Rapid hamstrings/quadriceps strength capacity in professional soccer players with different conventional isokinetic muscle strength ratios

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Abstract

Muscle strength imbalance can be an important factor in hamstrings muscle strain. A hamstrings/quadriceps (H/Q) strength ratio based on concentric peak torque values ($H_{con}:Q_{con}$) has traditionally been used to describe the potential for knee-joint destabilization. Because certain standard actions in soccer are explosive, the analysis of the H/Q strength ratio based on the rate of torque development ($H_{rtd}:Q_{rtd}$) might also be useful in the evaluation of joint stability. The objective of this study was to compare the $H_{rtd}:Q_{rtd}$ between professional soccer players with heterogeneous values of $H_{con}:Q_{con}$. Thirty-nine professional soccer players took part in the following procedures on different days: 1) Familiarization session with the isokinetic dynamometer, and 2) Two maximal isometric actions and five maximal concentric actions at $60°·s^{-1}$ for hamstrings (H) and quadriceps (Q). Participants were ranked according to their $H_{con}:Q_{con}$ ratio. The median third was excluded to form a high torque group (HTG), and a low torque group (LTG). Peak isometric (H) and concentric (H and Q) torques and rate of torque development (H) were significantly greater in the HTG group. Similarly, $H_{con}:Q_{con}$ (0.68 ± 0.02 *vs.* 0.52 ± 0.03) and $H_{rtd}:Q_{rtd}$ (0.54 ± 0.12 *vs.* 0.43 ± 0.16) were significantly greater in the HTG group than in the LTG group. There was no significant correlation between $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$. It can be concluded that $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ are determined, but not fully defined, by shared putative physiological mechanisms. Thus, the physiologic and clinical significance of $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ to an athlete's individual evaluation might be different.

Key words: Muscular torque, isometric action, injury.

Introduction

Although aerobic metabolism predominates as the mechanism of glucose utilization during most soccer games, explosive, anaerobic maneuvers (sprints, jumping and tackles) are often decisive events that lead to scoring during a game. During a match, elite players typically cover a total distance of 9-12 km, changing their activity or direction every 4-6 s (Mohr et al., 2003; Stølen et al., 2005). The constant, dynamic nature of their activity explains, to some extent, the relatively high rates of injury among professional soccer players compared with participants in other sports and occupations (Hawkins et al., 1999). Epidemiological studies have demonstrated that muscular strain is one of the primary injuries sustained in professional soccer. Indeed, Woods et al. (2004) found that hamstrings strains accounted for 12% of all injuries sustained over two seasons, resulting in 15 matches and 90 days missed per club per season on average. Moreover, the recurrence rate for hamstrings injuries (12%) was

significantly greater than the re-injury rate for all other injuries (7%). Thus, many researchers (Hawkins et al., 2001; Hewett et al., 1999; Small et al., 2009), associations (Woods et al., 2004) and clubs have proposed the establishment of injury prevention and rehabilitation programs, aiming to minimize the impact of injuries on both the health and performance of soccer players.

Although hamstrings injuries are often multifactorial in origin, epidemiological evidence suggests that poor eccentric muscular strength and muscle strength imbalance play a central role in acute focal muscle injuries (Croisier et al., 2008). Croisier et al. (2008) have demonstrated that players with strength imbalances were 4 to 5 times more likely to sustain a hamstrings injury when compared with a normal control group. Strength imbalance traditionally has been assessed by determining the conventional concentric hamstrings:quadriceps ratio ($H_{con}:Q_{con}$) and the functional eccentric hamstrings :concentric quadriceps ratio ($H_{ecc}:Q_{con}$) using peak torque values during a maximal voluntary contraction (MVC) (Camarda and Denadai, 2012; Kannus, 1994). However, the typical timing (50-250 ms) of explosive movements (e.g., jumping and sprint running) may not allow for maximal muscle force to be reached (Aagaard et al., 2002). Moreover, usually only a short amount of time (< 50 ms) exists to stabilize the knee joint during rapid match play situations (Krosshaug et al., 2007). Thus, Zebis et al. (2011) have recently hypothesized that the $H_{con}:Q_{con}$ and $H_{ecc}:Q_{con}$ ratios may not reflect the potential to stabilize the knee joint during explosive movements.

The rate of torque development (RTD) has been used to describe the ability to generate explosive strength, which may be essential to sports performance and to performing functional tasks (Aagaard et al., 2002). The RTD is the slope of the nonlinear torque-time curve (Δtorque/Δtime), and its maximal values are attained during the window of time between 80-120 ms (Corvino et al., 2009). Based on these aspects, Zebis et al. (2011) have recently introduced the RTD hamstrings:quadriceps strength ratio ($H_{rtd}:Q_{rtd}$) to assess the potential for knee joint stabilization during the explosive movements of elite soccer players. However, the validity of this method as a clinical screening tool has not been extensively studied.

Considering that 1) the $H_{con}:Q_{con}$ ratio has been utilized as an indicator of muscle strength imbalance (Heiser et al., 1984; Kim and Hong, 2011) and that 2) the correlation between the early phase RTD (<100 ms from the onset of contraction) during MVC and the maximal force achievable is moderate ($r = 0.45$-0.60) (Andersen and Aagaard, 2006), it is reasonable to hypothesize that a

direct relationship might exist between H_{con}:Q_{con} and H_{rtd}:Q_{rtd}. Thus, the aims of this study were a) to compare the H_{rtd}:Q_{rtd} ratios between professional soccer players with heterogeneous values for H_{con}:Q_{con}, and b) to determine whether any correlation exists between the H_{con}:Q_{con} and H_{rtd}:Q_{rtd} ratios in this group.

Methods

Thirty-nine male professional soccer players (24.2 ± 3.5 years, 74.3 ± 7.8 kg, 1.78 ± .08 m), with at least 5 years of experience each in the sport (4 practices and 1-2 matches per week), volunteered for the study. According to the team's medical staff, all of the players included in this investigation were injury-free at the time of testing. In addition, an injury report form was used to determine each players' past history of major injuries to any knee joint structures (bone, ligament, muscle, tendon), and those with previous knee or thigh muscle injuries were excluded from the study. All risks associated with the experimental procedures were explained prior to the initiation of the players' involvement in the study, and each participant completed a written informed consent. The experiments were conducted in accordance with the Helsinki Declaration and approved by the local ethics committee.

Experimental design
The participants were instructed to report to the laboratory at the same time (± 2 h) on two separate days within a period of 1-2 weeks. Each participant was required to attend a laboratory orientation session to lessen the effects of learning on subsequent strength testing. During this session, each participant completed 2 maximal isometric actions and 5 maximal concentric actions for knee extensors (KE) and knee flexors (KF) on a Biodex isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, N.Y.) at $60°·s^{-1}$. On the second visit, athletes performed maximal isokinetic concentric actions (at $60°·s^{-1}$) and maximal isometric actions on a Biodex isokinetic dynamometer. Upon study completion, participants were ranked according to their H_{con}:Q_{con} ratio, which was prioritized as the primary indicator of muscle strength imbalance (Heiser et al., 1984; Kim and Hong, 2011). The median third was excluded to form a high torque group (HTG, n = 13), and a low torque group (LTG, n = 13). There was no overlap in the H_{con}:Q_{con} values between the groups.

Procedures
Isokinetic and isometric testing
Participants were placed in a sitting position and securely strapped into the test chair. Extraneous movement of the upper body was limited by two cross-shoulder harnesses and an abdomen belt. The trunk/thigh angle was set at 85°. The axis of the dynamometer was aligned with the right knee flexion-extension axis, and the lever arm was attached to the participant's shank with a strap. Participants were asked to relax their leg so that the effects of gravity on the passive limb and lever arm could be measured. The range of motion (ROM) for the knee test was

70° [from 90° to 20° knee flexion (0° = full extension)]. To ensure full extension of the knee, the anatomical 90° position was identified by manual measurement with a goniometer. Concentric measurements involved five continuous, reciprocal (maximal) knee extensions–flexions, which were performed at $60°·s^{-1}$. Isometric tests were conducted using the same equipment and positioning, and participants were instructed to sustain 5-second maximal isometric actions for KE and KF at a fixed knee joint position of 70° (Zebis et al., 2011). For each type of muscle action (i.e., isometric knee flexion and extension), 2 maximal trials were performed, separated by a rest period of 60 seconds. These tests (i.e., isometric and concentric) were performed in random order, using only the dominant (preferred kicking) limb and a five-minute recovery was allowed between them. Instructions were given to the subjects to perform all actions as fast and forceful as possible to obtain both maximal torque and RTD.

Data processing
Isokinetic actions
The isokinetic data were analyzed using specific algorithms created in the MatLab Environment (The Math-Works, Natick, Massachusetts, USA). Torque curves were smoothed using a 10 Hz Butterworth fourth-order zero-lag filter. The action yielding the highest torque value produced from 5 individual efforts was used for further analysis. The peak torque was calculated as the average torque achieved over a range of 10° around the angle at which the highest torque value was reached (Oliveira et al., 2010). The following parameters were obtained: peak torques of the quadriceps and hamstrings and a conventional H_{con}:Q_{con} ratio for the dominant leg.

Isometric actions
Torque curves were smoothed using a 10 Hz Butterworth fourth-order zero lag filter. The highest torque achieved between the 2 isometric actions was considered to be the peak torque. The peak torque was calculated as the average torque over a 1-s period around the torque plateau level. RTD (Nm/s) was defined as the slope of the torque–time curve (i.e., Δtorque/Δtime) at incremental time intervals of 0-50 ms, starting from the onset of contraction (Aagaard et al., 2002). Onset of muscle action was deemed to have occurred once the torque level exceeded the baseline at rest by >7.5 N·m.

Statistical analysis
Data are presented as the mean ± SD values. The distribution of dependent variables was examined by the Shapiro-Wilk test. A t-test was performed to test the null hypothesis that the HTG and LTG groups were similar. The magnitude of the difference between H_{con}:Q_{con} and H_{rtd}:Q_{rtd} was determined by calculating the effect size (ES) (Cohen, 1988). Pearson product-moment correlation was calculated to evaluate the association between H_{con}:Q_{con} and H_{rtd}:Q_{rtd}. Statistical significance was set at $p \leq 0.05$.

## Results

Table 1 presents the mean ± SD values of the variables

Table 1. Mean value (±SD) of the variables obtained during isometric and isokinetic tests of hamstrings and quadriceps for the upper- (HTG) and lower-third (LTG) values groups.

Parameter	Overall N = 39	HTG N = 13	LTG N = 13	ES
Hisom (Nm)	157.3 (26.7)	172.8 (19.0)	141.1 (39.1) *	1.01
Qisom (Nm)	303.8 (41.7)	301.4 (39.6)	292.3 (41.7)	.22
Hcon (Nm)	153.6 (20.6)	163.6 (16.7)	137.3 (18.7) *	1.52
Qcon (Nm)	255.3 (29.4)	240.4 (24.3)	259.6 (27.9) *	.74
Hrtd (Nm.s^{-1})	915.5 (399.1)	1047.0 (405.0)	806.9 (349.4) *	.64
Qrtd (Nm.s^{-1})	1921.1 (549.4)	1929.1 (590.0)	1862.1 (504.0)	.12

Hisom - peak isometric torque of hamstrings; Qisom - peak isometric torque of quadriceps; Hcon - peak concentric torque of hamstrings; Q - peak concentric torque of quadriceps; Hrtd - rate of torque development of hamstrings; Qrtd - rate of torque development of quadriceps; ES - effect size. * $p < 0.05$ in relation to HTG group.

obtained during isometric and isokinetic tests of H and Q. Peak isometric torque (H), peak concentric torque (H and Q) and RTD (H) were significantly greater in the HTG group than in the LTG group ($p < 0.05$). The peak torque angle of H ($34.6 \pm 2.7°$ *vs.* $34.1 \pm 2.1°$) and Q ($71.5 \pm 4.5°$ *vs.* $70.7 \pm 4.1°$) was not significant different between HTG and LTG groups, respectively ($p > 0.05$).

Figure 1 presents the mean ± SD values of $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ for the HTG and LTG groups. The mean $H_{con}:Q_{con}$ value was significantly greater in the HTG group ($p < 0.05$, ES = 6.2). Similarly, the mean $H_{rtd}:Q_{rtd}$ value was significantly greater in the HTG group ($p < 0.05$, ES = 0.77).
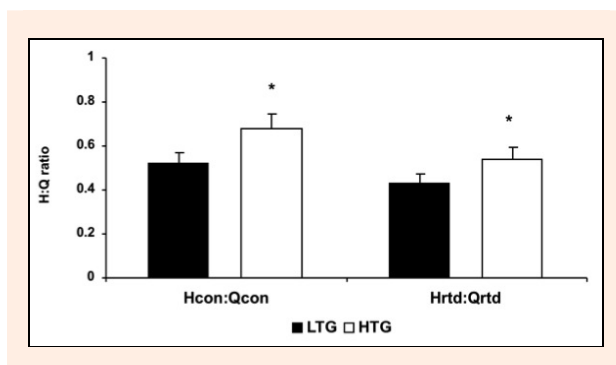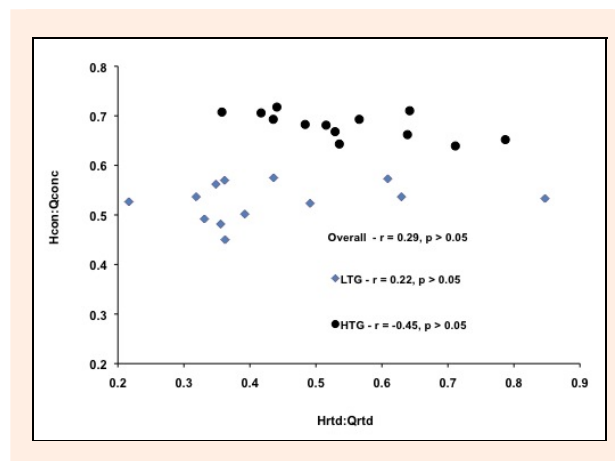

Figure 1. Mean value ± SD of the concentric hamstrings:quadriceps ratio (Hcon:Qcon) and rate of torque development hamstrings:quadriceps strength ratio (Hrtd:Qrtd) for the upper- (HTG) and lower-third (LTG) values groups. * $p < 0.01$ in relation to LTG.

The correlations between $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ in the HTG group (r = - 0.45), the LTG group (r = 0.22) and in the overall sample (r = 0.29) were not statistically significant ($p > 0.05$) (Figure 2).

Discussion

The main objective of this study was to compare the $H_{rtd}:Q_{rtd}$ ratios among professional soccer players who have heterogeneous values for $H_{con}:Q_{con}$. Because maximal strength/torque and RTD likely share some common underlying mechanisms (Andersen and Aagaard, 2006), we hypothesized that $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ could demonstrate a direct relationship in a group of soccer players with heterogeneous values of $H_{con}:Q_{con}$. Indeed, we have found that both $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ were significantly

lesser in the LTG group when compared to the HTG group. However, the correlation between these indices in both groups was not statistically significant, to some extent undermining our initial hypothesis. Thus, the physiological and clinical meanings of the $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ indices for the evaluation of soccer players may be different.

Figure 2. Correlation between the concentric hamstrings:quadriceps ratio (Hcon:Qcon) and rate of torque development hamstrings:quadriceps strength ratio (Hrtd:Qrtd) in both the upper- (HTG) and lower-third (LTG) values groups.

Playing and training for soccer appear to increase the strength of the muscles about the knee joint. Indeed, Gür et al. (1999) and Lehence et al. (2009) have demonstrated higher concentric and eccentric peak torque values of knee flexors and concentric peak torque of knee extensors in adult soccer players when compared with junior soccer players. Due to repetitive nature of the soccer-specific activities, the magnitude of the improvement of muscle strength may favor the greater development of the quadriceps muscles compared with the hamstrings, altering both $H_{con}:Q_{con}$ and $H_{ecc}:Q_{con}$. However, Gür et al. (1999) have demonstrated that $H_{ecc}:Q_{con}$ was higher in adult players (> 21 years) than young players (< 21 years) only at the dominant knee. Additionally, Lehence et al. (2009) have found higher percentage of lower limb muscular imbalance within junior players (< 17 years - 61%; < 21 years - 58%) than adult players (50%). Thus, training background seems to reduce the muscle imbalance and, consequently, the risk of injury. Moreover, there was

no significant correlation between muscle balance (i.e. $H_{con}:Q_{con}$ and $H_{ecc}:Q_{con}$) and both vertical jumping and 10-m sprint time, which are important components of physical performance during soccer (Lehence et al., 2009). Thus, it seems that peak torque ratio measurements have greater importance for clinical evaluation than performance in soccer.

The $H_{con}:Q_{con}$ has been traditionally used to measure imbalances between anterior and posterior thigh muscles, to predict the risk of hamstrings muscle strain and to assess the efficacy of various rehabilitation programs (Coombs et al., 2002). Indeed, Croisier et al. (2008) have found that players with strength imbalances were 4 to 5 times more likely to sustain a hamstrings injury when compared with players without strength imbalances. Moreover, restoring the balance between agonist and antagonist muscle groups significantly decreases the risk of injury. Given the timing of explosive movements (50-250 ms), and the time it takes for the knee joint to stabilize during rapid match play situations (Krosshaug et al., 2007), maximal muscle force may not be reached in these instances (Aagaard et al., 2002). Based on these findings, Zebis et al. (2011) suggest that the $H_{rtd}:Q_{rtd}$ ratio may more accurately reflect the potential for dynamic knee joint stabilization during rapid match situations. Indeed, they found that two athletes presented an anterior cruciate ligament injury within a year of undergoing neuromuscular testing. Interestingly, the H:Q ratios, based on the isometric peak torques produced by these athletes, had been similar to the group mean at the time, but their $H_{rtd}:Q_{rtd}$ values during the initial phase of action (< 50 ms) were markedly low (~40%). The authors speculated that early phase $H_{rtd}:Q_{rtd}$ (< 50 ms) might be useful in identifying players at a potentially greater risk for knee injury.

In our study population (professional athletes with heterogeneous $H_{con}:Q_{con}$ ratios), the mean $H_{rtd}:Q_{rtd}$ ratio in the HTG group was significantly greater than in the LTG group. Indeed, Andersen and Aagaard (2006) have found a moderately positive correlation ($r = 0.45$-0.60) between the RTD in the early phase of contraction (< 100 ms) and maximal torque. This correlation suggests that maximal muscle torque and RTD in the early phase of contraction (<100 ms) may share putative underlying physiological mechanisms (e.g., neural drive). However, we found that the correlations between $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ in the HTG ($r = - 0.45$) and LTG groups ($r = 0.22$) and in the overall sample ($r = 0.29$) were not statistically significant. Three different aspects of muscle dynamics may help to explain these results. First, the type of exercise utilized to determine $H_{con}:Q_{con}$ (isokinetic) and $H_{rtd}:Q_{rtd}$ (isometric) are different, which may complicate efforts to draw direct comparisons between them (Corvino et al., 2009). Basically, isometric and isokinetic muscle actions involve different motor control strategies that modulate torque production. Indeed, Coburn et al. (2005) have suggested that isometric torque production was modulated by both motor unit recruitment and firing rate, while for isokinetic concentric peak torque was modulated mainly by the motor unit recruitment. Moreover, some studies with different experimental focuses (i.e., strength training, muscular damage, previous stretch) (Holtermann et al.,

2007; Molina and Denadai. 2012; Oliveira et al., 2012) have demonstrated that changes in maximal muscle torque are not always accompanied by similar changes in RTD. Finally, it must be emphasized that, unlike maximal muscle torque and RTD, the $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ ratios compare the actions of two distinct muscle groups, which potentially increases the number of factors and combinations of factors that can influence these indices.

Thus, the physiological and clinical meanings of the $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ ratios for screening and longitudinal monitoring efforts may be distinct from one another. Prospective studies should be performed to analyze the isolated and associated potentials of $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ measurements to predict the risk of inferior limb injuries in soccer players. Regardless, rehabilitation programs that seek to normalize the $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ ratios should be geared more specifically toward addressing the H:Q ratio that is most sensitive for the given muscle imbalance.

Conclusion

Based on our findings, it can be concluded that professional soccer players with greater or lesser $H_{con}:Q_{con}$ ratios tend to demonstrate similar trends in their $H_{rtd}:Q_{rtd}$ ratios. However, the lack of any significant correlation between the $H_{con}:Q_{con}$ and $H_{rtd}:Q_{rtd}$ measurements suggests that the physiological and clinical meanings of these ratios in the evaluation of an athlete may be distinct from one another.

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Key points

- Soccer players with high (0.66-0.70) and low (0.50-0.54) conventional concentric hamstrings:quadriceps ratios (H_{con}:Q_{con}) tend to demonstrate similar profiles (i.e., high and low, respectively) in their rate of the torque development H/Q ratio (H_{rtd}:Q_{rtd}).
- The lack of a significant relationship between H_{con}:Q_{con} and H_{rtd}:Q_{rtd} suggests that these ratios are determined, but not fully defined, by shared putative physiological mechanisms.
- Preseason screening programs that monitor hamstrings:quadriceps ratios should recognize that the physiologic and clinical significance of H_{con}:Q_{con} and H_{rfd}:Q_{rfd} to an athlete's individual evaluation might be different.

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