Sport Sci Health (2017) 13:175–181
DOI 10.1007/s11332-016-0337-2

ORIGINAL ARTICLE

Isokinetic assessment of agonist and antagonist strength ratios in collegiate taekwondo athletes: a preliminary study

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Received: 22 October 2016 / Accepted: 1 December 2016 / Published online: 16 February 2017

Abstract
Purpose The purpose of this study was to compare the gender differences in isokinetic hamstring to quadriceps (*H*/*Q*) and hip abductor to adductor (AB/AD) strength ratios at different angular velocities in collegiate taekwondo athletes.
Methods Thirty collegiate taekwondo athletes (15 females and 15 males) participated in this study. Maximal isokinetic hamstring and quadriceps strengths were measured at different angular velocity (60° s^{-1}, 120° s^{-1}, and 240° s^{-1}) with isokinetic dynamometer (Cybex 770, USA). They also performed five isokinetic hip abductor and adductor contractions at 30° s^{-1}, and 60° s^{-1} on a following day.
Results Female athletes showed significantly lower in *H*/*Q* peak torque ratios than male athletes at 60° s^{-1} (right and left, $p < 0.05$) and 120° s^{-1} (right and left, $p < 0.05$). This difference was disappeared at high angular velocity (240° s^{-1}) when female athletes significantly increased the *H*/*Q* peak torque ratio as angular velocity increased (right and left, $p < 0.05$). However, there were no significant differences in hip AB/AD peak torque ratios between male and female.
Conclusions This preliminary study revealed that female taekwondo athletes show lower *H*/*Q* peak torque ratio than male athletes at slow angular velocity. The previous studies suggest that lower *H*/*Q* peak torque ratio could increase the potential risk of lower limb injuries especially female TKD athletes. Therefore, applications of additional training specially designed for strengthening hamstring muscles are recommended in clinical setting.

Keywords Taekwondo · Agonist to antagonist strength ratio · *H*/*Q* peak torque ratio · AB/AD peak torque ratio

Introduction

The assessment of isokinetic muscle strength is widely used to evaluate the muscle performance and for the purpose of rehabilitation [1, 2]. It also provides the information of ratios between agonist and antagonist muscle strength. In particular, hamstring to quadriceps (*H*/*Q*) peak torque ratio has received a lot of attention for rehabilitation and physical conditioning, because the low *H*/*Q* peak torque ratio can increase the risk of non-contact movement injuries [3, 4].

It is commonly accepted that the average *H*/*Q* peak torque ratios are ranged from 50 to 80% depending on different angular velocities and positions in healthy adults [1, 5]. There are various factors including gender, age, and sports types influence the result of *H*/*Q* ratio [1, 2, 6, 7]. Men typically show significant higher *H*/*Q* ratio than female [6]. A greater gender difference in *H*/*Q* ratio was observed during adolescence than adulthood [7]. This imbalanced *H*/*Q* ratio could attribute the incidence of

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anterior cruciate ligament (ACL) injury especially in female athletes. Hewett and colleagues reported that female athletes have suffered with knee injury ranged from 1.3 to 5.8 times more than male athletes [8]. Hence, the assessment of *H*/*Q* peak torque ratio may play important role in evaluating the predisposition to knee injury. However, a recent study found that there were no significant differences in *H*/*Q* ratio between healthy male and female [9]. The *H*/*Q* ratios were not differed between gender in judo and handball athletes while female soccer athletes show lower value of *H*/*Q* ratio than male athletes [2]. In addition, inconsistence results were observed by different angular velocities [2, 6]. Therefore, more investigations are required to identify the *H*/*Q* ratios by gender and different angular velocities.

In recent years, researchers reported that imbalanced hip abductor and adductor (AB/AD) peak torque ratio is also associated with the incidence of knee ligament injuries [10–12]. Hip abductor muscle strength has known to assist the varus–valgus position of knee joint. However, decreased hip abductor muscle strength may change the knee position during jumping to landing motion that may increase the risk of ACL injuries [12]. Padua et al. found that hip abductor muscle strength was a predictor of knee valgus alignments during a box-drop jumping [13]. Therefore, the balanced hip abductor and adductor muscle strength may prevent the knee valgus displacement during dynamic movements. However, little is known about the AB/AD torque ratios in taekwondo athletes.

Taekwondo (TKD) is an Olympic combat sport originated from Korean martial art. TKD competition is characterized by high intensity interval movements and over 90% points are earned by various kicking techniques [14]. The intensity of taekwondo competition and training was reported as over 85% of maximal heart rate, 7.5–11.9 mmol L^{-1} of blood lactate concentration, and 11–14 scales of rate of perceived exertion (RPE) [15–17]. Taekwondo training involves various movements such as jumping, skipping, and kicking to improve both technical and tactical skills as well as to enhance the lower limb's power, strength, and endurance [16]. In relation to injuries, Pieter et al. demonstrated that over 50% of injuries are occurred in lower limbs during TKD training and competition [18]. Therefore, the evaluation of lower limb muscle strength ratios between agonist and antagonist muscle may play an important role in preventing injuries and optimizing performance.

Although, more possibility in lower limb injuries is exposed during contact movements, non-contact movements also could induce the lower limb injuries such as ligament injuries and hamstring strain. For instance, stepping requires the balance between hamstring and quadriceps strength to change the direction quickly. Hamstring strength plays a function of 'brake motion' to change the direction. However, imbalanced *H*/*Q* ratio can decrease stability of knee; thus, potential risk of knee ligament injuries will be increased. In addition, hamstring strain is thought to occur during late swing phase of kicking when the hamstrings are at peak stretch to prepare the next combination kicking movements [19].

Currently, many studies related to *H*/*Q* peak torque ratios have been conducted, but there are only few studies investigated using TKD athletes even though over 90% techniques in TKD involves lower limbs movements. In addition, this study is the first investigation that examines both *H*/*Q* and AB/AD peak torque ratios in TKD athletes. Therefore, the purpose of this study was to compare the isokinetic *H*/*Q* and hip AB/AD peak torque ratios between male and female TKD athletes by different angular velocities. We hypothesized that male TKD athletes would have greater *H*/*Q* and AB/AD peak torque ratio than female TKD athletes.

Methods

Participants

Thirty collegiate TKD athletes (15 males and 15 females) voluntarily participated in this study. All athletes have been training 4 h day^{-1}, 5 times a week for at least 5 years. They were belonged to the division I group under the Korea Taekwondo Association (KTA). All athletes had no history of knee ligament injury or muscular damage for past 6 months. The detail procedures of the study were explained, and informed consent was obtained from all individual participants included in the study. This study was approved by the Institutional Ethics Review Board of the University. The characteristics of the participants are described in Table 1.

Procedure

Participants were asked to prohibit severe exercise two days before the test. Height (STDK Model 1, Japan), body weight (CAS, Korea), and body composition (dual-energy

Table 1 Characteristics of participants

	Male ($N = 15$)	Female ($N = 15$)
Age (years)	19.4 ± 0.99	19.1 ± 1.13
Height (cm)	178.0 ± 9.84	169.8 ± 6.30
Body weight (kg)	72.9 ± 9.95	61.4 ± 9.10
Percent body fat (%)	12.4 ± 2.24	23.4 ± 3.63
Lean tissue (kg)	59.7 ± 8.47	43.9 ± 5.31
Fat tissue (kg)	8.9 ± 1.95	14.4 ± 3.94

X-ray absorptiometry, DXA: Hologic, QDR-4500W, USA) were measured. DXA was calibrated daily with phantom, and the coefficient of variance was maintained less than 1.5%. Each participant wore comfortable clothes without any metal. Whole body scanning was taken for 7 min and the results were analyzed with technician.

The muscle strength was measured with isokinetic dynamometer (Cybex, 770 Norm, USA). Participants were asked to prohibit severe training at least 48 h before the experiment. Prior to conducting the isokinetic strength test, participants warmed up for 5 min including stretching and light jogging. Then, participants seated on the isokinetic dynamometer with their hip flexed at approximately 85° and upper body (trunk and waist) was stabilized with standard strapping to minimize movements. The length of lever arm was determined individually and resistance pad was placed at the proximal malleolus. Gravity correction was performed each leg before measurement. Five maximal isokinetic quadriceps and hamstring contraction of each leg was performed at three different angular velocities (60, 120, and 240° s^{-1}) with 1-min interval between trials. Each isokinetic contraction was performed through a full range of motion; the *H*/*Q* peak torque ratio was calculated as [(hamstring strength) ÷ (quadriceps strength) × 100].

On a following day, the maximal hip abduction and adduction strength was measured with side lying position (Fig. 1). To stabilize the position, participant's opponent leg and trunk were immobilized with strap band. Resistance pad was placed above proximal to the knee joint. The test leg was placed in approximately 5° of hip flexion. Gravity correction was performed with each leg. Each participant performed five maximal concentric contractions of hip adduction and abduction at two different angular velocities (30° s^{-1} and 60° s^{-1}) with 1-min interval. The highest peak torque was normalized with body weight (Nm kg^{-1}) and the AB/AD peak torque ratio was calculated as [(abduction strength) ÷ (adduction strength) × 100].

Fig. 1 Side lying position

Statistical analysis

All data were expressed as means and standard deviation. Independent *t* test was applied using with SPSS 22 to compare the gender difference in *H*/*Q* and hip AD/AB peak torque ratios. Cohen's *d* effect size was calculated. Repeated measures ANOVA was used to determine the difference in *H*/*Q* peak torque ratio among different angular velocity. Statistical significant level was set at 0.05.

Results

The *H*/*Q* peak torque ratios are described in Table 2. The *H*/*Q* ratios were range from 52.4 to 68.3% in collegiate TKD athletes. There was a significant gender difference in *H*/*Q* peak torque ratio ($p < 0.05$). Female athletes showed significantly lower *H*/*Q* peak torque ratio than male athletes at low (60° s^{-1}) and mid (120° s^{-1}) angular velocities (right, left, $p < 0.05$, respectively). However, there was no significant gender difference at high angular velocity (240° s^{-1}).

The changes of *H*/*Q* peak torque ratio at different angular velocities are described in Fig. 2. The *H*/*Q* peak torque ratio significantly increased as angular velocity increased in female athletes ($p < 0.05$). However, there were no significant differences in *H*/*Q* peak torque ratios in male athletes among different angular velocities.

The AB/AD peak torque ratios are presented in Table 3. The AB/AD peak torque ratios were range from 78.3 to 89.3% in collegiate TKD athletes. There were no

Table 2 Gender differences of *H*/*Q* peak torque ratios in collegiate taekwondo athletes

H/*Q* ratio (%)	Female ($N = 15$)	Male ($N = 15$)	*t* value	ES
60° s^{-1}				
Right	52.4 ± 7.10	62.8 ± 8.88	3.36*	1.29
Left	52.8 ± 5.76	59.4 ± 7.52	2.67*	0.99
120° s^{-1}				
Right	56.8 ± 9.33	66.2 ± 9.12	2.79*	1.02
Left	57.7 ± 6.59	64.1 ± 7.53	2.46*	0.90
240° s^{-1}				
Right	62.1 ± 13.11	68.3 ± 8.82	1.53	0.55
Left	61.7 ± 11.19	64.5 ± 8.46	0.75	0.28

ES effect size

* Significant different between male and female athletes, $p < 0.05$

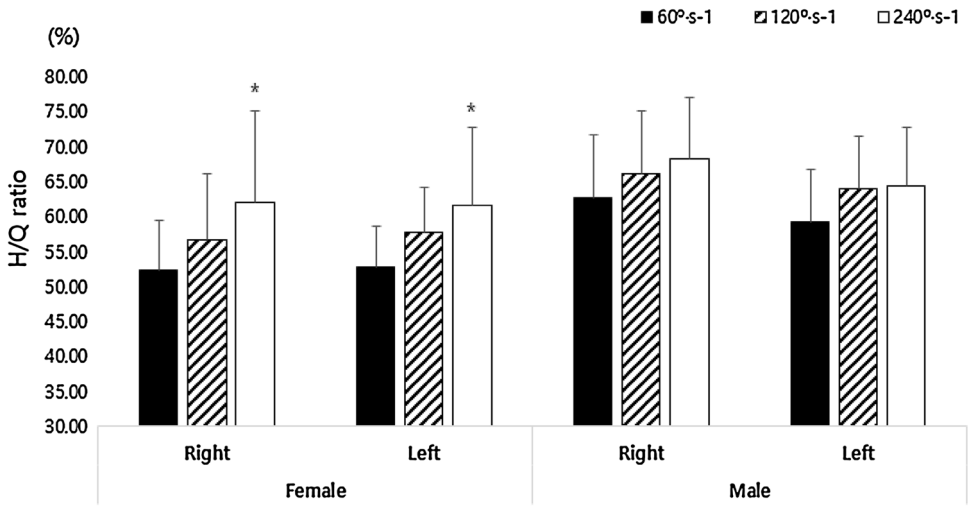

Fig. 2 The differences of *H/Q* peak torque ratio by different angular velocities in collegiate taekwondo athletes. *Significant differences between 60° s^{-1} and 240° s^{-1} in female athletes, $p < 0.05$

significant differences in hip AB/AD peak torque ratio between male and female athletes at both 30° and 60° velocity.

Discussion

This present study was investigated to compare the gender differences of *H/Q* and hip AB/AD peak torque ratios in collegiate taekwondo athletes. To the best of our knowledge, this is the first approach to evaluate the both *H/Q* and hip AB/AD peak torque ratios in collegiate taekwondo athletes. Our main findings are as follows: (1) female athletes showed significantly lower *H/Q* peak torque ratios at low (60° s^{-1}) and mid (120° s^{-1}) angular velocity than male athletes. However, this difference was disappeared at high angular velocity (240° s^{-1}) when female athletes significantly increased the *H/Q* peak torque ratio as angular velocity increased (right and left, $p < 0.05$); (2) there were no significant gender difference in hip AB/AD peak torque ratios.

Gender difference

The ratios between agonist and antagonist muscle strength have received a lot of attention in the field of rehabilitation [20]. In particular, monitoring *H/Q* peak torque ratio provides the information for predisposition to injury [1]. In the current study, the *H/Q* peak torque ratio was significantly lower in female than male athletes. Previous studies supported our results that female athletes showed relatively lower in *H/Q* peak torque ratio compared to male athletes [2, 21]. Female soccer athletes also revealed significantly lower *H/Q* peak torque ratio than male athletes [2]. El-Ashker et al. implemented the hamstrings and quadriceps strength at three different angular velocity conditions (60° s^{-1}, 180° s^{-1}, 300° s^{-1}) and found that female had lower *H/Q* peak torque ratio in all conditions compared to male [21]. Many researchers pointed out that decreased hamstring strength and low *H/Q* peak torque ratio in female athletes are associated with neuromuscular development during adolescence [22–24]. Boys increase relatively large in hamstring strength (boys; 179 vs girls; 24%) comparing to quadriceps strength (boys; 148 vs girl; 44%) during adolescence [24]. These imbalanced neuromuscular functions in female athletes were correlated with incidence of low extremity injury including ACL injury and hamstring strain [4]. It is commonly known that decreased the *H/Q* peak torque ratio below 50–60% may increase the risk of predisposition to ACL injury [25]. The *H/Q* peak torque ratios in our female athletes were ranged from 52 to 61% that might have more possibility for lower limb injuries. A

Table 3 Gender differences of hip AB/AD peak torque ratios in collegiate taekwondo athletes

AB/AD ratio (%)	Female ($N = 15$)	Male ($N = 15$)	t value	ES
30° s^{-1}				
Right	79.3 ± 22.04	78.3 ± 16.24	0.13	0.05
Left	82.2 ± 11.15	81.3 ± 17.67	0.15	0.06
60° s^{-1}				
Right	83.0 ± 19.40	84.6 ± 19.00	0.24	0.08
Left	87.7 ± 10.52	89.3 ± 18.90	0.28	0.10

ES effect size

recent study reported that the incidence of non-contact leg injury was significantly higher who had lower *H*/*Q* peak torque ratio (<60%) in basketball athletes [26]. These imbalanced *H*/*Q* peak torque ratios may decrease the ability to control anterior–posterior axis motion which lead to high incidence of knee injury in female athletes [27]. Moreover, it has been also suggested that a highly developed quadriceps muscle contributes to decreased antagonist hamstrings co-activation [28].

Angular differences

In the present study, female athletes increased *H*/*Q* peak torque ratio as angular velocity increased. Similar results were observed in previous studies [1, 2]. Eighty-one collegiate male and female athletes (basketball, soccer, softball, and volley ball) increased the *H*/*Q* peak torque ratio as angular velocity increased [1]. In other sports, such as judo and handball, female athletes also showed higher *H*/*Q* peak torque ratio at high angular velocity than low angular velocity [2]. A previous study has found that muscle force was adversely related with velocity [29]. We assumed that increasing velocity may decrease relatively large in quadriceps muscle strength than hamstrings thus, the *H*/*Q* peak torque ratio might increase in female athletes.

The importance of *H*/*Q* peak torque ratios in TKD athletes

Taekwondo competition is an Olympic combat sport which characterized with high intensity intermittent movements with various kicking techniques [14]. The current study showed that female TKD athletes have lower *H*/*Q* peak torque ratios than male athletes at slow angular velocities (60° s^{-1}, 120° s^{-1}). The gender difference of these muscle strength ratios was thought to be different activity patterns between male and female athletes [17]. A previous study reported that fatigue resistance was different between genders after TKD competition in youth athletes, where only male TKD athletes increased countermovement jump [17]. We assume that gender-related differences according to the training status and hormonal regulation may influence [17, 30] the consequences of neuromuscular activation such as *H*/*Q* peak torque ratios. The prevalence of low extremity injuries represents over 50% which explain the major injury body part during TKD training and competition [18, 31]. For instance, TKD athletes perform various kicking combined with stepping, jumping, and turning movements for leading out the opponent motion that bring the opportunity of point chance. These non-contact movements involve many close kinetic chain motions that involve potential risk of non-contact lower limb injuries. Moreover, the incidence of hamstring strain often observed not only lack of flexibility but also decrease in hamstring strength [19]. Although, male TKD athletes showed greater *H*/*Q* ratios than female athletes in current study, both the athletes had relatively low *H*/*Q* peak torque ratios ranged from 50 to 60%. This ratio showed similar pattern with previous collegiate sports athletes [1]. However, our participants showed relatively lower *H*/*Q* peak torque ratio compared to judo athletes (male; 69%, female; 72%) in the previous study [2]. We believed that these differences between different sports are due to the training adaptations, level of competition, and sports characteristics. For instance, judo training involves various pulling movements which stimulate hamstring contractions whereas taekwondo training involves many extending movements which more stimulate quadriceps contraction. Therefore, we suggest that taekwondo training should involve special training program for stimulating antagonist (hamstrings) muscle contraction. In addition, this study was conducted during post-season periods which training intensity and volume were relatively lower than pre- or season periods. A previous study reported that athletes who participate regular training show significant improvement in hamstring strength than their counterpart [32].

AB/AD peak torque ratios

Accompanying with *H*/*Q* peak torque ratios, hip AB/AD peak torque ratios have shown to relate with non-contact knee injury mechanisms [10–12]. In particular, hip-abductor muscle strength plays important role for valgus-knee alignments during dynamic movements [11]. It has been also suggested that wider pelvis with weak abductor muscle strength may lead to greater kinematic alteration especially coronal and frontal plane in female athletes. In the current study, no significant differences in hip AB/AD peak torque ratios were observed between male and female athlete at both 30° and 60° velocities. Sugimoto and colleagues conducted isokinetic hip abductor and abductor strength test in healthy male and female subjects and found no significant gender difference in hip AB/AD peak torque ratio [10]. Our study also did not find any differences between genders. However, this study showed higher mean hip AB/AD peak torque ratios value (male: 78.3–89.3%, female: 79.3–89.7%) compared to previous study (male: 64%, female: 57%) [10]. We assumed that different angular velocity and TKD characteristics may result in high hip AB/AD peak torque ratios in TKD athletes. Taekwondo kicking, such as spin hook kick and push kick, involves the various movements of hip extension, flexion, abduction, and adduction thereby hip abductors and adductors muscles are constantly stimulated. Moreover, TKD athletes' hip abductor and adductor muscles may be

well balanced because the support leg should be stabilized not only for kicking forcefully but also maintaining balance. Therefore, our TKD athletes show relatively high in AB/AD peak torque ratios compared to previous study which might less affect the risk of valgus displacement.

Limitation and suggestion

This study was conducted with traditional knee strength (Hcon/Qcon) ratio methods, although recent studies suggest that dynamic control ratios (DCR, Hecc/Qcon) are more appropriate assessment tool for evaluating the risk of ACL injury and hamstring strain [33, 34]. However, previous study demonstrated that Hcon/Qcon ratio revealed the similar result compared with Hecc/Qcon ratios [35]. Nevertheless, this limitation should be considered. In addition, this study was conducted as a preliminary Study, therefore future study should be monitored the prevalence of non-contact low limb injuries during training and competition.

Conclusion

Our study revealed that female athletes have lower *H*/*Q* peak torque ratio at low (60 s^{-1}) and mid (120 s^{-1}) angular velocities than male athletes. However, there were no gender differences in AB/AD peak torque ratios. However, there was no gender difference in *H*/*Q* peak torque ratio at high angular velocity (240° s^{-1}) and AB/AD peak torque ratios. The previous studies suggest that lower *H*/*Q* peak torque ratio could increase the potential risk of lower limb injuries especially female TKD athletes. Therefore, applications of additional training specially designed for strengthening hamstring muscles are recommended in clinical setting.

Acknowledgements This study was conducted without any financial assistance. We would like to express our gratitude to volunteers, research assistants, coaches, and athletes who were involved in this research project.

Compliance with ethical standards

Conflict of interest The authors declare that there was no conflict of interest regarding publication in this study.

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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