RELATIONSHIP BETWEEN MUSCLE ARCHITECTURE AND CONCENTRIC MOVEMENT VELOCITY DURING RESISTANCE EXERCISE

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We compared muscle architecture with concentric movement velocity (CMV) during resistance exercise (RE). Twenty-four RE active males (21.4 ± 1.8 yrs) completed a dominant leg, single-leg leg extension at 75 & 90% of 1-repetition maximum (1RM) to failure. Ultrasound measures of the vastus lateralis (VL) were taken to assess pennation angle (PA), muscle thickness (MT) & fascicle length (FL). MT & 1RM were moderately correlated (r=0.32). Further, PA & FL were significantly correlated with 75% 1RM peak (P) & average (Av) CMV, (r=0.41-0.75) & FL/MT was strongly correlated with 75% 1RM P & Av CMV (r=0.64-0.76). Additionally, multiple regression suggested PA & FL were significantly associated with CMV. The data suggest FL, PA & FL/MT are importantly related to CMV during moderate-to-heavy RE, to failure.

KEYWORDS: fascicle length, pennation angle, strength and conditioning movement velocity

INTRODUCTION: Muscle architecture, FL and PA, strongly influence muscle force production (Blazevich, 2006). Specifically designed training regimens have been shown to result in specific muscle architecture adaptations that most benefit the style of training (Blazevich, 2006). During a 14-week leg focused heavy-RE strength training study, changes in PA of the VL were related to changes in maximal strength (Aagaard et al., 2001). Greater increases in PA in a traditional based group, and greater increases in FL in a sprint/jump training group was observed during a 5-week training study (Blazevich et al., 2003). In general, hypertrophy and strength trained athletes tend to have greater PA and smaller FL, while speed and power athletes (I.e., Olympic weightlifters, track and field athletes) tend to have smaller PA and longer FL (Shigeki et al., 2008; Abe et al., 2000; Kumagali et al. 2000). The published literature suggests, longer FL are associated with speed and power, while greater PA are associated with greater force production. It is suggested that longer fascicles contain a larger number of simultaneously contracting sarcomeres to increase velocity of contraction and force generation over longer length ranges, while greater angulation related to a larger physiological cross section and slower contraction velocity, which enables a greater force production (Blazevich, 2006).

In a recent 8-week squat RE training study, Pareja-Blanco et al. (2017) suggest that using a higher velocity threshold to stop each set during training results in repetitions completed at a higher CMV when compared to the use of a lower velocity threshold training regimen. The researchers propose that training at a high velocity threshold results in less mechanical and metabolic training-related stress and different muscular structural and functional adaptations as compared to a lower velocity threshold training group. Additionally, we have presented preliminary data that suggests VBT RE results in similar increases in strength and faster CMV during submaximal RE loads (i.e., 75% & 90% 1RM) following 5 weeks of RE training, when compared to training to failure. However, to our knowledge no study has been published that compares CMV to muscle architecture (i.e., pennation angles, muscle thickness and fascicle length) during RE. Determining the extent of the relationship between muscle architecture and CMV during RE will extend and facilitate our understanding of structural and functional adaptations in response to VBT. The primary purpose of this study was to investigate the relationship between muscle architecture (i.e., pennation angles, muscular thickness, and fascicle length) and CMV during a set of RE completed at 75% and 90% 1-RM, to failure.

METHODS: 24 college-aged males volunteered to participate in this study. Subjects' physical characteristics are presented in Table 1. Subjects were instructed to not perform any lower body RE involving the quadriceps muscle group 24 hours prior to each participation day.

Table 1: Physical Characteristics

Variable	Mean	Std. Deviation
Age (years)	21.4	1.8
Height (cm)	180.3	6.5
Weight (kg)	77.9	10.5
Muscle Thickness (cm)	2.85	0.27
Pennation Angle (º)	12.1	1.5
Fascicle Length (cm)	13.85	2.24

On Day 1, subjects were instructed to arrive 4 hours fasted and hydrated. A series of anthropometric measurements of leg length, upper and lower leg length, waist circumference and thigh circumference were taken. Body composition was measured using an In-Body bioelectrical impedance device (InBody 770 – InBody USA, Cerritos CA). Ultrasound measures of the VL for each leg were taken at half the distance from the palpable center of the greater trochanter to the lateral condyle, which is about 50% the thigh distance (Blazevich et al., 2003; Fontana et al., 2016, Aagaard et al., 2001; Suetta et al., 2008). Measurements were taken with the subject sitting, when both the hip and knee were at 90^o and when the VL was relaxed. The ultrasound transducer (uSmart 3300 NexGen – Terason, Ormond Beach FL) was used to measure MT and PA in the longitudinal section of the muscle by manually tracing the fascicles and MT with on-screen calipers. VL fiber PA measurements were taken as the angle between the VL muscle fiber fascicles and the deep aponeuroses (Blazevich et al., 2003; Fontana et al., 2016, Aagaard et al., 2001; Suetta et al., 2008). PA were calculated using standard trigonometry [cos-1(a/f) = θ], where *f* is the FL, *a* is the deep aponeuroses length and *θ* is the PA (angle between the fascicle and aponeuroses). VL MT was measured in the same location as the distance between the superficial and deep aponeuroses of the VL (Blazevich et al., 2003; Fontana et al., 2016; Suetta et al., 2008). FL was estimated using the equation FL=(MT/sinθ), where *θ* is PA (Blazeich et al., 2003). Three ultrasound measurements were taken at each site and the average of the three measurements was used for data analysis. Subjects then completed a dominant leg, single-leg leg extension 1RM. 1RM was determined by consistently adding weight to a leg extension RE machine, until the subject could not perform a full repetition with the resistance. A full repetition was defined as completing 80% the leg extension movement distance from the initial warm-up repetitions. Once subjects could not reach a full repetition, the previous load was used and an increase in resistance, in increments of 2.5-5 lbs, was used until the subject could not complete a full repetition. Between repetitions, recovery time ranged from 1-3 minutes. Distance and velocity were monitored using an ultrasound sensor, NI-cRIO hardware, and custom-built software (NI-LabView) designed to measure the distance and time of the weight stack movement of the leg extension weight machine.

On Day 2, at least 48 hours after Day 1, dominant leg 1RM re-tests were performed to determine the reliability of initial 1RM testing. The highest 1RM value was used to determine 75 and 90% 1RM. On Day 3, at least 48 hours after Day 2, subjects performed as many repetitions as possible at 75% and 90% of the dominant leg 1RM. Hip and crossing shoulder straps were used to keep the subjects in a fixed position during RE trails. Total number of repetitions, resistance exercise time, and CMV of each repetition was recorded. The order of the percentage of 1RM sets were randomized and counter-balanced. The recovery time between each RE set ranged from 10 – 15 minutes to ensure full recovery. Each subject was instructed to perform each concentric portion of the repetition at maximum velocity, and perform the eccentric portion more slowly, under control and with a one second pause between each repetition. Pearson-product moment correlation was used to describe the relationship between CMV and muscle architecture variables. To provide another approached to the strength of the relationship between muscle architecture and CMV, multiple-regression analysis was performed using FL and PA as independent variables of CMV during 75 & 90% 1RM RE.

RESULTS: Anthropometric data suggested significant moderate correlations between thigh circumference and lean mass (r=0.43), as well as strong correlations between thigh circumference and vastus lateralis MT (r=0.70). MT was only moderately correlated with 1RM (r=0.32), while PA exhibited weak correlations with 1RM (r=0.27). FL exhibited moderate to strong correlations for MT (r=0.624) and PA (r=-0.80). MT was moderately correlated with 1RM (r=0.32). Moderate-to-strong correlations between characteristics of muscle architecture and CMV at 75 and 90% 1RM are displayed in Table 2. The relationships between PA and peak CMV is depicted in Figure 1 and FL/MT and peak CMV is depicted in Figure 2. Multiple regression analysis suggested FL and PA were significantly associated with peak CMV at 75% 1RM, ($p<0.001$, $R^2=0.630$). PA exhibited the strongest association with CMV ($P<0.0001$, partial correlation coefficients; FL r=-0.772, PA r=-0.487) at 75% 1RM.

Table 2: Relationship between muscle architecture and CMV

Variable	75% Average CMV	75% Peak CMV	90% Average CMV	90% Peak CMV
PA (º)	-0.63*	-0.75*	- 0.40	- 0.35
FL (cm)	0.49*	0.41*	0.43*	0.27
FL/MT (cm)	0.64*	0.76*	0.38	0.34

* Correlation is significant at 0.05.

Figure 1: Pennation angle and CMV

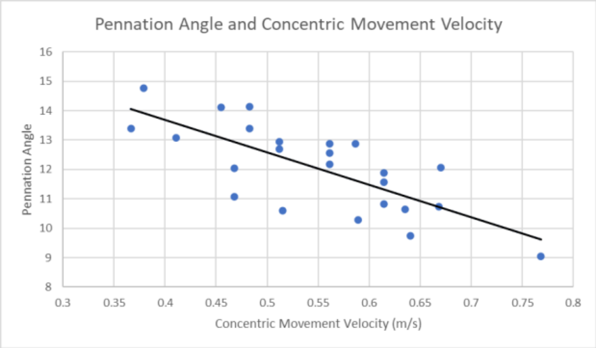
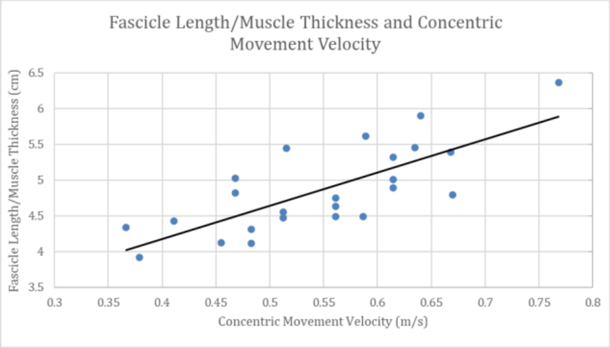


Figure 2: Relative Fascicle Length and CMV



DISCUSSION: Our study compared the relationship between muscle architecture and CMV during a single-leg leg extension RE. The data suggest a strong relationship between FL and PA and CMV at 75% 1RM (r=0.41 – 0.75). A longer FL was associated with faster peak (r=0.41, $p<0.05$) and average 75% CMV (r=0.49, $p<0.05$), while a greater PA was associated with a decrease in peak (r=-0.75, $p<0.01$) and average 75% CMV (r=-0.63, $p<0.01$). Previous studies have compared the relationship between FL and sprint and endurance performance (Abe et al., 2000; Kumagali et al. 2000), and concluded longer FL was associated with faster running speeds. Blazevich, (2006) suggests that longer fascicles contain a larger number of simultaneously contracting sarcomeres and this potentially results in an increase in the velocity of concentric muscle contractions. Moreover, previous studies have reported greater increases in PA following heavy RE training (Aagaard et al., 2001; Blazevich et al., 2003). Blazevich (2006) suggests greater fascicle angulation will result in a larger volume of contractile tissue to attach to the aponeurosis which could potentially result in greater force generation.

Our data suggests that absolute FL is moderately correlated with CMV (r=0.41-0.49), while the ratio of absolute FL to MT results in stronger correlations with CMV (r=0.64-0.76). Further, our data suggests there is a significant association between FL and MT (r=0.62) and this finding is in agreement with previous literature (Abe et al., 2000; Kumagali et al. 2000). Taken together, these findings extend previously published reports regarding these interrelationships. The use of the ratio between FL and MT (i.e., FL/MT) eliminates MT differences between subjects. The equation used to calculate absolute FL ($FL=MT/\sin\theta$) (Blazevich, 2006), implies that if two individuals have the same PA, but one has a greater MT, this individual will have a greater FL. However, our data suggests that since FL/MT is more strongly associated with CMV, this variable better explains this relationship rather than absolute FL. The rationale for the use of the ratio of FL/MT is as follows; as a result of a greater number of simultaneously contracting sarcomeres in a series, longer fascicles facilitate muscle contractions at higher shortening speeds (i.e., greater CMV), while greater PA enables higher force production due to greater physiological cross-sectional area and attachment to the tendon or aponeurosis (Blazevich, 2006). Individuals with a greater MT, will exhibit both greater FL and greater muscle cross sectional area attachments when compared to individuals with similar PA and less MT. Short-term RE training studies have shown that specific characteristics of muscle architecture adapt to the type of training stimulus (Blazevich, 2006; Blazevich et al., 2003). The muscle architecture of individuals who train or participate in the type of activities that require a combination of both high force and high CMV will adapt and result in greater MT and FL and greater CMV across multiple repetitions during moderate-to-high intensity RE.

CONCLUSION: Muscle architecture (i.e., FL, PA and FL/MT) strongly influences CMV during resistance exercise. Both longer FL and a smaller PA result in greater peak and average CMV during moderate-to-high intensity RE. These data suggest FL, PA and the ratio of FL to MT are all involved in concentric movement velocity during moderate-to-heavy RE.

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