The Relationship between 30-m Sprint Running Time and Muscle Cross-sectional Areas of the Psoas Major and Lower Limb Muscles in Male College Short and Middle Distance Runners

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The purpose of this study was to investigate the relationship between 30-m sprint running time and muscle cross-sectional areas of the psoas major and lower limb muscles. In sixteen male college short and middle distance runners, the muscle anatomical cross-sectional areas (CSAs) of the psoas major, the quadriceps femoris, the hip adductors (ADD), the hamstrings, the triceps surae, and the tibialis anterior and extensor digitorum longus complex (DF) were measured using a magnetic resonance imaging system. In addition, the relative values of CSA to the two-thirds power of body weight (CSA-to-BW²/³) were calculated. A stepwise multiple regression analysis produced a prediction equation ($R^2 = 0.605$) of 30-m sprint running time with explanatory variables of ADD CSA-to-BW²/³ and DF CSA. The ADD CSA-to-BW²/³ had a negative partial regression coefficient ($r = -0.768$, $p < 0.01$) and the DF CSA had a positive partial regression coefficient ($r = 0.526$, $p < 0.05$). From the present results, it is concluded that to have greater hip adductor muscles relative to the body size and smaller dorsiflexors is advantageous for achieving higher performance in 30-m sprint running.

Keywords: Sprint performance, Multi-regression analysis, Magnetic resonance imaging

1. Introduction

Sprint running is a fundamental activity for many sports and improvement of its performance is an essential part of training programs for athletes. In most of sport activities, the distance covered by sprint running is less than 30-m (e.g. Deutsch et al., 1998; Duthie et al., 2003; Spencer et al., 2005). Therefore, the ability of sprint running over short distance is particularly important and to identify its determinant factors is an important research task.

A physical activity is achieved by the force generated by skeletal muscles. Therefore, its performance is affected by the force generation capacity of the working muscle(s) in the activity, and to identify the 'key' muscle(s) is especially important to design the content of training program. So far, several studies have reported how the force generating capacity of the lower limb muscles was related to the performance in sprint running over short distance. For example, Wisløff et al. (2004) found a strong correlation between maximal strength in half squats and 30-m sprint performance in elite soccer players. Cronin and Hansen (2005) also reported that squat jump and countermovement jump heights as well as average power output relative to body mass in 30-kg loaded jump squat were significantly correlated with 30-m sprint running time. In addition, Delecluse (1997) mentioned that individual differences in knee extension and plantar flexion force affect the variability of sprint performance in first 15-m in a 40-m sprint running. Furthermore, Johnson and Buckley (2001) investigated the kinetics of lower
limb at the 14-m point in a 35-m sprint running and concluded that the hip extension in late swing and early stance, concentric knee extension after mid-stance and concentric plantar flexion in late stance serve to generate sprinting speed. From these previous studies, it is expected that the strength and/or power generating capacity of leg extensor muscles is important for sprint running over short distance. However, there is a discrepancy in the relationship between the isokinetic or isometric torque generating capacity of each of hip, knee, and ankle joint and the performance in sprint running over short distance, the reason for which is not clear (e.g., Dowson et al., 1998; Newman et al., 2004; Cronin and Hansen, 2005; Requena et al., 2009).

On the other hand, it is well known that the force generating capacity of a muscle is closely related to its anatomical cross-sectional area (CSA) (Ikai and Fukunaga, 1968). And so, information on the relationship between muscle CSA and sport performances is useful to identify the ‘key’ muscle(s) affecting the performance. There have been a few studies investigating the relationship between sprint running performance and the CSA of the lower limb muscles (Kano et al., 1997; Hoshikawa et al., 2006). However, these studies took the time or mean velocity of 100-m sprint running as sprint running performance, and investigated only a few muscles (i.e., the quadriceps femoris, the hamstrings, and the hip adductors or the psoas major muscles). Therefore, it is still not clear which muscle(s) among the lower limb muscles is important for the performance in sprint running over short distance.

In the present study, 30-m sprint running time (Time30 m) and CSAs of the psoas major and lower limb muscles were measured in male college short and middle distance runners. Considering from the previous reports, it is hypothesized that, among the lower limb muscles, muscularity of the hamstrings, the quadriceps femoris, and the triceps surae muscles is important as they are agonist muscles in hip extension, knee extension and plantar flexion, respectively. The hip extension torque exerted through the mid-swing phase to early-stance phase in an acceleration of sprint running is accompanied by the electromyographic activity of the biceps femoris muscle (Baba et al., 2000). In addition, it has been reported that a great part of hip extension work done in push-off phase of sprint acceleration was accounted by the hamstrings (e.g., Jacobs et al., 1996). Therefore, we regarded the hamstrings as a hip extensor. The present study aimed to investigate how the CSAs of the psoas major and lower limb muscles are related to 30-m sprint running time.

2. Methods
2.1 Subjects

Sixteen male college short and middle distance runners participated in this study. All subjects train for their specialty on a routine basis. The profiles of the subjects are shown in Table 1. The study was conducted according to Declaration of Helsinki. Each subject was fully informed of the procedures to be used as well as the purpose of the study and gave informed consent.

2.2 Muscle anatomical cross-sectional area

Magnetic resonance images of the abdomen, right thigh, and right lower leg were obtained using a 1.5-T magnetic resonance imaging system (Signa 1.5 T, GE, USA) with a body coil to determine the muscle CSAs of the psoas major (PM), the quadriceps femoris (QF), the hip adductors (ADD) including the adductor magnus, the adductor brevis, and the adductor longus, the hamstrings (HAM), the triceps surae (TS), and the dorsiflexors (DF) including the

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Table 1 Profiles of subjects

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Mean 21.6 174.3 64.3
SD 1.3 5.4 5.0
tibialis anterior and extensor digitorum longus of the right side. In all imaging, the subject lay supine on a test bench of the magnetic resonance imaging system and was fixed at the hip and knee with straps. For imaging the abdomen, coronal images were first obtained to identify the positions of the lumbar vertebrae. Then, the cross-sectional image for the measurement of PM was obtained at the position between L4 and L5. During the scan, the subjects held their breath to prevent their abdominal from moving. For imaging the right thigh, coronal images were first obtained to identify the superior and inferior end of the femur. Then, the cross-sectional images for the measurement of ADD, QF, and HAM were obtained at the 30% (upper thigh), 50% (midthigh), and 70% (lower thigh) positions from the superior to the inferior end of the femur, respectively. For imaging the right lower leg, coronal images were first obtained to identify the superior end of the tibia and the lateral malleolus of fibula. Then, the cross-sectional image at the 30% (upper lower leg) position from the superior end of the tibia to the lateral malleolus of fibula was obtained for the measurement of TS and DF. The positions of the cross-sectional imaging were selected as the CSA of each muscle is nearly maximal (PM: Santaguida and McGill, 1995, QF: Akima et al., 1997, ADD: Kano et al., 1997; Masuda et al., 2003, HAM: Akima et al., 1997, TS and DF: Fukunaga et al., 1992). In all cross-sectional imaging, the condition of image acquisition was as follows: Sequence, Spin Echo; TE, 13 ms; TR, 500 ms; FOV, 480/260 mm; Matrix, 512×512. The imaging was conducted at least fifteen hours after a training session. The magnetic resonance images were transferred to a computer and the CSA of the each muscle was calculated using an open source image processing software (OsiriX, v.2.4) (Figure 1). The measurement was performed twice for the same magnetic resonance image and the mean value was used as representative of CSA. The mean coefficient of variance for the repeated measures was within 3%. In addition, the ratio of CSA to two-thirds power of body weight (CSA-to-BW\(^{2/3}\)) was calculated as an index of relative CSA to the body size, because CSA is proportional to the

![Figure 1](image-url)  
**Figure 1** Magnetic resonance images for measuring muscle cross-sectional areas. PM: the psoas major muscle, ADD: the hip adductors, QF: the quadriceps femoris muscle, HAM: the hamstrings, TS: the triceps surae muscle, DF: the tibialis anterior and the extensor digitorum longus complex.
square of body height, while the body weight is proportional to the cube of body height (Åstrand et al., 2003).

2.3 30-m sprint running time

The subject wearing flat shoes performed 30-m sprint running from a standing position on an all weather track. The timing of the start was left to the subjects. The time ($\text{Time}_{30 \text{m}}$) was measured using photo cells set at the 0-m and 30-m positions. Trial was repeated twice and the best time was adapted to the further analysis. The coefficient of variance in the two measurements was $1.1 \pm 0.8\%$.

2.4 Statistics

Descriptive data were represented as means $\pm$ standard deviations (SD). The coefficient of variance (CV) was calculated as $(\text{SD/mean}) \times 100\%$. Pearson’s product-moment correlation coefficient was used to determine the relationships between each of the CSA variables and $\text{Time}_{30 \text{m}}$. In addition, a stepwise multiple-regression analysis was applied to develop a prediction equation for $\text{Time}_{30 \text{m}}$ using the CSA and CSA-to-BW$^{2/3}$ as independent variables. All statistical analyses were performed using PASW Statistics 18.

3. Results

$\text{Time}_{30 \text{m}}$ in all subjects ranged from 3.92 sec to 4.36 sec ($4.16 \pm 0.12$ sec). The CVs for CSA and CSA-to-BW$^{2/3}$ of every muscle group were about $10\%$ (Table 2). Table 3 summarizes the correlation coefficients between $\text{Time}_{30 \text{m}}$ and either CSA or CSA-to-BW$^{2/3}$. Stepwise multiple-regression analysis produced a prediction equation of $\text{Time}_{30 \text{m}}$ as follows: $\text{Time}_{30 \text{m}} = -0.197 \times \text{ADD CSA-to-BW}^{2/3} + 0.039 \times \text{DF CSA} + 4.473$ ($R^2 = 0.605$). Standardized partial regression coefficients for ADD CSA-to-BW$^{2/3}$ and DF CSA were $-0.768$ (p $\leq 0.01$) and $0.526$ (p $< 0.05$), respectively (Table 4). The variance inflation factor was less than 10 for all independent variables. Figure 2 shows the relationship between the measured and predicted time.
Figure 2  Relationship between the measured and predicted time. The predicted time was calculated using the multiple regression equation, \( \text{Time}_{30m} = -0.197 \times \text{ADD CSA-to-BW}^{2/3} + 0.039 \times \text{DF CSA} + 4.473 \). The solid line is the line of identity.

4. Discussion

In the present study, we hypothesized that the muscularity of HAM, QF, and TS would be an important factor for achieving higher performance in sprint running over short distance. However, multiple regression analysis revealed that only the ADD CSA-to-BW\(^{2/3}\) has a positive effect on \( \text{Time}_{30m} \). This result denies the hypothesis and indicates that to have greater hip adductor muscles relative to the body size is advantageous for achieving higher performance in 30-m sprint running.

During acceleration of sprint running, the hip extension torque is exerted from the late-swing to early-stance phase, i.e., around foot contact (Baba et al., 2000; Johnson and Buckley, 2001), and the hip flexion angle at the foot contact is \( \sim 80^\circ \) at the second step of 40-m sprint running (Jacobs and van Ingen Schenau, 1992) and \( \sim 40^\circ \) even at the 60-m point of sprint running (Ito et al., 1997). On the other hand, the adductor magnus muscle acts as a hip extensor through the whole range of hip joint motion and the adductor brevis and the adductor longus muscles also act as hip extensors when the hip joint is flexed more than \( 25^\circ \) and \( 50^\circ \), respectively (Dostal et al., 1986). In addition, the moment arm of the hip adductors for hip extension is longer in the hip flexed positions, while those of other hip extensors such as the gluteus maximus muscle and the hamstrings are shorter in the hip joint flexed positions (Nemeth and Ohlsen, 1985; Dostal et al., 1986; Visser et al., 1990). Considering these, it is likely that the ADD greatly contributes to the exertion of hip extension torque during the late-swing to early-contact phase in sprint running over short distance. On the other hand, the adductor brevis and the adductor longus muscles act as hip flexors when the hip flexion angle is less than \( \sim 25^\circ \) and \( \sim 50^\circ \), respectively (Dostal et al., 1986). Therefore, the ADD would also have an important role in swinging back the lower limb.

From the present results, it is not clear which role of the ADD is related to the inter-individual difference in \( \text{Time}_{30m} \). However, it has been reported that leg extension capacity was important for sprint running over short distance (Delecluse, 1997; Johnson and Buckley, 2001; Wisløff et al., 2004; Cronin and Hansen, 2005) or the acceleration phase of sprint running (van Ingen Schenau et al., 1994). Considering this, it is likely that individual difference in the muscularity of the ADD may be related to that in exertion of hip extension torque during sprinting, and consequently related to the variability of \( \text{Time}_{30m} \). This idea is supported by the result that the ADD was selected as an explanatory variable only when represented relative to the body size. That is, the inter-individual difference in the capacity of generating a propulsive force to accelerate the body forward is a factor of the variability of \( \text{Time}_{30m} \), and thus, it is important to have large muscle CSA relative to the body size.

The present result also showed that the DF CSA had negative effect on \( \text{Time}_{30m} \). The reason for this result would be that not only the dorsiflexors cannot produce propulsive force but also its hypertrophy causes the increase of moment of inertia of a lower leg around the knee joint and of a lower limb around the hip joint, which prevents the quick movement of lower limb and increases sprint time (Bennett et al., 2009). The later reason would be applied to explain why the HAM, QF, and TS were not selected as explanatory variables of \( \text{Time}_{30m} \), although these are agonist muscles in leg extension. In addition, it is possible that muscles other than QF or TS contribute to knee extension or plantar flexion torque just as the gluteus maximus and the adductor magnus muscles contribute to knee extension during walking through the joint inter-segmental reaction.
force (Arnold et al., 2005).

The current results show that to have greater hip adductor muscles relative to body size and smaller dorsiflexors is advantageous for achieving higher performance in short distance sprint running. However, the prediction equation obtained in the present study can explain only 60% of the variability of Time30 m. In the present study, we did not measure the CSA of the gluteus maximus, which is an agonist muscle in hip extension. Most recently, Muramatsu et al. (2010) reported that, in high school athletes, sprinters tended to have larger gluteus maximus muscle than athletes in other sports, although the difference was not statistically significant. Therefore, it is possible that, in addition to the muscles tested in the present study, the muscularity of the gluteus maximus muscle is a determinant factor of inter-individual difference in Time30 m. Furthermore, factors other than muscle size (e.g., muscle fiber composition, Mero et al., 1981; muscle architecture such as fiber length, Kumagai et al., 2000; techniques in sprint, Mero et al., 1992; body composition, Weyand and Davis, 2005) could affect the sprinting ability. In future study, the effect of these factors should be investigated to clarify the determinants of performance in sprint running over short distance.

In addition, it should be noted that there is a possibility that the present result is not applicable for other subject groups. Kano et al. (1997) found significant correlations between 100-m sprint running time and the CSAs of the ADD and the HAM in male adult sprinters. In contrast, Hoshikawa et al. (2006) reported that, for boy sprinters aged from 13 to 16 years, PM-to-QF CSA ratio was selected as the positive explanatory variable for girl sprinters aged from 14 to 17 years. Considering these previous studies together, it is possible that the predictors of sprint running vary among subject groups, which should be clarified in future study.

5. Conclusion

The present study investigated how the anatomical cross-sectional areas of the psoas major and lower limb muscles are related to 30-m sprint running time in college short and middle distance runners. As a result of a stepwise multiple regression analysis, the ratio of cross-sectional area of the hip adductors to two-thirds power of body weight and the cross-sectional area of the dorsiflexors were selected as negative and positive explanatory variables, respectively, for 30-m sprint running time. The result indicates that to have greater hip adductor muscles relative to the body size and smaller dorsiflexors is advantageous for achieving higher performance in 30-m sprint running.

References

Muscle Cross-sectional Area and 30-m Sprint Running Time


