Torque-angle curve of the knee flexors in athletes with a prior history of hamstring strain

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ABSTRACT

Objectives: To investigate the knee flexor torque-angle curve after hamstring strain injury using different muscle action types and angular velocities.

Design: Cross-sectional.

Setting: Controlled laboratory study.

Participants: Thirteen collegiate athletes injured hamstring strain (21.0±0.8 years; 173.9±6.5 cm; 70.1±10.5 kg).

Main outcome measures: Concentric and eccentric knee flexor torque was measured at 60°/sec and 300°/sec. Peak torque and average torque every 10° were determined from torque-angle curve and the injured limb was compared with the non-injured limb.

Results: No significant differences were found in the concentric muscle actions. However, the eccentric peak torque was significantly lower in the injured limb at 60°/sec ($p = 0.048$) and at 300°/sec ($p = 0.002$). The average eccentric torque was significantly lower in the injured limb at 60°/sec from 10° to 20° of knee flexion (p = 0.012–0.018) and at 300°/sec from 10° to 60° of knee flexion (p = 0.005–0.049).

Conclusion: The knee flexor torque-angle curve changes with eccentric muscle action after hamstring strain injury. Eccentric torque declines were close to full knee extension at 60°/sec and a wide range of knee flexion at 300°/sec. The assessment and rehabilitation

of eccentric hamstring strength may be important to consider the effect of the angular velocity after hamstring strain injury.

Key words

hamstring injury, eccentric muscle action, high angular velocity, dynamometer

1. INTRODUCTION

Hamstring strain injury is the most prevalent type of muscle strain injury associated with playing sports, especially soccer, rugby, American football and sprinting (Ekstrand, Hägglund, & Waldén, 2011; Ekstrand, Waldén, & Hägglund, 2016; Feeley et al., 2008; Fuller, Taylor, Kemp, & Raftery, 2017; Opar et al., 2014). Re-injury rates after hamstring strain injury reportedly range from 13.9 to 63.3% such that previous hamstring strain injury is considered one of the main risk factors for re-injury (Visser, Reijman, Heijboer, & Bos, 2012; Green, Bourne, van Dyk, & Pizzari, 2020). Despite increased efforts to prevent recurring hamstring strains, several review articles report that the injury occurrence as well as the re-injury rates have not improved over the last three decades (Brukner, 2015; Mendiguchia, Alentorn-Geli, & Brughelli, 2012; Visser et al., 2012).

The mechanisms behind hamstring strain injury have been proposed in biomechanical studies (Bing et al., 2008; Chumanov, Heiderscheit, & Thelen, 2011; Higashihara, Nagano, Ono, & Fukubayashi, 2015, 2016; Schache, Dorn, Blanch, Brown, & Pandy, 2012; Sun et al., 2015). Hamstring strain injury is thought to occur during high-speed running (Ekstrand et al., 2011; Feeley et al., 2008; Fuller et al., 2017; Opar et al., 2014). As the sprinting speed increases, the calculated maximal hamstring force production also increases regardless of the hamstring muscle length changes (Chumanov, Heiderscheit, & Thelen, 2007; Dolman, Verrall, & Reid, 2014). Therefore, the phase of maximal hamstring muscle force production with the muscle lengthened position has a high potential risk of strain injury. During the late swing phase of sprinting, the hamstring muscles, which are exposed to high tensile force from eccentric muscle action, are elongated instantaneously (Bing et al., 2008; Chumanov et al., 2011; Higashihara et al., 2016; Schache et al., 2012; Sun et al., 2015). During the early stance phase, increases in knee flexion and hip extension moments were determined (Sun et al., 2015), and the hamstring muscles contracted concentrically. However, the changes in hamstring muscle length has not yet been clearly described yet. (Kenneally-Dabrowski et al., 2019; Liu, Sun, Zhu, & Yu, 2017; Sun et al., 2015). Thus, there two mechanisms have been reported for hamstring strain injury; however, knee extension loads to the hamstring muscles with rapid eccentric muscle action were considered prone to hamstring strain injury during the late swing phase. During the late swing phase of sprinting, the maximum knee extension angular velocity was reported to be over 1,000°/sec, and the knee flexion angles were shown to occur from 40° of knee flexion toward extension (Chumanov et al., 2007; Guex, Gojanovic, & Millet, 2012; Kivi, Maraj, & Gervais, 2002; Schache, Wrigley, Baker, & Pandy, 2009; Thelen et al., 2005). Therefore, the type of muscle action, angular velocity, and joint angle are all important for rehabilitation as well as for reducing further risk of re-injury after hamstring strain injury.

Isokinetic knee flexor strength assessment is commonly used for screening the future risk of hamstring strain re-injury (Green, Bourne, & Pizzari, 2018; Sugiura, Saito, Sakuraba, Sakuma, & Suzuki, 2008; Yeung, Suen, & Yeung, 2009). Isokinetic strength variables were peak torque and angle of peak torque indicated by the torque-angle curve. Considering the mechanism of hamstring strain injury, the characteristics of eccentric knee flexor torque-angle curve are important for assessment after injury. Hence, the angle of peak torque was reported to have low reliability with eccentric flexor muscle action (Timmins, Shield, Williams, & Opar, 2016). A previous study showed that the average angle-specific eccentric torque at 60°/sec with hamstring lengthened position (from 5° to 25° of knee flexion) was lower on the injured side than on the non-injured side after hamstring strain injury (Sole, Milosavljevic, Nicholson, & Sullivan, 2011). However, the changes in the angle-specific torque with the torque-angle curve at other angular velocities (except 60°/sec) and muscle action type are still poorly represented.

Therefore, we aimed to investigate the effects of a prior history of hamstring strain injury on hamstring muscle torque-angle curve at different angular velocities in concentric and eccentric strength testing. We hypothesized that any difference in the hamstring muscle torque-angle curve would be more pronounced at higher angular velocities with eccentric muscle action on the injured side as compared to the non-injured side.

2. METHODS

2.1. Participants

Thirteen collegiate athletes (age: 21.0 ± 0.8 years; height: 173.9 ± 6.5 cm; body mass: 70.1 ± 10.5 kg) all with previous histories of unilateral hamstring strain injury participated in this study. Hamstring strain injury was defined as the sudden onset of posterior thigh pain while playing sports in the past 3 years (Opar, Williams, Timmins, Dear, & Shield, 2013b; Sole et al., 2011). The injury diagnosis, location, severity and the rehabilitation after HIS were unknown due to the basis on self-reporting. All participants had returned to playing sports without pain. Participants who had other orthopaedic and/or neurological injuries, or any history of orthopaedic surgery to the lumbopelvic or lower extremities, and any history of hamstring strain injury within the last 12 weeks were excluded from the present study (Yeung et al., 2009). The subjects regularly played the following sports: track & field (6 sprinters and 2 jumpers), rugby (2), baseball (2) and lacrosse (1). The time after injury ranged from 4.5 months to 3 years. This study was approved by the ethics committee of a local institutional review board, and all participants provided written informed consent prior to enrolling in this research.

2.2. Experimental design

Participants were asked to visit a laboratory room on 2 occasions with each session separated by at least 72 hours. For the first visit, hamstring muscle strength measurement was performed with an isokinetic dynamometer for familiarization with the measurement protocol (Biodex 3, Biodex Medical System, Inc., Shirley, NY, USA). On the second day of measurements, hamstring strength was assessed. The laboratory room temperature was kept at 25°C (Ayala, De Ste Croix, Sainz De Baranda, & Santonja, 2013).

2.3. Isokinetic strength measurement of hamstring muscles

After a 15-minute warm-up period on a bicycle ergometer, both the concentric and eccentric isokinetic torque of the knee flexors were measured with Biodex 3 isokinetic dynamometer. The measurements were performed from 0° of full knee extension to 90° of knee flexion and angular velocities at 60°/sec and 300°/sec were used. Concentric knee flexion movement was performed at the beginning of eccentric measurement because of the setting for safety. Three sub-maximal practices were performed prior to 5 maximal trials. Subjects were allowed to take a 1-minute rest between each velocity session as well as a 3-minute break between muscle action type sessions (concentric and eccentric).

2.4. Data analysis

Row data of torque and angle, angular velocity was sampled at 1,000 Hz and outputted into MyoSystem 1200 software (Noraxon U.S.A., Inc., USA). Acceleration and deceleration phases were observed before and after reaching isokinetic motion. This non-isokinetic phase (acceleration and deceleration) was excluded from the angular velocity data; therefore, data from 10° to 60° of knee flexion were analyzed in the present study. For the torque values, a gravity correction of the limb was performed at 20° of knee flexion with relaxed (Aagaard, Simonsen, Trolle, Bangsbo, & Klausen, 1995). Gravity-corrected torque values were rectified using the methods of moving averages and normalized by their body weights, and then the torque-angle curve was drawn by each participant. To assess the torque-angle curve, the angle-specific averaged knee flexor torque of each participant was measured every 10° from 10° to 60° of knee flexion. The peak torque of torque-angle curve was also determined by fitting to a fourth-order polynomial curve (Brughelli & Cronin, 2007; Yeung & Yeung, 2008). Four conditions (concentric at 60°/sec (CON60) and 300°/sec (CON300), eccentric at 60°/sec (ECC60) and eccentric at 300°/sec (ECC300)) were analyzed.

2.5. Statistical analysis

Angle specific torque was divided into angles every 10° from 10° to 60° of knee flexion between the injured and non-injured limbs. Two-way repeated measures analysis of variance (6 angles for 2 limbs) was used in this study. Post-hoc analysis using Bonferroni correction were employed. Differences in the peak torque between the injured side and the non-injured side were compared using a paired t-test. The significance level was set as $p<0.05$ and all data were presented as mean ± standard deviation (SD). Additionally, the mean differences and 95% confidence interval (95% CI) was represented. To assess the magnitudes of differences on effect size, Cohen's d_z for t-test as well as post-hoc analysis and generalized eta-squared (η^2_G) for repeated measures were calculated (Bakeman, 2005; Faul, Erdfelder, Lang, & Buchner, 2007; Olejnik & Algina, 2003). The effect size was interpreted as small (dz ≥ 0.20; η2G ≥ 0.02), medium ($d_z \geq 0.50$, $\eta^2_G \geq 0.13$), or large ($d_z \geq 0.80$, $\eta^2_G \geq 0.26$) (Bakeman, 2005; Faul et al., 2007). All statistical analyses were performed using SPSS ver. 22.0 software (IBM Corporation, Chicago, IL).

3. RESULTS

There was a significant angle-limb interaction in ECC60 (p = 0.028; η^2_G = 0.008), and a post-hoc test showed that torque was significantly lower from 10° to 20° knee flexion (p=0.012; d_z=0.825; p=0.018; d_z=0.757, respectively) indicating a medium to large effect sizes as shown in Table 1. There was a significant main effect on both limbs with ECC300 (p = 0.003; η^2_G = 0.081). Post-hoc test results showed that significantly lower torque was found from 10° to 60°, indicating medium to large effect sizes (p = 0.005~0.049; d_z = 0.607~0.954) (Table2). Boxplots of eccentric torque-angle curve was shown in Fig.1 and Fig.2. As for the average concentric torque of knee flexion, there were neither significant main effects nor interactions.

Table1. Angle specific torque of eccentric contraction at 60° /sec between the injured and the non-injured limbs

Knee flexion angles (deg)	Injured limb (Nm / kg)	Non-injured limb (Nm / kg)	Mean difference (95 % CI)	*p*	d_z
10	1.641 ± 0.409	1.882 ± 0.335	-0.241 (-0.418 to -0.064)	0.012*	0.825
20	1.747 ± 0.358	1.925 ± 0.273	-0.178 (-0.321 to -0.036)	0.018*	0.757
30	1.730 ± 0.358	1.855 ± 0.279	-0.125 (-0.280 to 0.030)	0.105	0.486
40	1.650 ± 0.344	1.759 ± 0.284	-0.109 (-0.273 to 0.055)	0.173	0.402
50	1.535 ± 0.334	1.629 ± 0.275	-0.093 (-0.262 to 0.075)	0.251	0.335
60	1.427 ± 0.316	1.500 ± 0.243	-0.073 (-0.220 to 0.073)	0.297	0.302

The data are presented with mean ± SD.

* $p < 0.05$

Table 2. Eccentric angle specific torque at 300° /sec on the injured and the non-injured sides

Knee flexion angles (deg)	Injured	Non-injured	Mean difference (95%CI)	*p*	d_z
10	1.259 ± 0.312	1.439 ± 0.438	-0.180 (-0.346 to -0.013)	0.037*	0.652
20	1.712 ± 0.283	1.868 ± 0.387	-0.155 (-0.309 to -0.001)	0.049*	0.607
30	1.678 ± 0.256	1.853 ± 0.307	-0.175 (-0.291 to -0.058)	0.007*	0.907
40	1.636 ± 0.284	1.820 ± 0.275	-0.185 (-0.302 to -0.068)	0.005*	0.954
50	1.589 ± 0.288	1.779 ± 0.278	-0.190 (-0.315 to -0.065)	0.006*	0.917
60	1.597 ± 0.288	1.767 ± 0.265	-0.170 (-0.286 to -0.054)	0.008*	0.887

The data are presented with mean ± SD.

* $p < 0.05$

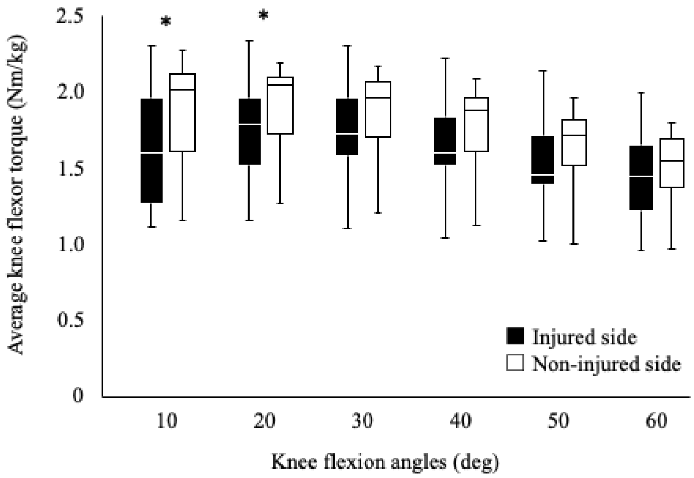

Fig. 1. Boxplots of eccentric torque-angle curve at 60°/sec on injured and non-injured limbs

The solid horizontal line of each boxplot indicates the median.

* indicates $p < 0.05$.

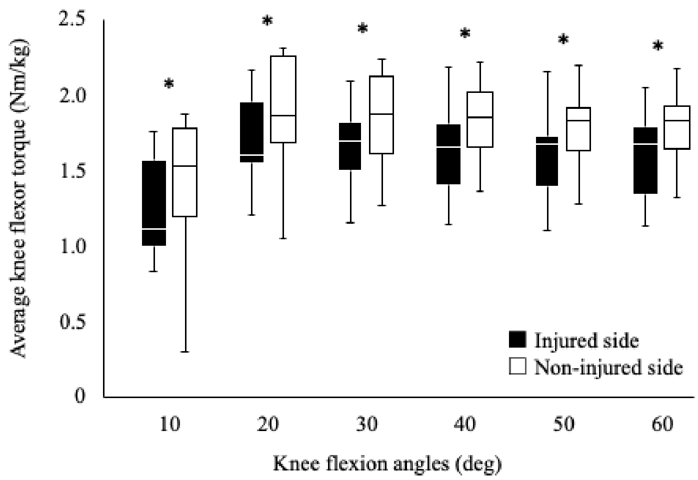

Fig. 2. Boxplots of eccentric torque-angle curve at 300°/sec on injured and non-injured sides

The solid horizontal line of each boxplot indicates the median.

* indicates $p < 0.05$.

There were no significant differences in concentric peak torque between the injured and non-injured sides (p = 0.408; d_z = 0.238; p = 0.471; d_z = 0.206, for CON60 and CON300, respectively) as shown in Table3. Significant decreases in the peak torque of the injured side compared to the non-injured side were found for ECC60 (p = 0.048; d_z = 0.611) and ECC300 (p = 0.002; d_z = 1.120) (Table 3). Boxplots of peak torque were shown in Fig.3.

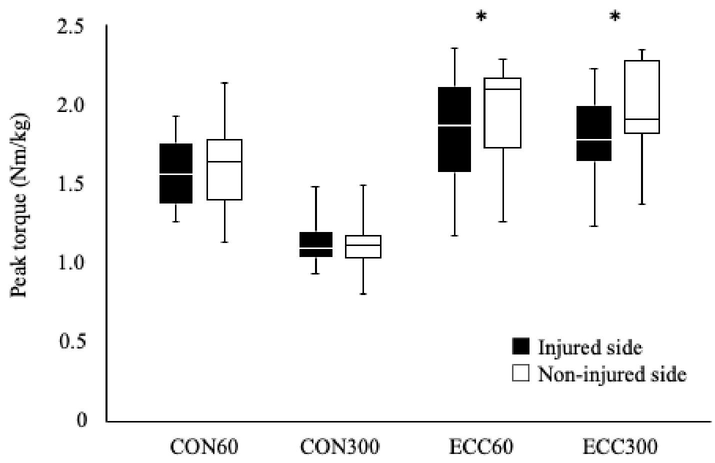

Fig. 3. Boxplots of peak torque on injured and non-injured sides with type of muscle action and angular velocity

CON60: concentric at 60°/sec; CON300: concentric at 300°/sec; ECC60: eccentric at 60°/sec; ECC300: eccentric at 300°/sec.

The solid horizontal line of each boxplot indicates the median.

* indicates $p < 0.05$.

Table 3. Peak knee flexor torque on the injured and the non-injured sides

	Injured	Non-injured	Mean difference (95%CI)	*p*	d_z
CON60	1.569 ± 0.230	1.610 ± 0.278	-4.116 (-14.581 to 6.348)	0.408	0.238
CON300	1.123 ± 0.146	1.091 ± 0.175	3.199 (-6.168 to 12.566)	0.471	0.206
ECC60	1.810 ± 0.378	1.961 ± 0.305	-15.143 (-30.115 to -0.171)	0.048*	0.611
ECC300	1.780 ± 0.274	1.961 ± 0.305	-18.108 (-27.882 to -8.333)	0.002*	1.120

The data are presented as the mean ± SD.

* $p < 0.05$

CON60, concentric at 60°/sec; CON300, concentric at 300°/sec; ECC60, eccentric at 60°/sec; ECC300, eccentric at 300°/sec.

4. DISCUSSION

The present research investigated the concentric and eccentric angle specific torque of the knee flexors after hamstring strain injury to assess the characteristics of torque angle curve. From the results of this study, the eccentric angle specific to average torque at 60°/sec from 10° to 20° was significantly lower on the injured side compared with the non-injured side. At 300°/sec, average eccentric torque from 10° to 60° of knee flexion in the injured side was lower than in the non-injured side. Furthermore, eccentric peak torque of knee flexors at both 60°/sec and 300°/sec were significantly lower on the injured side than on the non-injured side. It is not clear whether the participants had rehabilitation or compliance after the injury. They returned to full training and competition before the tests. Thus, knee flexor muscle strength after hamstring strain injury can manifest differently depending on muscle action type and angular velocity.

For eccentric knee flexor torque, the peak torque reduction was shown with the largest effect size at 300°/sec ($d_z = 1.120$) and medium to large effect sizes were found with measurement of torque every 10° from 10° to 60° ($d_z = 0.607$ to 0.954). Hamstring strain injury is proposed to occur at the terminal swing phase during high-speed sprinting, which has an eccentric knee flexor and extensor strength over 1,000°/sec (Chumanov et al., 2011; Higashihara et al., 2016; Schache et al., 2012; Sun et al., 2015; Yu et al., 2008).

However, isokinetic knee flexor strength measurement could only be obtained with angular velocities of 300°/s or less in a clinical situation due to low reliability of knee flexor strength measurement over 300°/sec (Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2003). Furthermore, another recent study has shown that the rate of torque development for 100 milliseconds from the onset of contraction was lower on the injured side compared to the uninjured side (Opar et al., 2013b). In this study, a reduction of knee flexor torque was revealed from 10° to 60° at 300°/sec for approximately 200 milliseconds. Therefore, the effects of hamstring strain injury should focus not only on the recovery of eccentric hamstring muscle strength at high angular velocity but also on instantaneous force development. A previous systematic review and meta-analysis of resistance training reported that adaptations after eccentric training were highly specific to the velocity and type of muscle action (Roig et al., 2009). Future studies are needed to confirm the velocity based on eccentric training effects on the instantaneous torque of the knee flexor.

At 60°/sec, eccentric knee flexor strength with close to full knee extension was significantly lower on the injured side as shown with a large effect size ($d_z = 0.825$). The present study results support previous research findings that hamstring muscle strength and electromyography (EMG) activation were both decreased at the hamstring lengthened position after hamstring strain injury (Sole et al., 2011). Previous studies have suggested that hamstring muscles should have sufficient muscle length for eccentric exercises after hamstring injury (Heiderscheit, Sherry, Silder, Chumanov, & Thelen, 2010; Schmitt, Tim, & McHugh, 2012). As such, rehabilitation protocols after hamstring strain injury that emphasize eccentric exercises with lengthened hamstring muscle would be more effective for return-to-play sports than conventional exercises of the hamstrings with lengthening (Askling, Tengvar, Tarassova, & Thorstensson, 2014; Askling, Tengvar, & Thorstensson, 2013). It is important to consider the position during knee extension and hip flexion in which the hamstring muscles is lengthened as it is effective not only for the assessment of hamstring muscle strength but also for building strength after hamstring strain injury. Further research is needed to confirm the effects of eccentric knee flexor training at the hamstring muscle lengthened position with the knee extended position.

To the best of our knowledge, this study is the first to clarify that the eccentric torque-angle curve of the knee flexors at 300°/sec was changed after hamstring strain injury. The characteristics of eccentric torque-angle curve after hamstring strain injury seemed to be different between 60°/sec and 300°/sec. Specific knee flexor weakness was shown with close to full knee extension with hamstring muscles lengthened at 60 °/sec, whereas at a wide range of motion at 300 °/sec. The reason for these differences remains unclear. Any change in knee flexor torque development, such as the torque-angle curve, is caused by the change in musculotendinous stiffness as well as neuromuscular function (Brughelli & Cronin, 2007). In the present study, hamstring viscoelastic properties were not investigated; therefore, it remains unclear whether eccentric knee flexor torque weakness on the injured side was caused by viscoelastic change. Changes in viscoelastic properties of hamstring injured limbs have not been reported in a previous study, but shorter fascicle length of injured biceps femoris compared with the uninjured side was reported (Timmins, Shield, Williams, Lorenzen, & Opar, 2015). The muscle fascicle length can be associated with the force–length relationship, but the evidence is limited (Timmins, Shield, Williams, Lorenzen, & Opar, 2016). On the other hands, neuromuscular changes after hamstring strain injury have been shown in previous studies (Opar, Williams, Timmins, Dear, & Shield, 2013a; Opar et al., 2013b). Eccentric hamstring peak torque and EMG activity were lower on the injured side than on the uninjured side or control (Opar et al., 2013a). The rate of torque development and EMG activity of strained hamstring muscles was significantly lower on the injured side than on the uninjured side (Opar et al., 2013b). It has been suggested that the decrease in maximal voluntary eccentric muscle action and hamstring muscle activation was affected by a neuromuscular inhibitory mechanism (Fyfe, Opar, Williams, & Shield, 2013).

Additionally, maximal voluntary force and hamstring muscle activation close to knee extension during high-velocity eccentric movement decreased (Higashihara, Ono, Kubota, & Fukubayashi, 2010). Therefore, participants have difficulty maintaining a high eccentric force level throughout the motion (Higashihara et al., 2010). Future studies should be conducted to examine the eccentric torque-angle curve at different angular velocities with muscle activation and/or neural excitability.

The strength of this study was that the torque-angle curve at 300°/sec after hamstring injury could be provided with an isokinetic dynamometer sampled at 1,000 Hz. In our pilot study, isokinetic variables were sampled at 100 Hz, such as the default setting of the isokinetic dynamometer. However, the torque-angle curve could not be obtained owing to the insufficient quantity of data. Limitations in the present research should be addressed. First, hamstring strain injury was based on self-reporting by each participant, and the diagnosis of the injury, location, and severity were uncertain. It is also unclear about rehabilitation for the injury. The participants did not report any pain or uncomfortable feeling of hamstring muscles with their sports as well as the measurements of this study. Secondly, the time period after hamstring strain injury varied from 4.5 months to 3 years which might have affected the present results. Since this study had a cross-sectional design, the risk of re-injury could not be determined. Further exploration of the incidence of injury and the association between eccentric knee flexor torque and re-injury risk should be clarified.

5. CONCLUSION

To the best of our knowledge, this study is the first to reveal the eccentric knee flexor torque-angle curve with different angular velocities after hamstring strain injury and return to full training and competition. At 60°/sec, declines in eccentric torque were observed close to full knee extension. At 300°/sec, declines in eccentric torque were observed at a wider range of knee flexion motion. An inadequate recovery of muscle strength was observed after hamstring strain injury. These results could imply both assessment and rehabilitation of hamstring injuries in clinical practice. Considering the knee flexor strength training, contraction velocity with instantaneous torque outputs at 300°/sec with the hamstring muscles in the lengthened position with the knee close to the extended range, is possibly important.

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