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A Comparative Study of White Muscle and Red Muscle Fiber Architectural Parameters

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Abstract

The primary objective of this research was to compare red muscle fiber and white muscle fiber muscle architectural parameters of vastus lateralis (VL). The study sample consisted of 70 recreationally active male students from Gwalior, Madhya Pradesh. One repetition maximum Dr. Hatfield test was used to determine muscle fiber type. Thirty (N_1 = 15 red muscle fiber group and N_2 = 15 red muscle fiber group) out of 70 samples were retained in study for further evaluation. Muscle architectural parameters (VL, pennation angle [PA], fascicle length [FA], and muscle thickness [MT]) were measured using B-mode ultrasonography. Independent sample t-test was employed to determine a significant difference between selected white muscle fibers group and selected red muscle fibers on the basis of selected muscle architectural parameters. The vastus lateralis muscle showed differences in its PA, FA, and MT between different muscle fiber groups. The PA of red muscle fiber group was greater than white muscle fiber group, whereas the FA and MT of white muscle fiber group were greater than red muscle fiber group. In conclusion, architectural parameters studies carried on specific sports group will be helpful in future, and muscle architectural parameters may be considered as a new approach for muscle fiber type classification in the future.

Keywords: Fascicle length, Muscle architecture, Muscle thickness, Pennation angle, Ultrasound, Vastus lateralis

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Introduction

Fast-twitch and slow-twitch muscle fibers are the two main types of skeletal muscle fiber. It's crucial to know the differences between each type's functionalities. Skeletal muscles are made up of individual muscle fibers; not all muscle fibers are the same. Movement and exercise programs would be incomplete without them. Slow-twitch muscle fibers have high concentrations of mitochondria and myoglobin.[1] Although they are smaller than the fast-twitch fibers, they are surrounded by more capillaries. Slow-twitch muscle fibers produce less force and are slower to produce maximal tension (lower myosin ATPase activity) but they are able to maintain longer-term contractions, key for stabilization and postural control. Fast-twitch muscle fibers produce a greater and quicker force, an important consideration for power activities. Typically, these have lower concentrations of mitochondria, myoglobin, and capillaries compared to our slow-twitch fibers, which means they are quicker to fatigue.[2,3] Slow-twitch muscle fibers facilitate long-distance endurance exercises like marathon running, whereas fast-twitch muscle fibers support short, forceful activities such as sprinting or weightlifting.

To successfully predict human movement and athletic performance, one of the most significant and dependable critical characteristics is muscle architecture.[4-10] Ultrasonography has been actively used since 1990 to examine muscle architectural characteristics. Various studies have analyzed how the architectures of the quadriceps, gastrocnemius, pectoralis major, and latissimus dorsi of swimmers, soccer players, sprinters, and distance runners are related to their sport performance.[11-13]

Gans and De Vries were the first to describe muscle architecture. Muscle architecture refers to the macroscopic arrangement of muscle fibers that control a muscle's mechanical function.[7] Pennation angle (PA) is defined as the angle between a fascicle's orientation and the tendon axis.[7] Muscle fiber length is defined as the distance from the origin of the most proximal muscle fibers to the insertion of the most distal muscle fibers.[13]

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Muscle thickness (MT) is defined as the thickness between two fascias of muscle. In general, thickness considered as the main factor for determining muscle size.[10] MT, muscle volume, PA, and fascicle length (FA) are all tightly correlated to maximal muscle strength and power.[7,13,14]

Scientific works on muscular architecture are presently trending in this time. Various architectural variables and their relationship with sports are briefly explained.

Muscle force is directly related to physiological cross-sectional area. Muscle velocity is inversely related to the length of the muscle fibers. Sprinters have longer fascicles than distance runners, and this is reflected in their leg muscle length. Sprinters' leg muscles have a longer FA vastus lateralis (VL) and a smaller PA than the general population. Greater PA permits a greater quantity of contractile tissue to bind to a given piece of tendon or aponeurosis, thus increasing the physiological cross-sectional area of a muscle.[15-17] The increment in PA will causes a cross-sectional area of muscle to have more number of fibers. This will, therefore, boost the muscular ability to produce more force. Manal *et al*.[18] discovered PA to be linked with MT and improvement in strength. However, an increment of PA with constant cross-sectional area has been reported to cause reduction of strength.[19] This condition was assumed to be influenced by the angle of pull of the fibers that are indirect to the draw of the muscle in total and thus causes the pull of the muscle in total lowered by the cosine of the PA. FA is the distance of fascicle from aponeurosis to another aponeurosis. Mathematically, it is a product of fascicle thickness and PA. FA will be increased with the increment of MT and decrement of PA. A difference in MT in the leg muscles (VL, gastrocnemius medialis and lateralis) is a significant element in distinguishing sprinters from long-distance runners.[7]

Aim of the Study

The primary objective of this research was to compare slow muscle fiber and white muscle fiber muscle architectural parameters of VL. The selected muscle architectural parameters for this research were PA, FA, and MT.

Materials and Methods

Study Participants

In this work of investigation, a total sample comprised 70 recreationally active male studying in schools of Gwalior, Madhya Pradesh, was considered as sample for the present investigation. Purposive sampling technique was employed for selecting sample. The selected sample was subjected to the Dr. F. Hatfield one repetition maximum test to determine their muscle fiber type. Thirty (N_1 = 15 red muscle fiber group and N_2 = 15 red muscle fiber group) out of 70 samples were retained in study for further evaluation. The selected subjects' age ranged between 12 and 19 years. Required data were collected after taking consent of concerned subject and parents of selected subject. This study was approved (File No. – Academic/PhD/384/964) by Departmental Research Committee of Lakshmibai National Institute of Physical Education, Gwalior, M.P., India.

Muscle Fiber Type Determination

Subjects performed a 1 RM protocol to determine the maximal load they could lift for the back squat with correct technique using a standard 20 kg Olympic barbell. Participants did a quick warm-up with a load they chose that allowed them to finish at least eight repetitions. Participants squatted with the bar across their posterior deltoids and until the tops of their thighs were parallel to the ground for each 1 RM attempt (descending and ascending for 2 s and 1 s, respectively). The National Strength and Conditioning Association established criteria for determining the one repetition maximum.[20] Participants rested passively for 15 min after completing their 1 RM load. Following a brief rest period, participants were directed to complete as many consecutive repetitions at 80% of their individual 1 RM load as possible in one continuous effort, following to the same descent, ascent, and bar positioning criteria as during 1 RM attempts. The test administrator vocally encouraged, led, and oversaw all attempts.[21] The results used as, <7 repetitions – fast-twitch muscles fibers are dominant and more than 8 repetitions – slow-twitch dominant.

Determination of Muscle Architectural Parameters

Before collecting ultrasound images, participants reported to the laboratory and laid supine for 15 min to allow fluid shifts to occur. Following that, non-invasive skeletal muscle ultrasound images using B-mode ultrasonography (Wipro GE Voluson E) of the quadriceps muscles were obtained. To improve spatial resolution, a 12 MHz linear probe scanning head was coated with water soluble transmission gel and positioned on the skin's surface to create acoustic contact without disturbing the dermal layer to gather the image. All measurements were collected on the dominant leg by the same technician. For each muscle in all individuals, the anatomical position for all ultrasound measurements was standardized. Briefly, PA was defined as the angle at which muscle fiber fascicles inserted into the deep aponeurosis. The length of the fascicular path between the insertions into the superficial and deep aponeurosis was quantified, and the missing component of the fascicle was calculated by extrapolating linearly the fascicular path and the aponeurosis where the fascicular path went beyond the obtained picture. MT was determined by measuring the distance between the subcutaneous adipose tissue and the intermuscular contact (MT). The average of three successive frames was calculated. Repeated scanning of MT, PA, and FA [Figure 1] measurements yielded intraclass correlation values varying from 0.9 to 0.996 (P <0.001).[4]

Statistical Analysis

An independent sample t-test was employed to determine a significant difference between selected white muscle fibers group and selected red muscle fibers group on the basis of selected muscle architectural parameters. Statistical significance was considered at an alpha-level of $p < 0.05$. The statistical analyses were performed using SPSS version 20.

Results

Table 1 depicts the descriptive statistics of the research participants' age, weight, and height. The selected subject's age mean and standard deviation were 17 years and 1.25 years, respectively. The selected subject's body mass mean was 66 kg, and the standard deviation was 5.75 kg. The selected subject's mean height was 171 cm, and the standard deviation was 6.20 cm.

The mean and standard deviation of muscle architectural parameter, that is, MT of quadriceps, for different muscle fiber

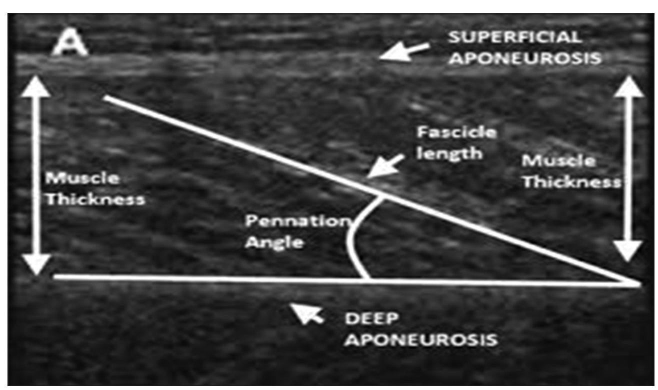

Figure 1: Vastus lateralis muscle architectural parameters

Table 1: Descriptive statistics of physical characteristics of selected subjects

Age (years)	*Body mass (kilogram)*	*Height (cm)*
17±1.25	66±5.75	171.7±6.20

groups are shown in Table 2 and represent the descriptive statistics of VL muscle architecture of selected groups. The mean and std. dev. of PA for VL red fibers was 15.04 ± 2.40 cm, and for white fibers, it was 16.86 ± 2.55. The FA for VL white fibers was 114.55 ± 6.75 mm, and for red fibers, it was 107.8 ± 5.10 mm. The MT for VL red fibers was 1.96 ± 0.50 cm, and for white fibers, it was 2.97 ± 0.61 cm.

The value of the Levene's test and T-statistics is shown in Table 3. The Levene's assumption is used in the two-sample t-test to determine group homogeneity. The resulting value for the Levene's test is 0.724, 0.754, and 0.820, all of which are more than 0.05, indicating that the equality of variance assumption is not violated. Thus, the null hypothesis of equality of population means of the two groups is rejected, and it may be concluded that the muscle architectural parameters of VL of white muscle fibers and selected red muscle fibers are different. The T-values found for PA, FL, and MT are −2.009, 3.090, and 4.904, respectively, which is significant since $P = 0.00$, which is <0.05.[22] Furthermore, from Table 2, it is clearly visible that the FL and MT of the white muscle fibers (114.55 cm and 2.97 cm) group are greater than those of the red muscle fibers (107.8 cm and 1.96 cm), PA of the red muscle fibers group (15.04°) is greater than those white muscle fibers group (16.86°), and therefore, it may be concluded that selected white muscle fiber group had greater FL, and MT than the red muscle fiber group, and there was a significant difference among the groups on selected muscle architectural parameters.

Table 2: Descriptive statistics of VL muscle architecture of selected groups

Muscle Architecture	*Red muscle fiber*		*White muscle fiber*	
	Mean	*Std. dev.*	*Mean*	*Std. dev.*
Pennation angle (⁰)	15.04	2.40	16.86	2.55
Fascicle length (mm)	107.8	5.10	114.55	6.75
Muscle thickness (cm)	1.96	0.50	2.97	0.61

Table 3: The significance of the difference in mean muscle architectural parameters between selected white muscle fibers and selected red muscle fibers

Muscle Architectural Parameters	*Levene's test for equality of variances*		*t-test for equality of means*		
	F	*Sig.*	*t*	*df*	*Sig. (two tailed)*
Pennation angle (0)					
Equal variances assumed	0.127	724	-2.009	28	0.044
Fascicle length (mm)					
Equal variances assumed	0.100	754	3.090	28	0.004
Muscle thickness (cm)					
Equal variances assumed	0.820	373	4.904	28	0.000

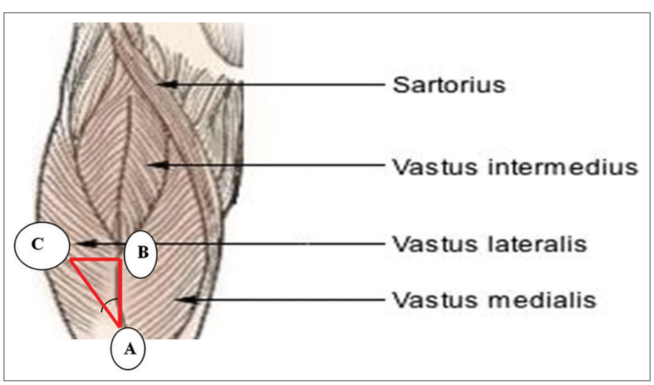

Figure 2: Vastus lateralis muscle architectural parameters are represented in triangle ABC

Discussion

In this work, the vastus lateralis muscle architecture parameters for red muscle fiber and red muscle fiber were investigated. The parameters used for this comparison investigation were PA, FA, and MT. An independent sample t-test was employed to determine a significant difference between selected white muscle fibers and selected red muscle fibers in terms of selected muscle architectural parameters. Our observations demonstrate the importance of architectural parameters in the vastus lateralis in distinguishing red and white muscle fibers. According to this research and researches completed by others, the white muscle fiber group had thicker vastus lateralis and longer muscle fibers in their leg muscles than the red muscle fiber group, according to the research. In the leg muscles of the white muscle fiber group, the PA (the angle at which a muscle contracts and shortens) is less than in the leg muscles of the red muscle fiber group. Because muscles with a larger PA contract at a slower contraction than muscles with a smaller PA, the white muscle fiber group has the physiological advantage of being better able to create high-speed contractions in their leg muscles. White muscle fibers lower PA, greater FA, and better strength production can be explained using geometric functions also – let's assume an right angle triangle ABC on the surface of vastus lateralis, as shown in Figure 2, where side AC represents the FA, AB represents the aponeurosis, and BC represents width of the muscle. Angle BAC represents the PA.

Considering PA as function of Cosine then, $\text{Cos}\,\theta = \frac{AB}{AC}$, since the cosine angle decreases, the length of AC increases, which clearly establishes the lower PA of muscle allows them to have larger FA. Let's consider AB as , AB as $\vec{a}$ and BC $\vec{b}$ as the resultant vector, therefore, resultant will be: $R=\sqrt{\vec{A}^2+\vec{B}^2+2\,AB\cos\theta}$ As, the value of cosine decreases (Cos 17 = 0.9563, Cos 16 = 0.9612, and Cos = 0.9659), its function value increases and overall resultant increases.

Studies by Abe *et al.*,[11] Kumagai *et al.*,[13] Blazevich *et al.*,[17] Blazevich[23] reported that greater FA of muscles represents longer sarcomeres in series, which means that greater FA would be beneficial when for force production at fast movement speeds which is typical properties of white muscle fibers. The increment of the length of contractile element will enable faster contraction velocity and more force that can be applied at an increasing velocity. We believe that future research comparing muscle characteristics and performance across sports will benefit from these results.

Conclusions

We compared the muscle architectural parameters between white muscle fibers and selected red muscle fibers using ultrasonography. The vastus lateralis muscle showed differences in its FL, PA, and MT between white and red muscle fiber groups. The PA of red muscle fiber group was greater than white muscle fiber group, whereas the FA and MT of white muscle fiber group were greater than red muscle fiber group. These architectural parameters studies carried on specific sports group will be helpful in future, and muscle architectural parameters may be considered as a new approach for muscle fiber type classification in the future.

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