HUMAN MOVEMENT
2018; 19(1): 44–50

RELATIONSHIP BETWEEN MUSCLE ARCHITECTURE AND BADMINTON-SPECIFIC PHYSICAL ABILITIES

original paper
DOI: https://doi.org/10.5114/hm.2018.73611

ALI MD NADZALAN[1], NUR IKHWAN MOHAMAD[1], JEFFREY LOW FOOK LEE[1], CHAMNAN CHINNASEE[2]

[1] Sultan Idris Education University, Tanjong Malim, Malaysia
[2] Thaksin University, Khao Rup Chang, Thailand

ABSTRACT

Purpose. The study aimed at determining the relationships between muscle architecture and badminton-specific physical abilities.

Methods. The total of 30 university level badminton players (mean age: 22.1 ± 1.4 years) were recruited as participants and underwent assessment of muscle architecture and badminton-specific physical abilities. Pennation angle, fascicle length, and muscle thickness of vastus medialis, vastus lateralis, rectus femoris, and biceps femoris were determined with ultrasonography for muscle architecture variables. Lunge one repetition maximum (1RM), lunge relative 1RM, standing long jump, vertical jump, and agility t-test were performed for physical abilities. The relationship between all muscle architectures and physical abilities was determined with the use of Pearson correlation.

Results. The results showed that the pennation angle and muscle thickness were positively correlated while fascicle length was negatively correlated with the physical abilities except for the agility test.

Conclusions. The study demonstrates that the possibilities of training performed by athletes affect their muscle architecture; further studies are required to examine how different kinds of training affect muscle architecture, which can then influence performance in sports.

Key words: pennation angle, fascicle length, muscle thickness, ultrasonography, strength, jump performance

Introduction

Performance of sport-specific movements is largely controlled by muscles around the limbs. The efficiency of these skills could be improved by examining the details of the muscles and their relationship with the required movements. Muscle architecture is the physical arrangement of muscle fibres. Several parameters can be distinguished in muscle architecture, including muscle thickness, pennation angle, and fascicle length. Muscle thickness is measured from an aponeurosis to another aponeurosis (Figure 1). Muscle thickness could be related to muscle size, i.e., muscle thickness increases in tandem with muscle size. Pennation angle is the direction of fascicle form the aponeurosis to another aponeurosis (Figure 1). The increment in penna-

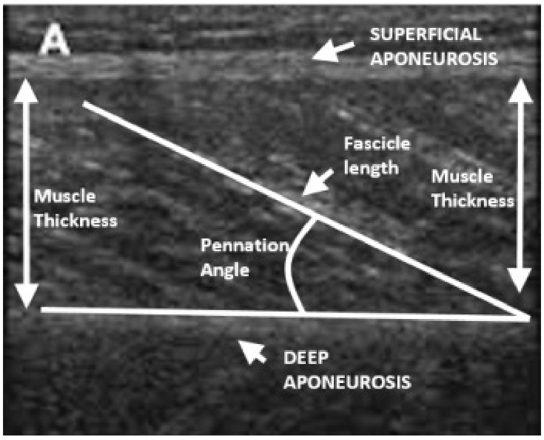

Figure 1. Muscle architecture of vastus lateralis

Correspondence address: Ali Md Nadzalan, Faculty of Sports Science and Coaching, Sultan Idris Education University, 35900 Tanjong Malim, Perak, Malaysia, e-mail: ali.nadzalan@fsskj.upsi.edu.my

Received: September 14, 2017
Acepted for publication: November 1, 2017

Citation: Nadzalan AM, Mohamad NI, Lee JLF, Chinnasee Ch. Relationship between muscle architecture and badminton-specific physical abilities. Hum Mov. 2018;19(1):44–50; doi: https://doi.org/10.5114/hm.2018.73611.

tion angle will cause the cross-sectional area of the muscle to have more fibres. As a result, the muscle would be able to generate more force [1]. Fascicle length, in turn, is the distance of fascicle from aponeurosis to another aponeurosis (Figure 1). A greater fascicle length was thought to represent either a bigger number of sarcomeres in line or longer sarcomeres [2]. Sarcomere is the contractile element in the muscles. The increment of the length of the contractile element will enable faster contraction and more force that can be applied at an increasing velocity [3].

Several researchers have found that different muscle architecture elicited different advantages for specific movements. For example, a larger pennation angle was observed to be more beneficial during jumping movements [2, 4]. In contrast, a lesser pennation angle seems more beneficial during sprint movements [5–7].

Besides, longer fascicles were noted to be more beneficial for vertical jumps [2, 4] and sprinting performance [5–7] owing to the muscles' contractions at relatively fast shortening speeds in order to exert large forces. In contrast, shorter fascicles were found more beneficial for long distance running [5, 8] because of the movement economy that is required for such events.

Badminton is a sport that involves a lot of high intensity movements [9], including fast accelerations, decelerations, and rapid changes of directions over short distances [10–13]. Badminton players need to be agile and have the ability to perform multiple lunge movements, especially during attempts to return the shuttlecock dropped near the net. They also need to perform multiple jumping movements that are critical during the attempt to execute forearm smashes.

To the best of the authors' knowledge, no studies to date have attempted to examine the relationship of muscle architecture with sport-specific physical movements, such as in badminton. Thus, this study aimed to investigate the relationship between muscle architectures of the lower body and the badminton-specific physical abilities. The badminton-related movements were measured by the lunge, jumps, and agility tests. It is hypothesized that a significant relationship exists between muscle architecture and the badminton-specific physical abilities.

Material and methods

Experimental approach to the problem

The participants were familiarized with test protocols before being tested on 2 occasions within 24 hours. The first testing session involved data collection on the anthropometrics and muscle architecture with the use of ultrasonography. During this session, the participants' body mass, height, and muscle architecture were determined. Physical ability tests were conducted in the second testing session. Correlation analysis was performed to determine if the participants' lower body muscle architectures were related to physical abilities.

Participants

The total of 30 university level badminton players, currently active participating in university level badminton tournaments (mean age: 22.1 ± 1.4 years), were recruited for the study. They had no medical problems and were screened with the Physical Activity Readiness Questionnaire (PAR-Q) prior to testing.

Image analyses

The muscle thickness, pennation angle, and fascicle length of biceps femoris (BF), rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) muscles were measured with B-mode ultrasonography (F37, Aloka Ltd., Tokyo, Japan). All measurements were conducted on the participant's self-reported dominant side.

During the measurement, the ultrasound probe was positioned longitudinally to the muscles examined [14]. The probe positioning was maintained with equal contact pressure during all measurements. The BF muscle architecture was determined in participants lying prone with the leg straight in a resting position. The measurements of VL, VM, and RF pennation angle and muscle thickness were conducted in participants lying supine with the leg straight in a resting position [15, 16]. The fascicle length was calculated in accordance with the following equation [17]:

$$\text{fascicle length} = \frac{\text{muscle thickness}}{\sin(\text{pennation angle})}$$

All measurements were performed by the same technician to ensure construct validity. The intraclass correlation coefficients (ICC) for repeated scanning of muscle architecture measurements as performed by the researcher ranged from 0.9 to 0.95 ($p < 0.001$).

Forward lunge one repetition maximum

The multiple-repetition maximum testing protocol was conducted for the one repetition maximum

(1RM) lunge (ICC: 0.92–0.97, $p < 0.001$), as indicated in the guidelines of the National Strength Conditioning Association [18]. The participants were instructed to stand with their hands holding a barbell placed on their shoulders, with their feet shoulder width apart. They lunged forward with their dominant foot and lowered the thigh until parallel with the ground, and then returned back to the starting position. They were required to take a big step forward during downward position, with the leading knee not extended beyond the toes of the same leg. The non-dominant foot was not to move from its starting position, and the head had to face forward for neutral neck position. Each participant was given 3 trials on each of the loads tried. The dominant foot was determined by asking the badminton players which limb they preferred to kick a ball [19].

Vertical jump

Vertical jump equipment (Vertec, USA) was used to measure the vertical jump height (ICC: 0.90–0.95, $p < 0.001$). The test commenced with setting the Vertec in which the standing height of the participant with one arm fully extended upward was taken to set the lowest vane. The participant then jumped and touched the highest possible vane. The players were allowed to swing their arms and bend their knees as to mimic the real movement in badminton. The jump height was measured as the difference between the standing height and the jumping height. The participants were given 3 trials and the greatest jump height was taken as the vertical jump score.

Standing long jump

A standing long jump mat (Trident, Malaysia) was used to measure the standing long jump distance (ICC: 0.88–0.96, $p < 0.001$). The participants were to jump as far as possible, landing on both feet, without falling backwards. Three trials were given and the greatest distance was taken as the standing long jump score.

Agility t-test

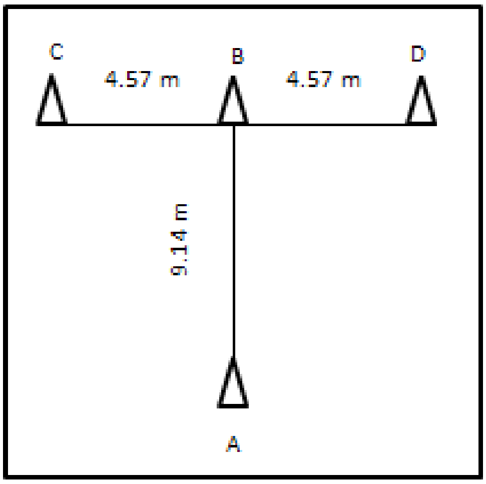

Figure 2. Agility t-test set up

Four cones were set up as illustrated in Figure 2. The participants started with ready position and stand behind the line at cone A. They sprinted to cone B, and then shuffled sideways to cone C, cone D, and then cone B. Each time the participants arrived at cone B, C, and D, they were to touch the base of the cone. Lastly, the players ran backwards to cone A. The ICC range was 0.85–0.90 ($p < 0.01$).

Statistical analyses

Descriptive data and mean scores were analysed with the use of descriptive statistics. Pearson correlation was applied to determine the relationships between muscle architecture and all the physical abilities tested. The value of $p < 0.05$ was set as the indicator of statistical significance. The SPSS software version 23 (IBM, New York, USA) was used to conduct all the statistical analyses.

Ethical approval

The research related to human use has been complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the authors' institutional review board or an equivalent committee.

Each participant read and signed the informed consent for testing approved by the Sultan Idris Education University and Thaksin University Ethics Committee (code E 060/2559).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Table 1 presents the physical characteristics of the participants involved in the study.

Table 2 shows the means and standard deviations of the physical abilities scores among the participants.

Table 3 provides the correlation analyses of vastus lateralis muscle thickness (VLMT), vastus lateralis pennation angle (VLPA), vastus lateralis fascicle length (VLFL), vastus medialis muscle thickness (VMMT), vastus medialis pennation angle (VMPA), vastus medialis fascicle length (VMFL), rectus femoris muscle thickness (RFMT), rectus femoris pennation angle (RFPA), rectus femoris fascicle length (RFFL), biceps femoris muscle thickness (BFMT), biceps femoris pennation angle (BFPA), and biceps femoris fascicle length (BFFL) with lunge 1RM, relative 1RM, vertical jump, standing long jump, and agility t-test. The results showed that all the muscle architectures were significantly correlated with lunge 1RM and lunge relative 1RM, except for VMFL and BFFL. For the vertical jump, VLMT, VMFL, and BFFL were proved not significantly correlated. On the other hand, VMMT, RFMT, RFPA, BFMT, and BFPA were shown to be significantly correlated with standing long jump. Finally, only VMMT, RFMT, and BFPA turned out significantly correlated with agility performance.

Table 1. Physical characteristics of the participants

Age (years)	22.1 ± 1.40
Body mass (kg)	70.1 ± 2.93
Height (cm)	173 ± 3.50
Vastus lateralis muscle thickness (cm)	2.37 ± 0.07
Vastus lateralis pennation angle (°)	17.5 ± 1.42
Vastus lateralis fascicle length (cm)	7.94 ± 0.48
Vastus medialis muscle thickness (cm)	2.56 ± 0.06
Vastus medialis pennation angle (°)	16.7 ± 0.89
Vastus medialis fascicle length (cm)	9.06 ± 0.30
Rectus femoris muscle thickness (cm)	2.56 ± 0.06
Rectus femoris pennation angle (°)	16.7 ± 0.89
Rectus femoris fascicle length (cm)	9.06 ± 0.30
Bicep femoris muscle thickness (cm)	2.48 ± 0.11
Bicep femoris pennation angle (°)	15.0 ± 0.77
Bicep femoris fascicle length (cm)	9.57 ± 0.14

Discussion

The major finding in this study was that there were relationships between some of the muscle architecture factors and the physical performance in badminton.

Table 2. Physical abilities scores of the participants

	Lunge 1RM (kg)	Lunge relative 1RM (1RM/BM)	VJ height (cm)	SLJ distance (cm)	Agility t-test (s)
Score	69.3 ± 4.09	0.99 ± 0.02	45.9 ± 1.36	2.53 ± 0.05	10.6 ± 0.24

1RM – one repetition maximum, BM – body mass, VJ – vertical jump, SLJ – standing long jump

Table 3. Correlation analysis of muscle architectures and lunge 1RM, relative 1RM, VJ, SLJ, and AG

Muscle	Architecture	Lunge 1RM	Lunge relative 1RM	VJ	SLJ	AG
		r	r	r	r	r
VL	MT	0.44*	0.39*	0.32	0.18	–0.22
	PA	0.58**	0.50**	0.43*	0.36	–0.20
	FL	–0.50**	–0.44*	–0.37*	–0.34	0.16
VM	MT	0.72***	0.63***	0.62***	0.47**	–0.43*
	PA	0.57**	0.53**	0.41*	0.27	–0.26
	FL	–0.30	–0.29	–0.12	–0.03	0.09
RF	MT	0.76***	0.64***	0.65***	0.60**	–0.38*
	PA	0.73***	0.63***	0.60***	0.52**	–0.33
	FL	–0.60***	–0.54**	–0.47**	–0.35	0.26
BF	MT	0.77***	0.67***	0.67***	0.59**	–0.36
	PA	0.68***	0.63***	0.58**	0.52**	–0.37*
	FL	0.02	–0.09	0.05	0.01	0.17

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

1RM – one repetition maximum, VJ – vertical jump, SLJ – standing long jump, AG – agility t-test, VL – vastus lateralis, VM – vastus medialis, RF – rectus femoris, BF – biceps femoris, MT – muscle thickness, PA – pennation angle, FL – fascicle length

Almost all the muscle architectures examined in the study were shown to have significant relationships with lunge 1RM and relative 1RM, except for the fascicle length of VM and BF. Muscle thickness and pennation angle turned out positively correlated, while fascicle length proved to be negatively correlated with the lunge 1RM. The results of the study were in line with those obtained by Nadzalan et al. [20] among untrained men. It was also found that the muscle architectures examined were able to predict the absolute score of strength better than the relative score.

The muscle thickness and pennation angle of VM, RF, and BF, as well as the pennation angle of VL were shown to be positively correlated, while the fascicle length of VL and RF proved negatively correlated with the vertical jump performance, which was measured by vertical jump height in this study. Besides, the muscle thickness and pennation angle of RF and BF, as well as the muscle thickness of VM were positively correlated with the standing long jump performance, while no relationships were found for the fascicle length for all the muscles. This was the first study to examine the relationship between muscle architecture and horizontal jumping performance (i.e. standing long jump). Previous studies on squat, countermovement, and drop jumps indicated that individuals having thicker muscles, greater pennation angles, and shorter fascicles performed better in the jumps, which supports the findings of this study.

Also, this was the first known study to examine the relationships of muscle architecture with the agility performance. The results showed that the muscle thickness of VM and RF, as well as the pennation angle of BF were negatively correlated with the agility t-test performances. No significant relationships were found with the fascicle length of all the muscles examined in the study. No previous research has examined the relationship of muscle architecture and agility performance, although some [5–7] proved that thicker, less pennated, and longer fascicles were more beneficial for sprinting performance.

Overall, greater pennation angle and muscle thickness were found to be positively correlated with strength and jumping performance. This argument is logical since the number of fibres increased in thicker and more pennated muscles enhances the force production ability [21].

On the basis of the results one can state that the increasing pennation angle that contributes to the rising physiological cross-sectional area [2] will allow high force to be produced during this movement. Contrasting with squat, lunge is a more complex movement, in which both the downward and upward phases need to be critically controlled by the performer because of the instability imposed by one foot. The lunge movement requires high control during the eccentric phase to make sure that no uncontrolled movement happens to the knee or ankle that could lead to their injury.

In contrast to the lunge 1RM and jumping performance, the study revealed that pennation angle and muscle thickness were negatively correlated with agility performance. This was in line with what had been observed for sprinting performance [5–7]. Besides, this study also showed that participants with shorter fascicles were able to lift more loads during the lunge and produced better performance during vertical and standing long jump as well. This demonstrated the effectiveness of shorter fascicles to control the increased eccentric forces during the descent phase of lunge movement and during the push off during the concentric phase, suggesting that longer fascicles are not highly capable in dealing with large contraction forces. Earp et al. [2] suggested that this condition might be explained by the behaviour of the longer fascicles that have more potential places of fascicle disruption, which can contribute to higher fascicle instability. Future research could attempt to examine the hypothesis.

Some previous studies examined the effects of resistance training on muscle architecture [21–26]. It has been found that different resistance training programs might cause different changes to the fascicle pennation angle. Heavy resistance training was shown to result in an increment of muscle cross-sectional area, fascicle thickness, and pennation angle [22, 27]. Bloomquist et al. [26] observed muscle thickness and pennation angle increase as a consequence of deep and shallow squats but no difference between groups was shown. Nonetheless, conflicting results were obtained in some studies that found no changes, or even reported a decrement in the pennation angle owing to resistance training [16, 28]. The contrasting outcomes could be due to the different training loads and velocity of movement applied in those studies. Thus, more research is required to develop better understanding of the effects of various training processes on the adaptation of muscle architecture.

Conclusions

Overall, the study demonstrated the existence of relationships between lower body muscle architecture and strength and jumping performance. The findings suggest the importance of having thicker, more pennated, and shorter fascicles of lower body muscles for enhancing strength and jumping performance among badminton players. It is recommended that future studies are conducted on examining the effects of different training regimes or protocols on muscle architecture. The selected exercises should depict the movements characteristic of badminton, such as squats for vertical-jump smash based movement and lunges for horizontal court based movement. In contrast to traditional strength training, which requires individuals lifting heavy loads for bigger and thicker muscles, badminton demands speed and power in movement, which could be disrupted by muscles that are too big and too thick. Thus, future studies can also be conducted on the effects of velocity-specific hypertrophy training on the muscle architecture and sports performance.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

References

1. Manal K, Roberts DP, Buchanan TS. Optimal pennation angle of the primary ankle plantar and dorsiflexors: variations with sex, contraction intensity, and limb. J Appl Biomech. 2006;22(4):255–263; doi: 10.1123/jab.22.4.255.
2. Earp JE, Joseph MF, Kraemer WJ, Newton RU, Comstock BA, Fragala MS, et al. Lower-body muscle structure and its role in jump performance during squat, countermovement, and depth drop jumps. J Strength Cond Res. 2010;24(3):722–729; doi: 10.1519/JSC.0b013e3181d32c04.
3. Sacks RD, Roy RR. Architecture of the hind limb muscles of cats: functional significance. J Morphol. 1982;173(2):185–195; doi: 10.1002/jmor.1051730206.
4. Earp JE, Kraemer WJ, Cormie P, Volek JS, Maresh CM, Joseph M, et al. Influence of muscle-tendon unit structure on rate of force development during the squat, countermovement, and drop jumps. J Strength Cond Res. 2011;25(2):340–347; doi: 10.1519/JSC.0b013e3182052d78.
5. Abe T, Kumagai K, Brechue WF. Fascicle length of leg muscles is greater in sprinters than distance runners. Med Sci Sports Exerc. 2000;32(6):1125–1129; doi: 10.1097/00005768-200006000-00014.
6. Kumagai K, Abe T, Brechue WF, Ryushi T, Takano S, Mizuno M. Sprint performance is related to muscle fascicle length in male 100-m sprinters. J Appl Physiol. 2000;88(3):811–816; doi: 10.1152/jappl.2000.88.3.811.
7. Stafilidis S, Arampatzis A. Muscle–tendon unit mechanical and morphological properties and sprint performance. J Sports Sci. 2007;25(9):1035–1046; doi: 10.1080/02640410600951589.
8. Blazevich AJ, Sharp NC. Understanding muscle architectural adaptation: macro- and micro-level research. Cells Tissues Organs. 2005;181(1):1–10; doi: 10.1159/000089964.
9. Sturgess S, Newton RU. Design and implementation of a specific strength program for badminton. Strength Cond J. 2008;30(3):33–41; doi: 10.1519/SSC.0b013e3181771008.
10. Baker D. Improving vertical jump performance through general, special, and specific strength training: a brief review. J Strength Cond Res. 1996;10(2):131–136; doi: 10.1519/1533-4287(1996)010<0131:IVJPTG>2.3.CO;2.
11. Chin MK, Steininger K, So RC, Clark CR, Wong AS. Physiological profiles and sport specific fitness of Asian elite squash players. Br J Sports Med. 1995;29(3):158–164; doi: 10.1136/bjsm.29.3.158.
12. Chin MK, Wong AS, So RC, Siu OT, Steininger K, Lo DT. Sport specific fitness testing of elite badminton players. Br J Sports Med. 1995;29(3):153–157.
13. Hughes MG, Bopf G. Relationships between performance in jump tests and speed tests in elite badminton players. J Sports Sci. 2005;23(2):194–195.
14. Klimstra M, Dowling J, Durkin JL, MacDonald M. The effect of ultrasound probe orientation on muscle architecture measurement. J Electromyogr Kinesiol. 2007;17(4):504–514; doi: 10.1016/j.jelekin.2006.04.011.
15. Pang BS, Ying M. Sonographic measurement of Achilles tendons in asymptomatic subjects: variation with age, body height, and dominance of ankle. J Ultrasound Med. 2006;25(10):1291–1296; doi: 10.7863/jum.2006.25.10.1291.
16. Rutherford OM, Jones DA. Measurement of fibre pennation using ultrasound in the human quadriceps in vivo. Eur J Appl Physiol Occup Physiol. 1992;65(5):433–437; doi: 10.1007/BF00243510.
17. Alegre LM, Jiménez F, Gonzalo-Orden JM, Martín-Acero R, Aguado X. Effects of dynamic resistance training on fascicle length and isometric strength. J Sports Sci. 2006;24(5):501–508; doi: 10.1080/02640410500189322.
18. Baechle TR, Earle RW. Essentials of strength training and conditioning. Champaign: Human Kinetics; 2008.
19. Brophy R, Silvers HJ, Gonzales T, Mandelbaum BR. Gender influences: the role of leg dominance in ACL injury among soccer players. Br J Sports Med. 2010;44(10):694–697; doi: 10.1136/bjsm.2008.051243.
20. Nadzalan AM, Mohamad NI, Lee JLF, Chinnasee C. Relationship between lower body muscle architecture and lunges performance. Journal of Sports Science and Physical Education. 2016;5(2):15–23.
21. Blazevich AJ, Cannavan D, Coleman DR, Horne S. Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. J Appl Physiol. 2007;103(5):1565–1575; doi: 10.1152/japplphysiol.00578.2007.

22. Aagaard P, Andersen JL, Dyhre-Poulsen P, Leffers AM, Wagner A, Magnusson SP, et al. A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. J Physiol. 2001;534(Pt 2):613–623; doi: 10.1111/j.1469-7793.2001.t01-1-00613.x.
23. Blazevich AJ. Effects of physical training and detraining, immobilisation, growth and aging on human fascicle geometry. Sports Med. 2006;36(12):1003–1017; doi: 10.2165/00007256-200636120-00002.
24. Earp JE. The influence of external loading and speed of movement on muscle-tendon unit behaviour and its implications for training. Doctoral dissertation. Perth: Edith Cowan University; 2013.
25. Earp JE, Newton RU, Cormie P, Blazevich AJ. The influence of loading intensity on muscle-tendon unit behavior during maximal knee extensor stretch shortening cycle exercise. Eur J Appl Physiol. 2014;114(1):59–69; doi: 10.1007/s00421-013-2744-2.
26. Bloomquist K, Langberg H, Karlsen S, Madsgaard S, Boesen M, Raastad T. Effect of range of motion in heavy load squatting on muscle and tendon adaptations. Eur J Appl Physiol. 2013;113(8):2133–2142; doi: 10.1007/s00421-013-2642-7.
27. Blazevich AJ, Giorgi A. Effect of testosterone administration and weight training on muscle architecture. Med Sci Sports Exerc. 2001;33(10):1688–1693; doi: 10.1097/00005768-200110000-00012.
28. Blazevich AJ, Gill ND, Bronks R, Newton RU. Training-specific muscle architecture adaptation after 5-wk training in athletes. Med Sci Sports Exerc. 2003;35(12): 2013–2022;doi:10.1249/01.MSS.0000099092.83611.20.