation of the injury, understanding the mechanisms and risk factors of the injury is critical.Our previous study found that hamstring muscle optimal lengths were positively correlated to hamstring flexibility (Wan et al, 2017).These results combined together indicate that hamstring muscles with good flexibility may have lower muscle strains in a given movement such as sprinting, and support the flexibility as a risk factor for hamstring injury. However, the effect of hamstring flexibility on the maximal strains of hamstring muscle-tendon units in sprinting still remained unknown.

As a continuation of our recent study, the purpose of this study was to examine the relationship between of hamstring flexibility with maximal strains of hamstring muscle-tendon units in sprinting. We hypothesized that maximal strains of hamstring muscle-tendon units in sprinting would be negatively correlated to hamstring flexibility. We also hypothesized that maximal strains of hamstring muscle-tendon units in sprinting would be different for different genders. We finally hypothesized that maximal strains of hamstring muscle-tendon units in sprinting would be different for different hamstring muscles. The results of this study would provide further theoretical evidence of the role hamstring flexibility played in hamstring muscle strain injury, and set a theoretical basis for future studies on the prevention and rehabilitation of hamstring strain injuries.

METHODS: Twenty college students (10 males and 10 females) regularly participating in exercise and sport activities in which sprinting was frequently performed volunteered to participate in this study. All participants had no history of hamstring injury or other lower extremity injuries that prevented them from performing the tasks in this study before participating in this study. The use of human subjects was approved by the Institutional Review Board of Beijing Sport University.

After sufficient warming up, each participant underwent a passive straight leg raise (PSLR) test to determine hamstring flexibility of each leg, a sprinting test to obtain lower extremity kinematic data of each leg in sprinting, and then an isokinetic strength test to determine hamstring muscle optimal length of each leg.In the PSLR test, the participant had three trials for each leg. The maximum hip flexion in the PSLR test was recorded as flexibility score for each leg.

In the sprinting test, retroreflective markers were placed at the L4-L5 interface and bilaterally at the anterior superior iliac spine, the top of the crista iliaca, the lateral and medial femur condyles, the lateral and medial malleolus, the tibial tuberosity, the center of the second and third metatarsals and the posterior calcaneus. The participant completed three acceptable sprinting trials for each leg with maximum effort with a 2 minute rest between two consecutive trials. An acceptable trial was a trial in which trajectories of all markers were collected in a full running gait cycle. The trajectories of the reflective markers in the sprinting test were recorded using a Motion Analysis videographic acquisition system with eight cameras at a sample rate of 200 frames per second. Maximal lengths of hamstring muscle-tendon units in sprinting were determined from the lower extremity kinematic data.

In the hamstring isokinetic strength test, participants sit on the IsoMed 2000 strength testing system with a hip flexion of 90°.The thigh and lower leg of the test leg were secured on the seat and dynamometer arm of the strength testing machine, respectively, and the knee flexion/extension axis was aligned with the rotation axis of the dynamometer. The rotation speed and range of the dynamometer arm were set 10°/s and 110°, respectively, with the dynamometer arm position at leg fully extension as 0°.The participant had three isokinetic knee flexion trials with maximum effort for each leg with a 90 sec rest between trials. The knee flexion torque data measured by the dynamometer in the strength testing system were collected using a MegaWin 2.4 system at a sample rate of 100 sample/channel/sec. The trajectories of the reflective markers in isokinetic strength test were recorded using a Qualisys videographic acquisition system with ten video cameras at a sample rate of 100 frames per second. The peak knee flexion torque was identified for each trial. The trial with the highest peak knee flexion torque was used to determine optimal lengths of hamstring muscle-tendon units. The maximal strain of each hamstring muscle-tendon unit was determined as the ratio of maximal length deformation of the hamstring muscle-tendon unit to the optimal length of the hamstring muscle-tendon unit.

To test our first hypothesis, linear regression analysis with dummy variable was performed to express the maximal strain of each hamstring muscle-tendon unit as a function of hamstring flexibility score

$$y = a_0 + a_1 x + a_2 \beta + a_3 x \beta + e$$

where y was the maximal strain of hamstring muscle-tendon; x was the hamstring flexibility score; β was the dummy variable representing gender ($\beta = 0$ for males, $\beta = 1$ for females); and a_0 to a_3 were regression coefficients. The best regression equation was determined through a backward selection procedure. A regression coefficient was kept in the best regression equation if (1) the contribution of the corresponding term to the regression measured by partial R^2 was greater than 0.03, and (2) the overall regression was statistically significant. Two-way ANOVA with mixed design were performed to test our second and third hypothesis by determining the effects of muscle and gender on the magnitudes of maximal muscle strains, with muscle treated as a repeated measure while gender as independent measure.Turkey's test was performed as post hoc analysis to locate significant differences when a main effect was significant.All data analyses were performed using SPSS Version16.0 (SPSS, Chicago, IL, USA).Statistical significance was defined as the type I error rate lower than or equal to 0.05.

RESULTS: The best regression equation for the maximal strain of biceps long head muscle-tendon unit (y) as a function of flexibility score (x) was

$$y = 0.2916 - 0.0020x \quad (R^2 = 0.4519, p = 0.001)$$

The best regression equation for the maximal strain of semimembranosus muscle-tendon unit (y) as a function of flexibility score (x) was

$$y = 0.2576 - 0.0018x (R2 = 0.4160, p = 0.001)$$

The best regression equation for the maximal strain of semitendinosus muscle-tendon unit (y) as a function of flexibility score (x) was

$$y = 0.2548 - 0.0017x (R2 = 0.3597, p = 0.001)$$

The ANOVA showed no significant interaction effect of muscle and gender and no significant main effect of gender on maximal muscle strain ($p = 0.826$, and $p = 0.433$), but a significant main effect of muscle on maximal strain ($p = 0.003$).Post hoc analyses revealed that the maximal muscle strains of biceps long head (0.071 ± 0.058) and semitendinosus (0.064 ± 0.054) were greater than that of semimembranosus (0.070 ± 0.055).

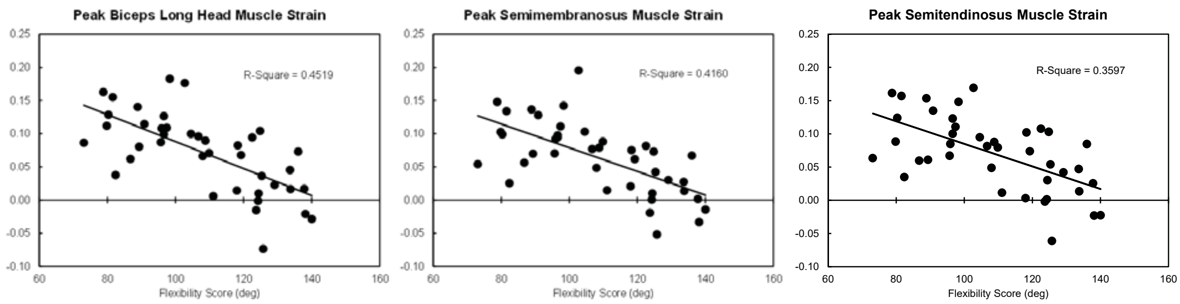

Figure 1. Relationship between maximal hamstring muscle-tendon unit strain and flexibility

DISCUSSION: The results of this study support our first hypothesis that maximal strains of hamstring muscle-tendon units in sprinting would be negatively correlated to hamstring flexibility. The best regression equations showed that the greater the flexibility score, the lower the maximal strains of hamstring muscle-tendon units. Previous studies showed that muscle strain was the direct cause of muscle strain injury, and that the greater the muscle strain, the higher risk for muscle strain injury (Garrett et al, 1987; Leiber and Friden, 1993). The current results suggest that in sprinting, athletes with good hamstring flexibility have lower maximal strains of hamstring muscle-tendon units, and thus should be at lower risk for hamstring injury compared to athletes with poor hamstring flexibility.
The results of this study do not support our second hypothesis that maximal hamstring muscle strains would be different for different genders. The results showed that there were not significant differences in maximal strains of hamstring muscle-tendon units between genders in

sprinting. These results indicate that there should be no difference in the risk for hamstring injury in sprinting between genders in terms of maximal strains of hamstring muscle-tendon units in sprinting. This indication, however, is inconsistent with most clinical studies showing that men have higher rates of hamstring injury than women (Cross et al, 2013; Dalton et al, 2015; Opar et al, 2014).A possible explanation for this disagreement may be that the exercise intensity and fatigue level are different between genders in games and practices. Future studies may be needed to further understand the gender difference in hamstring injury.
The results of this study support our third hypothesis that maximal strains of different hamstring muscle-tendon units would be different in sprinting. The results of this study showed that the maximal muscle-tendon strains of biceps long head muscle and semitendinosus were greater than that of semimembranosus in sprinting. These results indicate that biceps long head and semitendinosus may be at higher risk for muscle strain injury compared to semimembranosus in sprinting, which is consistent with the results of epidemiological studies. Biceps long head was the most frequently injured muscle among the hamstring muscles (De Smet and Best, 2000; Slavotinek et al, 2002; Askling et al, 2007).The injury rate of semitendinosus appears to be higher than that of semimembranosus (Koulouris and Connell, 2003).
The cross-sectional nature is a limitation this study. Future longitudinal studies are needed to confirm that the maximal strains of hamstring muscle-tendon units of individual athletes can be reduced by improving hamstring muscle flexibility.

CONCLUSION: Maximal strains of hamstring muscle-tendon units in sprinting are negatively correlated to hamstring flexibility across individuals, which indicate that hamstring flexibility may be a risk factor for hamstring strain injury. Maximal strains of hamstring muscle-tendon units are different among hamstring muscles in sprinting, which may explain the different injury rate among hamstring muscles.

REFERENCES:

Askling, C.M., Tengvar, M., Saartok, T., Thorstensson, A. (2007). Acute first-time hamstring strains during high-speed running: a longitudinal study including clinical and magnetic resonance imaging findings. *American Journal of Sports Medicine*, 35, 197-206.
Cross, K.M., Gurka, K.K., Saliba, S., Conaway, M., Hertel, J. (2013). Comparison of hamstring strain injury rates between male and female intercollegiate soccer athletes. *American Journal of Sports Medicine*, 41, 742-748.
Dalton, S.L., Kerr, Z.Y., Dompier, T.P. (2015). Epidemiology of Hamstring Strains in 25 NCAA Sports in the 2009-2010 to 2013-2014 Academic Years. *American Journal of Sports Medicine*, 43, 2671-2679.
De Smet, A.A., Best, T.M. (2000). MR imaging of the distribution and location of acute hamstring injuries in athletes. *American Journal of Roentgenology*, 174, 393-399.
Garrett, W.E., Safran, M.R., Seaber, A.V., Glisson, R.R., Ribbeck, B.M. (1987). Biomechanical comparison of stimulated and nonstimulated skeletal muscle pulled to failure. *American Journal of Sports Medicine*, 15, 448-454.
Koulouris, G. Connell, D. (2003). Evaluation of the hamstring muscle complex following acute injury. *Skeletal Radiology*, 32, 582-589.
Lieber, R.L., Friden, J. (1993). Muscle damage is not a function of muscle force but active muscle strain. *Journal of Applied Physiology*, 74, 520-526.
Opar, D.A., Drezner, J., Shield, A., Williams, M., Webner, D., Sennett, B., et al. (2014). Acute hamstring strain injury in track-and-field athletes: A 3-year observational study at the Penn Relay Carnival. *Scandinavia Journal of Medicine and Science in Sports*, 24, 254-259.
Slavotinek, J.P., Verrall, G.M., Fon, G.T. (2002). Hamstring injury in athletes: using MR imaging measurements to compare extent of muscle injury with amount of time lost from competition. *American Journal Roentgenology*, 179, 1621-1628.
Wan X.L., Qu F., Garrett W.E., Liu H., Yu B. (2017). Relationships of Hamstring Muscle Optimal Length with Hamstring Flexibility and Strength: Indication to Hamstring Muscle Strain Injury.*Journal of Sports and Health Science* (In press).