The effect of hamstring flexibility on peak hamstring muscle strain in sprinting

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Abstract

Background: The effect of hamstring flexibility on the peak hamstring muscle strains in sprinting, until now, remained unknown, which limited our understanding of risk factors of hamstring muscle strain injury (hamstring injury). As a continuation of our previous study, this study was aimed to examine the relationship between hamstring flexibility and peak hamstring muscle strains in sprinting.

Methods: Ten male and 10 female college students participated in this study. Hamstring flexibility, isokinetic strength data, three-dimensional (3D) 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 peak hamstring muscle strains in sprinting were determined for each participant.

Results: The muscle strain of each of the 3 biarticulated hamstring muscles reached a peak during the late swing phase. Peak hamstring muscle strains were negatively correlated to hamstring flexibility (0.1179 ≤ R² ≤ 0.4519, p = 0.001) but not to hip and knee joint positions at the time of peak hamstring muscle strains. Peak hamstring muscle strains were not different for different genders. Peak muscle strains of biceps long head (0.071 ± 0.059) and semitendinosus (0.070 ± 0.055) were significantly greater than that of semimembranosus (0.064 ± 0.054).

Conclusion: A potential for hamstring injury exists during the late swing phase of sprinting. Peak hamstring muscle strains in sprinting are negatively correlated to hamstring flexibility across individuals. The magnitude of peak muscle strains is different among hamstring muscles in sprinting, which may explain the different injury rate among hamstring muscles.

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Keywords: Hamstring flexibility; Hamstring muscle strain injury; Injury risk factor; Muscle biomechanics; Muscle strain; Muscle strain injury

1. Introduction

Hamstring muscle strain injury (hamstring injury) is one of the most common injuries in sports involving sprinting. The high injury and recurrence rates of hamstring injury result in significant time and financial losses and unfortunate consequences. Although tremendous efforts have been made to prevent hamstring injury and improve the rehabilitation of the injury, the injury and recurrence rates have remained unchanged in the past 3 decades.

Identifying risk factors is critical for effective prevention of hamstring injury and improvement of rehabilitation outcomes of the injury. Although hamstring flexibility is one of the potential risk factors for hamstring injury many studies were focused on, the results of epidemiologic studies of effects of hamstring flexibility on hamstring injury or re-injury rate were contradictory. A recent systematic literature review with meta-analysis failed to show evidence to support flexibility as a risk factor.

Many theoretical studies, however, have provided evidences that support hamstring flexibility as a risk factor for hamstring injury. Several animal studies demonstrated muscle strain as the direct cause of muscle strain injury. Muscle strain is defined as the ratio of muscle length deformation to muscle resting length and can be approximated using muscle optimal length. Alonso et al. reported that the legs with less flexible hamstring muscles have greater optimal knee flexion angles at which isokinetic knee flexion moment was maximal, indicating that less flexible hamstring muscles have less hamstring optimal
muscle lengths. Our previous study found that hamstring muscle optimal lengths were positively correlated to hamstring flexibility. 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 flexibility as a risk factor for hamstring injury. However, the effect of hamstring flexibility on the peak hamstring muscle strains in sprinting, until this study, remained unknown.

As a continuation of our recent study that showed the relationship between hamstring muscle optimal lengths and hamstring flexibility, the purpose of this study was to examine the relationship of hamstring flexibility with actual peak hamstring muscle strains in sprinting. We hypothesized that peak hamstring muscle strains in sprinting would be negatively correlated to hamstring flexibility. We also hypothesized that peak hamstring muscle strains in sprinting would be positively correlated to hip and knee joint positions at the time of peak muscle strains, which reflects the comprehensive effects of hip flexion and knee extension on hamstring lengths. We further hypothesized that peak hamstring muscle strains in sprinting would be different for different genders. We finally hypothesized that peak hamstring muscle strains in sprinting would be different for different hamstring muscles. The results of this study should provide further theoretical evidence of the role hamstring flexibility plays in hamstring muscle strain injury and set a theoretical basis for future studies on the prevention and rehabilitation of hamstring as well as other muscle strain injuries.

2. Materials and methods

2.1. Participants

Twenty sports-majored college students (10 males and 10 females) with sprint training experience who regularly participate in exercise and sport and participated in our previous study volunteered to participate in this study. The activities these subjects are involved in include basketball, soccer, and running. The means ± SD of ages, standing heights, and body masses of these participants were 24.6 ± 3.1 years, 173.9 ± 3.3 cm, and 65.9 ± 6.1 kg for male participants and 23.6 ± 0.9 years, 163.8 ± 3.8 cm, and 53.5 ± 4.4 kg for female participants, respectively. All participants had no history of hamstring injury or other lower extremity injuries before participating in this study that prevented them from performing the tasks in this study, and each provided written consent before data collection. The study was approved by the Institutional Review Board of Beijing Sport University.

2.2. Protocol

After sufficient warm-up, each participant underwent a passive straight leg raise (PSLR) test to determine hamstring flexibility bilaterally, a sprinting test to obtain lower extremity kinematic data of both legs in sprinting, and then an isokinetic strength test to determine hamstring muscle optimal lengths bilaterally. In the PSLR test, the participant had 3 trials for each leg as described in our previous study. The participant laid on the floor in a supine position. The tester raised the participant’s leg with one hand and monitored the pelvis rotation with the other hand placed on the anterior superior iliac spine of the contralateral side. The participant’s leg was raised with a straight knee to a hip flexion angle at which the tester clearly felt the resistance to further hip flexion or a pelvis posterior rotation. The body position with this maximum hip flexion was recorded 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 iliac, the lateral and medial femur condyles, the lateral and medial malleolus, the tibial tuberosity; and the center of the second and third metatarsals and the posterior calcaneus. The participant completed 3 acceptable sprinting trials for each leg with maximum effort with a 2 min rest between 2 consecutive trials. An acceptable trial was a trial in which trajectories of all markers were collected in a full running gait cycle. The distance from the starting line and near edge and the center of the motion capture area was 20 m and 25 m, respectively. All participants used a standing start technique to start sprinting.

After the sprinting test, the participant had a bilateral isokinetic strength test in which the markers were remained on the body landmarks and the marker on L4-L5 was removed. The participant was seated on the IsoMed2000 strength-testing system (D&R Ferstl GmbH, Hemau, Germany) with a hip flexion of 90°. The thigh and the lower leg of the testing leg were secured on the seat and the dynamometer arm, respectively, of the strength-testing machine. The participant had 3 isokinetic knee flexion trials at an angular speed of 10°/s with maximum effort for each leg. The detailed setup of the isokinetic strength test was described in our previous study.

2.3. Data collection

The body position with maximum hip flexion angle in the PSLR test was recorded using a high definition digital camera (SONY HVR-V1C; Sony Corp., Tokyo, Japan) with its optical axis perpendicular to the sagittal plane of the participant’s body. The trajectories of the reflective markers in the sprinting test were recorded using a Motion Analysis videographic acquisition system with 8 cameras (Raptor-4; Motion Analysis Inc., Santa Rosa, CA, USA) at a sample rate of 200 frames per second. The trajectories of the reflective markers in the isokinetic strength test were recorded using a videographic acquisition system (Oqus 400; Qualisys, Gothenburg, Sweden) with 10 video cameras at a sample rate of 100 frames per second. The knee flexion torque data measured by the dynamometer in the strength-testing system were collected using a MegaWin 2.4 system (Mega Electronics Ltd., Kuopio, Finland) at a sample rate of 100 sample per channel per second, and the videographic and dynamometer data collections were time synchronized by the Qualisys Track Manager computer program package (Version 2.9; Qualisys).

2.4. Data reduction

The maximal hip flexion angle in the PSLR test trail was reduced from the digitized digital photo of the maximal hip
flexion angle taken in the PSLR test. The average of the maximal hip flexion angles from 3 PSLR trials was used as the hamstring flexibility score for each leg. The raw three-dimensional (3D) trajectories of reflective markers of an isokinetic strength test trial and in a running gait cycle were filtered through a low-pass digital filter at an estimated optimal cutoff frequency of 13 Hz.\textsuperscript{20} Instantaneous locations and orientations of pelvis, thigh, and shank segment reference frames were determined from 3D coordinates of reflective markers. Instantaneous locations of hamstring muscle origins and insertions in the laboratory reference frame were calculated from the local coordinates of the origins and insertions and instantaneous orientations and locations of corresponding segment reference frames. Instantaneous muscle lengths of a given hamstring muscle were determined as instantaneous distances between origin and insertion of the muscle. Detailed descriptions of the calculation of instantaneous muscle lengths can be found elsewhere.\textsuperscript{25,27,28} Muscle optimal length of a hamstring muscle was identified as the muscle length corresponding to the maximal peak hamstring force. Instantaneous force of each muscle was identified as the muscle length corresponding to the moment arms of hamstring muscles. The detailed calculation of instantaneous muscle force was described in detail in our previous study.\textsuperscript{25} A running gait cycle was defined as the time period between 2 consecutive foot strikes of the same foot. The time of a foot strike was defined as the time represented by the first frame in which the vertical coordinate of the heel or toe became a constant. The time of a toe off was defined as the time represented by the frame immediately after the last frame in which the vertical coordinate of the toe was a constant. The stance phase was defined as the duration from a foot strike to the subsequent toe off of the same foot, and the swing phase was defined as the duration from a toe off to the subsequent foot strike of the same foot. Running speed was represented by the averaged horizontal velocity of the L4-L5 marker during a gait cycle. Instantaneous muscle strains ($\varepsilon_t$) of biarticulated hamstring muscles of the given leg in a gait cycle were calculated from instantaneous muscle lengths ($L_t$) and optimal lengths ($L_0$) of the corresponding muscles throughout a given gait cycle as

$$
\varepsilon_t = \frac{L_t - L_0}{L_0}
$$

Instantaneous knee joint angles were reduced as the Euler angles of the shank relative to the thigh with an order of rotations of (1) flexion–extension, (2) valgus–varus, and (3) internal–external rotations. Instantaneous hip joint angles were reduced as the Euler angles of thigh relative to the pelvis with an order of rotation of (1) flexion–extension, (2) abduction–adduction, and (3) internal–external rotations. Detailed descriptions of joint angle calculations can be found elsewhere.\textsuperscript{29} The hip–knee joint configuration at the time of peak muscle strains was used to represent hip and knee joint position and defined as the sum of hip flexion angle and supplementary angle of knee flexion angle at the time of peak muscle strains.

2.5. Data analysis

To test our first 3 hypotheses, linear regression analysis with a dummy variable was performed to determine the relationships of peak muscle strain with flexibility score and hip–knee configuration angle at the time of peak muscle strain for each of the biceps long head, semimembranosus, and semitendinosus. The full regression model was

$$
y = a_0 + a_1x_1 + a_2x_2 + a_3\beta + e
$$

where $y$ was peak muscle strain; $x_1$ was hamstring flexibility score; $x_2$ was hip–knee configuration angle at the time of peak muscle strain; $\beta$ was the dummy variable representing gender ($\beta = 0$ for males, $\beta = 1$ for females); $a_0$ to $a_2$ were regression coefficients; and $e$ was the residual. The best regression equation was determined through a backward selection procedure. A regression coefficient was kept in the regression equation if (1) the contribution of the corresponding term to the regression measured by partial $R^2$ was greater than 0.03 and statistically significant and (2) the overall regression is statistically significant.

Two-way analysis of variance (ANOVA) with mixed design were performed to test our fourth hypothesis by determining the effects of muscle and gender on the magnitudes of peak 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 $\leq 0.05$.

3. Results

The mean running speeds were $7.97 \pm 0.49$ m/s and $6.94 \pm 0.43$ m/s for the male and female participants, respectively. The mean duration of the stance phase was $26.54\% \pm 2.82\%$ and $27.08\% \pm 2.01\%$ for the male and female participants, respectively. The muscle strain–time curves of 3 hamstring muscles reach peaks during the late swing phase (Fig. 1).

The best regression equation for the peak muscle strain ($y$) of biceps long head as a function of flexibility score ($x$) was

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

The hip–knee configuration angle at the time of peak muscle strain and gender were excluded from the regression with contributions to the overall regression as 0.0352 ($p = 0.119$) and 0.0242 ($p = 0.190$), respectively (Fig. 2A).

The best regression equation for the peak muscle strain ($y$) of semimembranosus as a function of flexibility score ($x$) was

$$
y = 0.2576 - 0.0018x \quad (R^2 = 0.4160, p = 0.001)
$$

The hip–knee configuration angle at the time of peak muscle strain and gender were excluded from the regression with
contributions to the overall regression as 0.0443 \( (p = 0.090) \) and 0.0266 \( (p = 0.181) \), respectively \( (\text{Fig. 2B}) \).

The best regression equation for the peak muscle strain \( (y) \) of semitendinosus as a function of flexibility score \( (x) \) was

\[
y = 0.2548 - 0.0017x \quad (R^2 = 0.3597, p = 0.001)
\]

The hip–knee configuration angle at the time of peak muscle strain and gender were excluded from the regression with contributions to the overall regression as 0.0161 \( (p = 0.335) \) and 0.0078 \( (p = 0.505) \), respectively \( (\text{Fig. 2C}) \).

The ANOVA showed no significant interaction effect of muscle and gender and no significant main effect of gender on peak muscle strain \( (p = 0.826 \text{ and } p = 0.433) \), but a significant main effect of muscle on peak muscle strain \( (p = 0.003) \) \( (\text{Table 1}) \). Post hoc analyses revealed that the peak muscle strains of biceps long head and semitendinosus were greater than that of semimembranosus \( (p = 0.004) \) \( (\text{Table 1}) \).

4. Discussion

Potential for hamstring muscle strain injury exists during the late swing phase of sprinting. The results of this showed that 3 hamstring muscles had peak muscle strains during the late swing phase. These results are consistent with previous studies that demonstrated that hamstring muscle lengths peaked during the late swing phase of treadmill sprinting\(^27\) and over-ground sprinting\(^28,30\). As previously studies showed, the direct cause of muscle strain injury is muscle strain during muscle
eccentric contraction. The results of this study and previous studies therefore indicate that risk for hamstring muscle injury in sprinting exists during late swing phase. However, previous studies also indicated a potential for hamstring muscle strain injury during the late stance phase because hamstring lengths also peaked during the late stance phase. This difference among previous studies was explained as the difference between treadmill and over-ground running. The results of current study, however, do not support this explanation. A careful examination of the setups for experiments in current study and the study by Yu et al. leads to a belief that the participants in the study by Yu et al. might have been still accelerating as the distance between the starting line and the motion capture area was only 10 m. As a recent study showed the anterior tilt angle of the pelvis and the hip flexion angle are increased when accelerating with trunk in a forward lean in comparison to sprinting with a consistent speed with trunk in an upright position. This angle difference would result in an increased hamstring muscle length deformation during the late stance phase. The results of this study support our first hypothesis that peak hamstring muscle strains in sprinting would be negatively correlated to hamstring flexibility. The results showed that hamstring flexibility score had significant contributions to the regressions of peak hamstring muscle strain. The best regression equations showed that the greater the flexibility score, the lower the peak hamstring muscle strain. These results support flexibility as a risk factor for hamstring injury in sprinting as previous studies showed that muscle strain was the direct cause of muscle strain injury, regardless of muscle force and strain rate, and that the greater the muscle strain, the higher risk for muscle strain injury. The current results suggest that in sprinting, athletes with good hamstring flexibility have lower peak hamstring muscle strains, which indicate that they may have lower risk for hamstring injury compared to athletes with poor hamstring flexibility. Nevertheless, the results of this study are inconsistent with the results of some epidemiologic studies in which hamstring flexibility did not significantly contribute to the prediction of hamstring injury. Possible explanations of those results include small sample size, lack of consideration of the movement type of hamstring injury occurred, small variation in flexibility, large number of participants with previous hamstring injury, great variation in age, and intervention to hamstring flexibility. Future studies are needed to understand the relationship between hamstring flexibility and strain injury.

The results of this study do not support our second hypothesis that peak hamstring muscle strains in sprinting would be correlated to hip and knee joint configuration at the time of peak hamstring muscle strains. The results showed that the hip–knee angle at the time of peak muscle strains had no significant contributions to regressions of peak hamstring muscle strains in sprinting. The hip–knee configuration angle is the sum of hip flexion angle and supplementary angle of knee flexion angle, and represents the overall hip and knee joint angular position that affects hamstring length. Increasing hip flexion or increasing knee extension would increase hamstring muscle lengths and thus increase hamstring strain. The results of this study, however, suggest that differences in peak hamstring strains among participants in sprinting cannot be explained by the difference in hip and knee joint angular position among participants at the time of peak hamstring strains, which is largely due to the similarity of the movement among participants in sprinting.

The effect of hamstring flexibility on peak hamstring muscle strains could be attributed to the effect of hamstring flexibility on hamstring muscle optimal lengths found in our previous study. As previously described, muscle strain is defined as the ratio of muscle length deformation to muscle optimal length. Our previous study demonstrated that hamstring muscle optimal lengths were positively correlated to hamstring flexibility. Our current study demonstrated that peak hamstring muscle strains were also correlated to hamstring flexibility, but not to the hip and knee joint configuration at the time of peak hamstring strains. These results combined together suggest that the effect of hamstring flexibility on peak hamstring muscle strains in sprinting is mainly due to the effect of muscle flexibility on hamstring muscle optimal lengths across participants.

The results of this study do not support our third hypothesis that peak hamstring muscle strains would be different for different genders with the same hamstring flexibility and hip and knee joint configuration at the time of peak hamstring muscle strains. The results showed that gender had no significant contributions to regressions of peak hamstring muscle strains in sprinting. Our previous study showed that, with the same flexibility score, the hamstring muscle optimal lengths of females were shorter in comparison to males, which indicated that females might have greater muscle strains in running in comparison to males. The current study, however, showed that this was not true. These results indicate that there should be no difference in the risk for hamstring injury in sprinting between genders in terms of peak hamstring strains in sprinting. This indication, however, is inconsistent with most clinical studies showing that men have higher rates of hamstring injury than women in various sports involving high-speed running. A possible explanation for this disagreement may be that the exercise intensity and fatigue level are different between genders in games and practices. An elevated level of fatigue may result in kinetic and kinematic adjustments in the sprinting mechanics due to decreased muscle strength, which in turn affect the peak hamstring muscle strains. Future studies of gender and fatigue effects on peak hamstring muscle strains may be needed to confirm the results of this study and

| Muscle                  | Peak muscle strain (mean ± SD) | p value |
|-------------------------|-------------------------------|---------|
|                         | Male                          | Female  |
| Biceps long head        | 0.078 ± 0.047                 | 0.064 ± 0.069 | 0.433 |
| Semimembranosus         | 0.070 ± 0.045                 | 0.058 ± 0.063 | 0.433 |
| Semitendinosus          | 0.078 ± 0.049                 | 0.063 ± 0.061 | 0.433 |

p value 0.003 0.003
understand interaction effects of gender and fatigue on peak hamstring muscle strains in sprinting to further understand the gender difference in hamstring injury.

The results of this study support our fourth hypothesis that peak muscle strains of different hamstring muscles would be different in sprinting. The results of this study showed that the peak muscle strains of biceps long head 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 epidemiologic studies. Epidemiologic studies demonstrated that biceps long head was the most frequently injured muscle among the hamstring muscles.\(^{40,42}\) Some studies also showed that the injury rate of semitendinosus was higher than that of semimembranosus,\(^{40,41}\) while other studies showed contrary results.\(^{43,44}\)

The relationships of hamstring flexibility and peak hamstring muscle strains found in this study are limited as cross-sectional relationships. These cross-sectional relationships only suggest that individuals with good hamstring flexibility may have lower peak hamstring muscle strains compared to those with poor flexibility, which does not necessarily mean that improving hamstring flexibility would result in a decrease in peak hamstring muscle strains in sprinting for a given individual. Future longitudinal studies are needed to confirm that the peak hamstring muscle strains of individual athletes can be reduced by improving hamstring muscle flexibility.

5. Conclusion

The potential for hamstring muscle strain injury may exist during the late swing phase of sprinting with constant speed. Peak hamstring muscle strains in sprinting are negatively correlated to hamstring flexibility across individuals. The magnitudes of peak muscle strain are different among hamstring muscles in sprinting, which may explain the different injury rate among hamstring muscles.

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Authors’ contributions

XW carried out the experiments, performed the data processing and statistical analysis, and drafted the manuscript; BY and HL conceived of the study, participated in its design and coordination, and helped to draft the manuscript; FQ and WEG helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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