

Architectural characteristics of vastus lateralis muscle and jump performance in young men

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Abbreviations:

CMJ: counter-movement jump

SJ: squat jump

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muscle architecture

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pennation angle

fascicle length

Summary

Muscle architecture describes the geometric design of a muscle. It will have a great influence in the force generating capacity and the shortening velocity of skeletal muscle. The purpose of the present study was to investigate the relationship between architectural characteristics of one leg muscle and jump performance in a group of physical education students.

Ten male students of physical education volunteered for the study. They were tested for their dynamic explosive force by asking them to perform jump tests on a force platform. Skeletal muscle architecture of vastus lateralis was visualized using ultrasonography and their body composition was evaluated. Isolated muscle thickness and fascicle pennation angle of vastus lateralis were measured in vivo, and fascicle length was estimated, using the ultrasonographer.

Absolute fascicle length of vastus lateralis was greater compared with other studies, carried out with sprinters, distance runners and controls. Nonetheless, when it was expressed relative to limb length, was comparable to that observed in 100 m sprinters, or controls. The relationships between muscle architecture and muscular performance could be stronger in greater and more homogeneous groups.

In conclusion, our subjects have similar vastus lateralis muscle architecture compared with the literature. The relationships between muscle architecture and jump performance are not clear, probably because there are more variables involved, like fibre type and neural activity.

Introduction

Jump tests have been widely utilised in combination with sprint tests, to evaluate track athletes and other populations (Berthoin et al., 2001; Blazeovich et al., 2003; Hoffman and Kang, 2003; Hennessy and Kilty, 2001; Wilson et al., 1995). Well-trained athletes tend to have better performance in these tests than recreational athletes or untrained controls.

Biochemical properties are important in determining maximal shortening velocity and force of a muscle. However, muscle architectural characteristics have been shown to play an important role in sprint performance (Kumagai et al., 2000a) and strength (Brechue and Abe, 2002), so it is likely that they will have great influence on jump performance. Some authors have found differences in pennation angles, muscle thickness and fascicle length from leg extensor muscles, between athletes and untrained controls (Abe et al., 2000; Kearns et al., 2000; Kawakami et al., 1993). Elite athletes tend to have greater muscle thickness and fascicle length than controls, whereas pennation angles are sometimes similar between these groups. Elite powerlifters have greater pennation angles of the vastus lateralis muscle than that observed in sprinters or controls (Brechue and Abe, 2002). Furthermore, some studies have reported that fascicle length is greater in 100-m sprinters compared to untrained controls (Abe et al., 2000). Even more, a significantly negative correlation has been observed between 100-m sprint running time and fascicle length of leg muscles in elite male sprinters (Kumagai et al., 2000a). These findings point out that some of the differences in strength and sprint performance between athletes and untrained subjects could be produced by the muscle architectural characteristics of each group.

There are several researches where muscle architecture and strength variables have been studied, but only few studies have associated muscle architecture and performance in sprint or strength tests (Abe et al., 2000, 2001; Kumagai et al., 2000a, 2000b; Brechue and Abe, 2002). As far as we know, there are no studies where muscle architecture and jump performance have been associated.

Vastus lateralis muscle has been taken as representative of quadriceps muscles. Its relative contribution to the total knee extension force has been estimated to be 22% (Narici et al., 1992).

The purpose of the present study was to investigate the relationship between architectural characteristics of vastus lateralis muscle and jump performance in a group of physical education students.

Materials and methods

Subjects

Ten male students of physical education volunteered for the study. A physical activity questionnaire was used to quantify their average physical activity, and revealed that all of them were physically active. However, none of the subjects were taking part in any regular strength/endurance training programme or competitive sports more than two days a week.

All subjects were tested for their dynamic explosive force by asking them to perform jump tests. Skeletal muscle architecture of vastus lateralis muscle was visualized using ultrasonography and their body composition was evaluated. Details of the testing procedures are described below.

Variables	Mean (\pm SD)
Age (years)	18.3 (0.5)
Weight (Kg)	70.4 (2.9)
Height (cm)	181.0 (4.9)
FFM (kg)	65.1 (2.7)
% body fat	7.6 (1.4)
Thigh circumference (cm)	55.4 (2.2)
Thigh length (cm)	45.4 (2.1)

Table 1: Descriptive data on body size and composition for the physical education students. *Abbreviations: FFM: fat-free mass.*

Testing

Explosive force

Dynamic explosive force was measured on a force platform (Quattro Jump, Kistler) performing a maximal countermovement jump (CMJ) and a squat jump (SJ). Vertical ground reaction forces were sampled at 500 Hz. Jump heights, peak vertical force, peak power, braking and acceleration impulses and the ratio of impulses were assessed.

The subjects were carefully familiarized with the testing procedures during a session before the measurements, using the feedback option of Quattro Jump software. This tool allowed us to show each subject his ground reaction forces in real time, making it possible to learn faster the jump technique. All SJs and CMJs were performed with the hands placed on hips and trunk movements during jump were minimized. To standardise jump technique in SJ subjects were positioned on the force platform such that the knee angle was 90 degrees (Figure 1). The subjects were instructed to keep the squatted position during 4 s before performing the jump. Three maximal jumps were recorded for each test condition and the best performance was used for the statistical analysis.

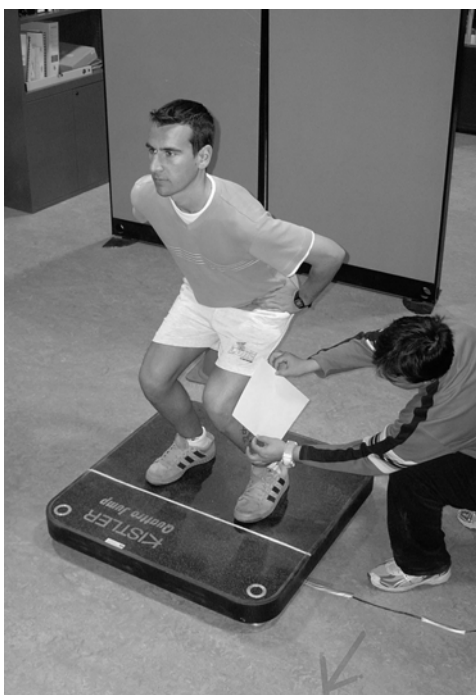


Figure 1: Subject position for the Squat Jump test. The knee angle of 90 degrees was tested before each jump.

Anthropometry

Each subject's body composition was evaluated on the following parameters: weight, height, fat free mass (FFM) and percent body fat. Skinfold measurements using Holtain caliper were taken from 6 sites (triceps, subscapular, umbilicus, suprailium, thigh and lower leg). FFM was calculated by subtracting fat mass from total mass. Thigh length was measured from the greater trochanter to the lateral condyle of the femur.

Skeletal muscle architecture

B-mode ultrasonography was used to record sagittal images of vastus lateralis muscle while subjects lay supine with the knee fully extended. All subjects remained relaxed during the ultrasound scanning. Ultrasound images were recorded using a Toshiba sonolayer Just Vision 400 real time scanner with a 7.5 MHz linear array transducer.

Isolated muscle thickness and fascicle pennation angle (midway between greater trochanter and lateral condyle of the femur), were measured *in vivo* using the ultrasonographer.

Mediolateral width of vastus lateralis was determined over the skin surface and the position of one-half of the width was used as measurement site. The pennation angle was defined as the angle between the fascicle and deep aponeurosis. For the determination of fascicle pennation angles the position of the transducer was manipulated while viewing the ultrasound image in real time. The angles between the echoes of the deep aponeurosis of the muscle and the echoes from interspaces among the fascicles were measured. The distance between the subcutaneous adipose tissue-muscle interface and intermuscular interface was defined as muscle thickness. Fascicle length was estimated as the length of the hypotenuse of a triangle with an angle equal to the pennation angle, and the side opposite to this angle equal to the muscle thickness, by the following equation: Fascicle length = Muscle thickness / sin of the pennation angle. The model did not account for fascicle curvature.

The ultrasound images from vastus lateralis were recorded on a videotape and subsequently analysed by the medical software Osiris (v. 3.6). The examiner took five images from each recording and after accounting for the architecture variables he excluded those which showed the longest and the shortest fascicle length. Then, means of muscle thickness, pennation angles and fascicle length were assessed from the three images left and recorded for further analysis.

Statistics

Results are expressed as means (SD). Relationships between variables were examined by using Pearson product moment correlations with a significance detected at a level of $P < 0.05$.

Results

Subject anthropometrical characteristics are given in Table 1. Table 2 shows the SJ and CMJ variables of the 10 subjects. Mean values of vastus lateralis pennation

angles, muscle thickness and fascicle length were 16.4 (3.5) degrees, 2.45 (0.29) cm and 8.92 (1.92) cm, respectively.

SJ height correlated positively with CMJ height ($r=0.72$, $P<0.05$) and CMJ peak vertical force ($r= 0.69$, $P<0.05$), and CMJ height correlated positively with CMJ peak vertical force (0.69 , $P<0.05$) and CMJ acceleration impulse ($r=0.73$, $P<0.05$).

The relationships between jump performance and muscle architecture variables are shown in Table 3. CMJ height and vastus lateralis fascicle length were significantly correlated ($r=-0.82$, $P<0.01$). There was a slightly positive correlation between CMJ height and vastus lateralis pennation angle ($r=0.52$), but it was not statistically significant.

There was a negative significant correlation between vastus lateralis pennation angle and thigh length ($r= -0.66$, $P<0.05$). Significant correlations were observed between vastus lateralis pennation angle and fascicle length (Table 3). We found no significant correlations between isolated muscle thickness and pennation angles, although there was a tendency ($r=0.52$, not significant).

Variables	Units	Mean (\pm SD)
SJ height	m	0.301 (0.035)
CMJ height	m	0.352 (0.045)
SJ height / CMJ height	--	0.86 (0.08)
CMJ total time of concentric phase	s	0.276 (0.040)
Peak power SJ	W	3528 (357)
Peak power CMJ	W	3588 (354)
Peak power SJ / Body mass	W/kg	50.8 (5.3)
Peak power CMJ / Body mass	W/kg	51.3 (5.3)
SJ acceleration impulse	(N·s)	186.6 (8.5)
CMJ acceleration impulse	(N·s)	199.7 (12.0)
Braking impulse / Acceleration impulse in CMJ	--	0.47 (0.09)

Table 2: Jump performance variables in physical education students. Values are means (SD). *Abbreviations: SJ: Squat Jump; CMJ: Countermovement Jump.*

Variable 1	Variable 2	r	P
VL muscle thickness	VL pennation angle	0.52	ns
VL pennation angle	VL fascicle length	-0.77	<0.01
VL pennation angle	VL fascicle length / Thigh length	-0.66	<0.05
CMJ height	VL fascicle length	-0.82	<0.01
CMJ height	VL fascicle length / Thigh length	-0.75	< 0.05
CMJ height	VL pennation angle	0.52	ns
SJ height	VL fascicle length	-0.59	ns

Table 3: Pearson correlation coefficients between muscle architecture data and jump performance parameters. *Abbreviations: VL: vastus lateralis; SJ: Squat Jump; CMJ: countermovement jump. ns: not statistically viable.*

Discussion

Jump performance in our group was similar to other studies carried out with force platforms in the same centre (Alegre et al., 2003), but there were significant differences between our subjects and groups from previous studies undergone with Spanish physical education students, as well. Jump heights were higher than ours [CMJ: 0.416 (0.051) m and SJ: 0.342 (0.053) cm] (López y cols, 2001; Aguado, 1999).

In the current study, our group averaged 0.301 m in SJ and 0.352 m in CMJ. Their jump performance is lesser than that observed in the studies of Arteaga et al. (2000) Baker (1996), Berthoin et al., 2001; Hakkinen et al. (1996), Izquierdo et al. (1998; 1999), Ostrowski et al. (1997) and Young and Bilby (1993), with SJ heights from 0.320 m to 0.423 m and CMJ heights from 0.362 m to 0.464 m. Differences in jump performance could be explained by a decline in explosive strength of physical education students. They were physically active, but none of them did regular strength or endurance training. However, their percent body fat was quite low (<8%), compared with other studies (Häkkinen et al., 1996; Izquierdo et al., 1999; Kanehisa et al., 1998; Kearns et al., 2000), but similar compared with the subjects of Arteaga et al. (2000) . Differences may be related to their dietary habits and daily physical activity, but in our study we did no dietary record.

STUDIES	GROUPS		VASTUS LATERALIS			
	Subjects (n)	Gender	Muscle thickness (cm)	Pennation angle (°)	Fascicle length (cm)	Fascicle length / Limb length
Physical education students, present study	10	M	2.45 (0.29)	16.4 (3.5)	8.92 (1.52)	0.20 (0.03)
100 m sprinters T = 10.00-10.90 s (Kumagai et al., 2000)	22	M	2.75 (0.30)	19.0 (3.2)	8.63 (1.42)	0.22 (0.04)
100 m sprinters T = 11.04-13.42 s (Abe et al., 2001)	26	F	2.50 (0.37)	17.7 (2.8)	8.40 (1.24)	0.22 (0.03)
Distance runners 5000 m = 13.5-14.5' 42.2 km =130 - 145' (Abe et al., 2000)	24	M	2.47 (0.31)	23.7 (2.1)	6.15 (0.61)	0.15 (0.02)
100 m sprinters T = 11.00-11.70 s (Kumagai et al., 2000)	15	M	2.67 (0.32)	21.1 (2.1)	7.45 (1.04)	0.19 (0.02)
Sumo wrestlers (Kearns et al., 2000)	28	M	3.36 (0.46)	19.9 (3.5)	10.01 (1.61)	0.25 (0.04)
Untrained controls (Abe et al., 2000)	24	M	2.32 (0.46)	19.5 (3.6)	7.13 (1.18)	0.18 (0.03)

Table 4: Descriptive data on muscle thickness, pennation angle and fascicle length in the selected leg muscles from different populations.

Absolute fascicle length of vastus lateralis (8.92 cm) (Table 4) was greater compared with other studies, carried out with sprinters (7.45 cm), distance runners (6.15 cm) (Kumagai et al., 2000a) and controls (7.13 cm) (Abe et al., 2000). Nonetheless, when it was expressed relative to limb length (0.20), was comparable to that observed in 100 m sprinters (0.22, Abe et al., 2001; Kumagai et al. 2000a), or controls (0.18, Abe et al., 2000).

The discrepancies between our vastus lateralis measurements, compared with other studies, could be explained by anthropometric differences between our group and the subjects described in the literature (Aagaard et al., 2001), who averaged shorter heights than our group. On the other hand, subjects with similar average height than ours showed average vastus lateralis fascicle lengths of 11.28 cm (vs. 9.42 cm in our group), but with greater pennation angles (22.1° vs. 16.4° in our study) and greater vastus lateralis muscle thickness (3.00 cm vs. 2.45 cm in our group) (Brechue and Abe, 2002). This can be explained because Brechue and Abe measured muscle architecture in elite powerlifters, and they had an extreme muscle enlargement. Brechue and Abe reported a vastus lateralis muscle thickness of 3.69 cm for a group of heavy weight classes (body mass of 110 kg and above), greater than all the values in Table 4.

Muscle enlargement typically results in increased pennation angle and muscle thickness. Previous findings on the relationship between the muscle size and pennation angle are controversial. Kawakami et al. (2000) and Abe et al. (1998) found positive correlations in the triceps brachii long head (n= 637, r=0.81 and n= 51, r=0.83, respectively). However, there were no correlations between vastus lateralis muscle thickness and pennation angle in the studies of Kumagai et al. (2000a), Kearns et al. (2000), and Brechue and Abe (2002). We found a slightly positive correlation of r=0.52 (not significant) in our group. It seems that our subjects had not reached the set-point where this relationship became apparent (Brechue and Abe, 2002). Another possibility could be that the lack of correlations between muscle architecture and muscular performance could be produced, in part, by the limited number of subjects in our study. These relationships could be stronger in greater and more homogeneous groups (Ichinose et al., 1998). The third explanation might be the differences in the relationship between fibre angulation and muscle size, in different muscles (Ichinose et al., 1998).

We found a significant negative correlation between vastus lateralis fascicle length and CMJ height. Jump tests have been widely utilised to measure explosive force in athletes. The 100-m sprinters of Abe et al. (2000) and Kumagai et al. (2000a) showed low, but significant correlations, between vastus lateralis fascicle length and 100-m performance. Nonetheless, the type of muscle action required to perform a jump is different than the fast and repetitive contractions carried out during sprint running. Contact time of 100-m sprint in elite athletes is below 0.1 s, whereas the concentric phase of CMJ can reach 0.3 s (our subjects averaged 0.276 s). We found a slightly positive correlation between CMJ height and vastus lateralis pennation angle (0.52, not significant). Greater pennation angles have been commonly associated with high-force contractions, so it appears that in our subjects there was a relationship between jump performance and strength.

However, caution should be exercised with the correlations found in this study, because they are low, and with P values over 0.05. Muscle architecture is only one of the variables involved in force production and other factors have to be considered, like

fibre type, neural activation, and mechanical factors, like moment arm (Aguado et al., 2000; Lieber and Friden, 2000) and muscle shape (Abe et al., 1998, 2000; Kumagai et al., 2000a). Depending on the population, each factor will be more or less important in the force production.

Conclusions

- 1- Our subjects, Spanish physical education students, had similar vastus lateralis muscle architecture compared with the literature, especially when muscle architecture measurements are normalised to limb length.
- 2- Jump heights in our group were lesser than that reported in previous works. These differences could be explained by dietary habits and/or daily physical activity.
- 3- There were correlations between jump performance variables and muscle architecture parameters that are associated with maximal strength. However, there were no positive correlations between jump performance and fascicle length, possibly because muscle contraction times during a jump and sprint running are very different.
- 4- The relationships between muscle architecture and jump performance are not clear, probably because there are more variables involved, like fibre type and neural activation. Muscle architecture is only one of the factors implicated in the force production of a muscle. The importance of each one over the muscle strength will change, depending on the population tested.
- 5- Future research should include more subjects with different ages, gender and training background.

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