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**Research article**

**RELATIONSHIP BETWEEN LOWER BODY MUSCLE ARCHITECTURE AND LUNGES PERFORMANCE**

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**Abstract**

*Journal of Sports Science and Physical Education* 5(2): 15-23, 2016 - This study was conducted to determine the relationship between lower body muscle architectures and lunges performance. Thirty recreationally active, untrained men (mean age =  $22.21 \pm 1.59$  yrs old) were recruited and involved in two testing sessions; i) anthropometrics and muscle architecture, and ii) multiple-repetition maximum (RM) lunge test. Muscle thickness, pennation angle and fascicle length of vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF) and biceps femoris (BF) were analysed using ultrasonography. Multiple-RM lunge testing was used as an estimation of 1RM lunges performance. Correlation analysis was used to determine the relationship between lower body muscle architectures and lunges performance calculated absolutely and relatively (1RM/body mass). The overall results showed that muscle thickness and pennation angle of all muscles were significantly positive correlated with lunges performance. However, fascicle length was shown to be negatively correlated with lunges performance. Findings of this study suggested the important for having thicker, more pennated and shorter fascicle of lower body muscle in enhancing lunges performances that is one of the most specific movements in sport.

**Keywords:** *fascicle length, lunges, muscle thickness, pennation angle*

## Introduction

Previous studies have shown the existence of relationship between muscle architecture and performance and how training could alter the architecture of muscles (e.g. fascicle length, muscle thickness, pennation angle etc.) (Blazevich, 2006; Blazevich, Cannavan, Coleman, & Horne, 2007; Duclay, Martin, Duclay, Cometti, & Pousson, 2009; Earp, 2013; Earp et al., 2010; Earp, Newton, Cormie, & Blazevich, 2014). Among the types of training that have been investigated was resistance training in which has been shown to cause certain changes in muscle architecture (Blazevich, 2006; Blazevich et al., 2007; Bloomquist et al., 2013; Duclay et al., 2009; Earp, 2013; Earp et al., 2014; Seynnes, de Boer, & Narici, 2007). As such, study by Nimphius, McGuigan, and Newton (2012) showed strength training cause several changes to muscle architectures including muscle thickness and these changes were related to relative strength and speed improvements among female athletes.

Resistance training have been shown to increased pennation angle of muscles that been trained (Blazevich, 2006; Blazevich et al., 2007; Bloomquist et al., 2013; Duclay et al., 2009; Earp, 2013; Earp et al., 2014; Seynnes et al., 2007). The increment in pennation angle will causes a cross sectional area of muscle to have more number of fibers. This will therefore increase the muscle ability to produce more force. Manal, Roberts, and Buchanan (2006) found pennation angle to be correlated with muscle thickness and improvement in strength.

Several previous studies had found that muscle architecture was associated with running, squat movement and jumping performances (Abe, Kumagai, & Brechue, 2000; Earp et al., 2010; Kumagai et al., 2000). Study by Abe et al. (2000) has found that trained sprinters were shown to have thicker and longer fascicles, and lesser pennation angles in the vastus lateralis (VL) and the medial (MG) and lateral gastrocnemius (LG) compared to trained distance runners. In another study, 100-m sprinters with faster sprint times were shown to have greater muscle thickness at LG and smaller pennation angles at VL, MG, and LG compared to slower runners (Kumagai et al., 2000). Contrary to both studies, Earp et al. (2010) found greater muscle thickness and pennation along with shorter fascicles were beneficial for jumping ability at increased pre-stretch loads. These contrast findings suggested that the muscle architectures are different based on the training adopted by the individuals.

The concept of specificity in training has received considerable mention and attention over the past decade (Fleck & Kraemer, 2014). Thus, it is important to analyse the movements been performed in a specific sport as the more similar the training activity is to the actual sport movement, the greater the likelihood of positive carryover to performance (Fleck & Kraemer, 2014). In contrast to the squatting movement that have been used in training program for many years, most movements in sports involve an athlete to split apart their feet so that one foot is in front of the other. Several benefits evolved when performing exercises with one limb such as the ability to reduce bilateral deficit (Sale, 1988), detection of muscular imbalances and the greater proprioceptive demand while performing the split position (Tippett & Voight, 1995). To better train the body to become functional in various directions, lunge exercise is suggested to be included in the training program.

One of the most performed lunges technique is the forward lunges. Forward lunge started with a front step followed by a backward push. In order to enhance its effectiveness, the forward lunge should be performed with the lead leg been brought as far as possible to the

front as in descent phase, the knee should not exceed the toe. Forward lunge have been shown to activate thigh muscles especially quadriceps and hamstrings.

Consistent with the important of lunges movement in sports and due to the lack of studies conducted on finding the relationship between muscle architectures and lunges performances, it was the aim of this study to determine the relationship between muscle thickness, fascicle length and pennation angle of vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF) and biceps femoris (BF) on lunges performances.

## **Methods**

### ***Experimental Approach to the Problem***

30 men were involved as research participants in this correlation and cross-sectional experimental study. Participants involved in two testing sessions separated 24 hours between those sessions. The first testing sessions was the data collection for anthropometrics and muscle architecture using ultrasonography. During this session, participants' body mass, height, VL, VM, RF and BF muscle thickness, pennation angle, and fascicle length were collected. Multiple-RM lunges test was conducted on the second testing session. Correlation analysis was used to determine if there were relationships between participants' lower body muscle architecture and lunges performances.

### ***Participants***

30 recreationally active, untrained men (mean age =  $22.21 \pm 1.59$  yrs old) were recruited as study participants. Participants had no medical problems and not consuming any performance enhancing supplementation. Participants were screened prior to testing using PAR Q test. Each participant had read and signed an informed consent for testing and training approved by the Sultan Idris Education University Research Committee and had been conducted according to Declaration of Helsinki. Each participant self-reported that they were familiar with lunges movement and but had never involved in any systematic resistance training.

### ***Image Analyses***

Ultrasonography method was used to measure muscle thickness, fascicle length and pennation angle of VL, VM, RF and BF. These muscle architectures were measured using B-mode ultrasonography (F37, Aloka, Ltd, Tokyo, Japan) on the participant's self-reported dominant side.

During the measurement, the ultrasound probe was positioned longitudinally as prescribed in previous study (Klimstra, Dowling, Durkin, & MacDonald, 2007). The researcher maintained the probe positioning with equal contact pressure during all measurements. The measurement of VL, VM and RF muscle thickness and pennation angle were done while the subject lying supine with leg straight (Pang & Ying, 2006; Rutherford & Jones, 1992). The BF muscle architectures were determined while the subject lying prone with leg straight (Fredberg, Bolvig, Andersen, & Stengaard-Pedersen, 2008; Ward, Eng, Smallwood, & Lieber, 2009). All measurements were taken while the leg was in resting position. Based on the muscle thickness and pennation angle, fascicle length was calculated based on the equation used by Alegre, Jiménez, Gonzalo-Orden, Martín-Acero, and Aguado

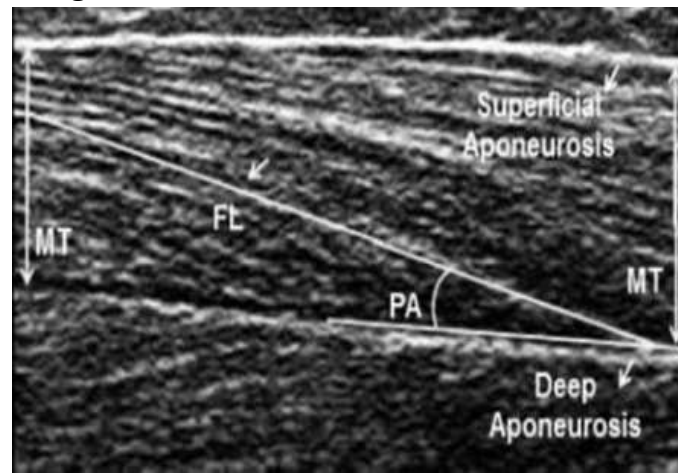
(2006) (equation 1). All ultrasound measurement was performed by the same researcher. Figure 1 showed the example of image taken during ultrasonography.

Three consecutive images were analyzed and averaged. The intraclass correlation coefficients for repeated scanning of muscle thickness, pennation angle and fascicle length measurements were ranged from 0.9 to 0.996 ( $p < 0.001$ ).

Equation 1

$$\text{Fascicle length} = \text{Muscle thickness} / \sin (\text{pennation angle})$$

**Figure 1:** Muscle architecture of vastus lateralis



### ***Forward lunges***

Participants were instructed to stand with their hands holding the bar placed on their shoulder, feet shoulder width apart. Participants lunged forward with the dominant foot and lowered the thigh to 90° or parallel with the ground, and then returned back to the starting position. Participants were needed to make a big step as during downward position, the knee should not extend beyond the toe. The non-dominant foot must not move from its starting position, and the head should always face forward.

### ***Multiple-RM procedure***

The multiple-RM testing protocol were conducted for the 1RM lunges performances following the guidelines by the National Strength Conditioning Association (Baechle & Earle, 2008). During the test, participants were instructed to warm up with a light resistance that easily allows 5 to 10 repetitions. Next, participants were provided with a 1-minute rest period. Participants were required to lift a load that he estimated can perform 8RM. If the participants were able to lift more than 8RM, the load was increased 10% to 20% of that load. The load was continuously changed if the participants can complete more than 8RM with proper exercise technique. Three trials were given for each participant to obtain the 8RM score. Failure were defined as the time point when the participant paused more than 1s when the leg was in the extended position, or if the participant was unable to complete each repetition in a full range of motion.

### Statistical Analyses

Reliability of measurement was calculated between the 3 trials using intra-class correlation coefficients (ICCs). 0.70 was considered as a minimum acceptable reliability (Baumgartner & Chung, 2001). Descriptive statistics were used to measure the descriptive data and mean score. Pearson Correlation was used to determine the relationship of the muscle architecture and the 1RM lunges performances calculated absolutely and relatively to body weight. Statistical significance was accepted at an  $\alpha$ -level of  $p \leq 0.05$ . All statistical analyses were conducted using SPSS version 23 (IBM, New York, USA).

### Results

Table 1 showed the physical characteristics of participants involved in this study.

**Table 1:** Physical characteristics of participants

| Age (years)      | Body mass (kg)   | Height (cm)       |
|------------------|------------------|-------------------|
| 22.21 $\pm$ 1.59 | 68.53 $\pm$ 3.26 | 170.46 $\pm$ 4.25 |

Table 2 showed the muscle architecture (muscle thickness, pennation angle and fascicle length) of the VL, VM, RF, BF, MG and LG.

**Table 2:** Muscle architecture of participants

| Muscles | MT (cm)         | PA (°)           | FL (cm)         |
|---------|-----------------|------------------|-----------------|
| VL      | 2.34 $\pm$ 0.08 | 17.06 $\pm$ 1.40 | 8.01 $\pm$ 0.55 |
| VM      | 2.61 $\pm$ 0.07 | 16.75 $\pm$ 0.97 | 9.01 $\pm$ 0.28 |
| RF      | 1.82 $\pm$ 0.08 | 12.19 $\pm$ 1.37 | 8.68 $\pm$ 0.62 |
| BF      | 2.45 $\pm$ 0.14 | 14.59 $\pm$ 0.86 | 9.73 $\pm$ 1.23 |

Table 3 showed the mean and standard deviation of absolute and relative 1RM score of the participants.

**Table 3:** Absolute and relative 1RM lunges score of participants

|       | Absolute 1RM (kg) | Relative 1RM (1RM/BM) |
|-------|-------------------|-----------------------|
| Score | 69.21 $\pm$ 4.14  | 1.01 $\pm$ 0.02       |

Table 4 showed the correlation analysis between muscle architecture and 1RM score (absolute and relative). Results showed there were significantly positive relationships between 1RM and all the muscle thickness and pennation angle of all the muscles investigated ( $p < 0.05$ ). Results also showed that significantly negative relationships existed between 1RM and the fascicle length of VL and RF ( $p < 0.05$ ). The fascicle length of BF were shown not to be correlated with 1RM lunges performance whether calculated absolutely or relatively ( $p > 0.05$ ).

**Table 4:** Correlation analysis of muscle architectures and 1RM lunges

| Muscle | Architecture | Absolute 1RM lunges<br>score<br>r | Relative 1RM lunges<br>score<br>r |
|--------|--------------|-----------------------------------|-----------------------------------|
| VL     | MT           | .535**                            | .487**                            |
|        | PA           | .605***                           | .562**                            |
|        | FL           | -.507**                           | -.482**                           |
| VM     | MT           | .727*                             | .559**                            |
|        | PA           | .597***                           | .519**                            |
|        | FL           | -.300                             | -.399*                            |
| RF     | MT           | .788***                           | .639***                           |
|        | PA           | .769***                           | .617***                           |
|        | FL           | -.671***                          | -.538**                           |
| BF     | MT           | .790***                           | .659***                           |
|        | PA           | .706***                           | .632***                           |
|        | FL           | -.077                             | -.211                             |

\*Data is significant at  $p < 0.05$

\*\* Data is significant at  $p < 0.01$

\*\*\* Data is significant at  $p < 0.001$

## Discussions

The major findings in this study were that there were relationships between the lower body muscle architectures and lunges performances. Pennation angle and muscle thickness were shown to be positively correlated with lunges performance. However, fascicle length was found to be negatively correlated with lunges performance. It was also found that the relationship between the muscle architectures examined were stronger with the absolute score of strength compared to the relative score.

Pennation angle of all muscles investigated were shown to be positively correlated with 1RM lunges performances. It is believed that with greater pennation, there will be more fibers that can be fit within a given cross-sectional area. This will then increases the physiological cross-sectional area of the muscle allowing for greater force to be developed (Blazevich et al., 2007). Based on the results, increasing pennation angle that contribute to increasing physiological cross-sectional area (Earp et al., 2010) will allow high force to be produced during this movement. Different from the squat, lunge is a more complex movement in which both the downward and upward phase need to be critically controlled by the performer because of the instability imposed by one foot. Lunges movement need to be highly controlled during eccentric phase to make sure no unnecessary movement happen to the knee and ankle that can possibly lead to those joints injuries. During eccentric movement or during descending phase, a lot of forces need to be produced by all the lower body muscles (in this study: quadriceps, hamstrings and gastrocnemius) and the pennation angle has been proven to be a contributing factor to this phase.

Besides that, findings in the current study also showed participants with shorter fascicle lengths had more ability to lift more loads during lunges movement. This demonstrated the effectiveness of shorter fascicles to control the increased eccentric forces during the descent phase of lunges 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. (2010) suggested that this condition might be explained by the behaviour of the longer fascicles that have more potential places of fascicle disruption that can contribute to higher instability of muscle fascicles. However, this was a possible explanation that still need to be investigated in the future research.

Understanding the muscle architecture roles during lunges movement will provide many benefits to coaches and athletes. Coaches and athletes will know the anatomical structure that will impose advantages to the athletes for the movement. A good training program would be able to be planned in order to impose specific adaptations to the muscle architectures.

Some previous studies have been conducted on examining the effects of resistance training on muscle architectures (Aagaard, Andersen, Dyhre-Poulsen, et al., 2001; Blazevich, 2006; Blazevich et al., 2007; Bloomquist et al., 2013; Earp, 2013; Earp et al., 2014). It has been found that different resistance training program might causes different changes to the fascicle pennation angle. Heavy resistance training were shown to result in increment of muscle cross sectional area (CSA), fascicle thickness and pennation angle (Aagaard, Andersen, Dyhre-Poulsen, et al., 2001; Blazevich & Giorgi, 2001). Bloomquist et al. (2013) in their study found muscle thickness and pennation angle increase as a result of deep and shallow squat but no different between groups were shown. Nonetheless, there were also studies that found no changes and some even reported decrement in pennation angle due to the resistance training (Blazevich, Gill, Bronks, & Newton, 2003; Rutherford & Jones, 1992). The contrast findings could be resulted by the different training loads and velocity of movement used in those studies. Thus, more studies are needed to develop better understanding of the effects of various training to the adaptations of muscle architecture.

The current findings of lunges performances were found to be different from previous studies of sprint performances. While previous study demonstrated that faster 100-m sprinters had longer fascicle length with lesser pennation angle in the gastrocnemius (Kumagai et al., 2000), current findings showed the contrast where shorter fascicle lengths with greater pennation angle will allow for more loads to be lifted during lunges. Current findings was in line with findings of Earp et al. (2010) where more pennated fascicles were correlated with jumping performances. However, despite the differences of pennation angle and fascicle length, it should be noted that thicker muscles was found to be advantages for running velocity, jump performances and lunges performances.

An interesting part of the findings was that muscle architectures investigated in this study were more correlated to the absolute score of lunges performance compared to if the score calculated relatively to the participants' body mass. It can be hypothesized from the current findings that muscle thickness, which was also used as an estimate of muscle size, was more crucial in producing force.

### **Practical Applications**

Overall, relationships existed between muscle architecture and 1RM lunges performances. Findings suggested the important for having thicker, more pennated and shorter fascicle of lower body muscle in enhancing lunges performances. Training could be planned to make specific changes in muscle architecture to allow for better performance in this movement which is one of the most performed movement in sport.

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