Short Communication

Relationships between lower body muscle structure and maximal power clean performance

John J. McMahon, Aaron Turner, Paul Comfort

Objectives: Correlational studies have linked distinct characteristics of lower body muscle structure (e.g. muscle thickness and pennation angle) to key variables attained during various tasks (e.g. squatting and jumping) which are beneficial to athletic development. The aim of this study was to explore relationships between lower body muscle structure and one-repetition maximum (1-RM) power clean.

Design and Methods: 15 resistance trained subjects (13 males, 2 females) had three ultrasound images of their vastus lateralis (VL) and medial gastrocnemius (MG) musculature taken at rest before participating in a 1-RM power clean protocol on two occasions interspersed by 48-72 hours.

Results: Intraclass correlation coefficients (ICC) demonstrated high within- and between-image reliability for the muscle structure measures (ICC ≥ 0.81, $p < 0.001$) and excellent between-session reliability for both the absolute and relative 1-RM power clean measurements (ICC = 0.96, $p < 0.001$). Significant moderate relationships were found between VL muscle thickness and relative 1-RM power clean ($r = 0.506$, $p = 0.027$), MG muscle thickness and absolute 1-RM power clean ($\rho = 0.476$, $p = 0.036$) and MG pennation angle and relative 1-RM power clean ($\rho = 0.543$, $p = 0.018$).

Conclusion: Results suggest that developing thickness of the knee extensor musculature and both thickness and pennation angles of the plantar flexor musculature may augment 1-RM power clean performance. As suggested by previous research, this can be achieved by completing heavy resistance (i.e. strength) training with emphasis placed on improving both the magnitude and rate of lower body force development.

(*Journal of Trainology* 2015;4:32-36)

Key words: muscle structure ■ pennation angle ■ fascicle length ■ weightlifting ■ strength

INTRODUCTION

The structure of human skeletal muscle, in terms of its thickness, fascicle length and pennation angle, is known to influence its force and velocity, and thus its power, capability during dynamic actions.[1] Specifically, a greater muscle thickness and pennation angle generally allows for an increase in force production whereas a greater fascicle length allows for an increase in fibre shortening velocity resulting in an increase in power output.[1] Each of these distinct aspects of skeletal muscle structure can be relatively easily and noninvasively determined for a range of upper and lower body muscles via the use of ultrasonography. As such, previous research has reported greater muscle thickness and pennation angle to be synonymous with various muscles of athletes whose sport requires high force output (e.g. powerlifters [2]), with a longer fascicle being reflective of the primary muscles of athletes who rely on high velocity muscle actions (e.g. sprinters [3]). Furthermore, correlational studies have linked certain characteristics of lower body muscle structure to successful performance during various dynamic and isometric tasks which are beneficial to athletic development.[2,4-6]

For example, greater thickness of the vastus lateralis (VL) muscle was significantly associated with the one repetition maximum (1-RM) back squat ($r = 0.82$, $p < 0.01$) and deadlift ($r = 0.79$, $p < 0.01$) performances of elite male powerlifters.[2] Furthermore, the percentage increase in VL muscle thickness observed in elite female softball players across a competitive season demonstrated a moderate, although non-significant, relationship ($r = 0.57$, $p = 0.18$) with the concomitant increase in relative 1-RM back squat performance.[4] Recently, the VL muscle thickness of both legs in elite male surfers was also found to be correlated with peak force ($r = 0.54$-0.77, $p \leq 0.04$), peak velocity ($r = 0.66$-0.83, $p < 0.01$) and jump height ($r = 0.63$-0.80, $p \leq 0.01$) attained in both the squat jump (SJ) and countermovement jump (CMJ), in addition to peak force ($r = 0.53$-0.60, $p \leq 0.04$) in the isometric mid-thigh pull (IMTP).[5]

The relationships noted between lower body muscle structure and successful dynamic and isometric performances in the aforementioned studies, however, are not exclusive to the thigh musculature. For example, lateral gastrocnemius (LG) muscle thickness was the best predictor ($R^2 = 0.12$-0.20) of absolute power produced by males during the SJ, CMJ and drop jump (DJ), whereas LG pennation angle was the most significant predictor ($R^2 = 0.17$-0.26) of relative power produced during each of these jumps.[6] The LG pennation angle of the left leg only, in elite male surfers (i.e. the dominant leg for the majority of athletes tested), was also found to be significantly corre-

Received June 13, 2015; accepted July 13, 2015
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Journal of Trainology **2015;4:32-36 ©2012 The Active Aging Research Center http://trainology.org/**

lated with peak velocity ($r = 0.63$, $p = 0.01$) in the CMJ, peak force ($r = 0.53$, $p = 0.04$) in the SJ, and both absolute ($r = 0.70$, $p < 0.01$) and relative peak force $r = 0.63$, $p = 0.01$) in the IMTP.[5] The results of the above research highlight the important contributions of both the knee extensor and plantar flexor musculature to successful performance of weightlifting, jumping and the IMTP.

Although many previous studies have established relationships between specific aspects of lower body muscle structure and tasks which require both high force (e.g. IMTP and 1-RM back squat)[2,4,5] and velocity (e.g. SJ and CMJ)[5,6] the link between muscle structural properties and tasks which require a combination of high force and velocity output, such as weightlifting movements, is unknown. Developing an understanding of the link between skeletal muscle structural properties and weightlifting movements would help to inform the construction of distinct training programs designed to induce the desired structural adaptations within the primary muscles that contribute to such performances (e.g. knee extensors and plantar flexors). Based on previous research, it would be expected that the aforementioned relationships observed between lower body muscle structure and 1-RM back squat, IMTP and vertical jump performances would be replicated with weightlifting movements, given the reported associations between each of these tasks.[5,7-10]

The aims of the present study were, therefore, to explore relationships between aspects of lower body muscle structure (e.g. VL muscle thickness, MG muscle thickness and MG pennation angle) and 1-RM power clean performance in resistance trained subjects. Based on the previous research presented above, it was hypothesized that 1-RM power clean performance (when expressed as absolute and relative (to body mass) values) would be positively correlated to VL muscle thickness, MG muscle thickness and MG pennation angle.

METHODS

Experimental Design

This study used a repeated measures design, whereby subjects were required to have three ultrasound images of their VL and MG musculature for both legs taken, at rest, before participating in a 1-RM power clean protocol. The 1-RM power clean protocol was repeated approximately 48-72 hours later (at the same time of day) to allow the between-session reliability of this measurement to be determined.

Subjects

Fifteen resistance trained subjects, two female and thirteen male (height 1.76 ± 0.08 m; body mass 79.84 ± 10.34 kg, age 23.2 ± 3.21 years), from a wide range of sports, volunteered to take part in this study. Criteria for participation in this study included being recreationally involved in weight training on a weekly basis (for a minimum of 6 months), currently free from injury, medically healthy to take part and able to perform the power clean exercise without any major technique faults (as determined by a qualified strength and conditioning coach). Subjects were provided with full participant information and all provided written informed consent. The study protocol was approved by the institutional review board and conformed to the principles of the World Medical Association's Declaration of Helsinki (1983).

Procedures

Muscle structure was imaged using a 7.5 MHz, 100 mm linear array, B-mode ultrasound probe (MyLab 70 XVision, Esaote, Genoa, Italy) with a depth resolution of 67 mm. Ultrasound images of the VL were taken at the half-way point between the greater trochanter and the distal muscle-tendon junction (as determined via ultrasound) of the VL while subjects lay in a relaxed supine position with their knees fully extended.[11,12] Resting images of the MG were captured at the half-way point between medial femoral condyle and the distal muscle-tendon junction while subjects lay in a pronated position with the feet the neutral (i.e. with the sole of foot at 90° to the tibia) and the knees fully extended.[11,12] Three images of both the VL and the MG musculature were taken by the same experimenter.

Each subject's 1-RM power clean was assessed following a standardised protocol.[13] In brief, subjects performed a warm-up which consisted of multiple (3-4 sets) submaximal power clean efforts performed with decreasing volume (6-2 repetitions) and increasing loads (matched to the volume) before commencing their first 1-RM attempt. The 1-RM for each subjects was then determined within five attempts (interspersed by 2-4 minutes of rest) by gradually increasing the load until an incomplete attempt occurred.[13] Relative power clean performances were calculated by dividing each individuals absolute 1-RM by their body mass. All 1-RM assessments were conducted using an International Weightlifting Federation approved Olympic barbell (20 kg) barbell and weights (Werksan, Moorestown, NJ, USA) in the presence of a qualified strength and conditioning coach.

Data Analysis

Muscle structural properties were analysed using ImageJ software (Wayne Rasband National Institute of Health, Bethesda, MD, USA). Muscle thickness was measured as the vertical distance between the superficial aponeurosis and the deep aponeurosis taken at the centre of the image.[4] The pennation angle was measured directly as the angle between the fascicle and the deep aponeurosis.[14] Three recordings of each muscle structural parameter for both the VL and the MG were performed by the same experimenter.

Statistical Analyses

Intraclass correlation coefficients (ICC) were used to assess reliability within- and between images for the muscle structure measures and between-sessions for the 1-RM power clean. Normal distribution was assessed using Shapiro-Wilk's test of normality. A Wilcoxon signed ranks test was used to determine bilateral differences in both MG muscle thickness and MG pennation angle, whereas a dependent t-test was used to determine bilateral differences in VL muscle thickness. Effect sizes were calculated and interpreted using the Cohen d method which defines < 0.35, 0.35-0.80, 0.80-1.50, > 1.50 as trivial, small, moderate, and large, respectively.[15] Relationships between variables were explored using Pearson's (r) or Spearman's correlation coefficients (ρ) based on data normality distribution. Correlation coefficients were interpreted as being weak (0.1-0.3), moderate (0.4-0.6) and strong (> 0.7) in line with previous recommendations.[16] SPSS software (version 20.0, IBM) was used for all the above calculations with an alpha level of $p = 0.05$ and post-hoc statistical power calculations were performed using G.Power 3.1.[17]

RESULTS

The results demonstrated very good to excellent within- and between-image reliability for the measurement of VL muscle thickness (ICC = 0.90-0.99, $p < 0.001$), MG muscle thickness (ICC = 0.92-0.99, $p < 0.001$) and MG pennation angle (ICC = 0.81-0.99, $p < 0.001$). There were no significant bilateral differences in average VL muscle thickness ($p = 0.61$, $d = 0.13$), MG muscle thickness ($p = 0.65$, $d = 0.06$) or MG pennation angle ($p = 0.14$, $d = 0.29$) with only trivial effects seen (Table 1). The bilateral average value of each muscle structural parameter was, therefore, taken forward for correlational analyses.

The between-session reliability of the 1-RM power clean measurement was also excellent when expressed in both absolute (ICC = 0.96, $p < 0.001$) and relative (ICC = 0.96, $p < 0.001$) terms, with average absolute and relative 1-RM power clean values of 86 ± 19 kg and 1.07 ± 0.17 kg.kg^{-1}, respectively.

As shown in Figure 1, positive moderate relationships were found between VL muscle thickness and relative 1-RM power clean ($r = 0.506$, $p = 0.027$, power = 0.71), MG muscle thickness and absolute 1-RM power clean ($\rho = 0.476$, $p = 0.036$, power = 0.63) and MG pennation angle and relative 1-RM power clean ($\rho = 0.543$, $p = 0.018$, power = 0.77). Both VL muscle thickness ($\rho = 0.428$, $p = 0.056$, power = 0.54) and MG pennation angle ($\rho = 0.406$, $p = 0.067$, power = 0.49) demonstrated moderate relationships with absolute 1-RM power clean, but these correlations fell just short of statistical significance. Finally, a weak and non-significant relationship was found between MG muscle thickness and relative 1-RM power clean ($\rho = 0.264$, $p = 0.171$, power = 0.26).

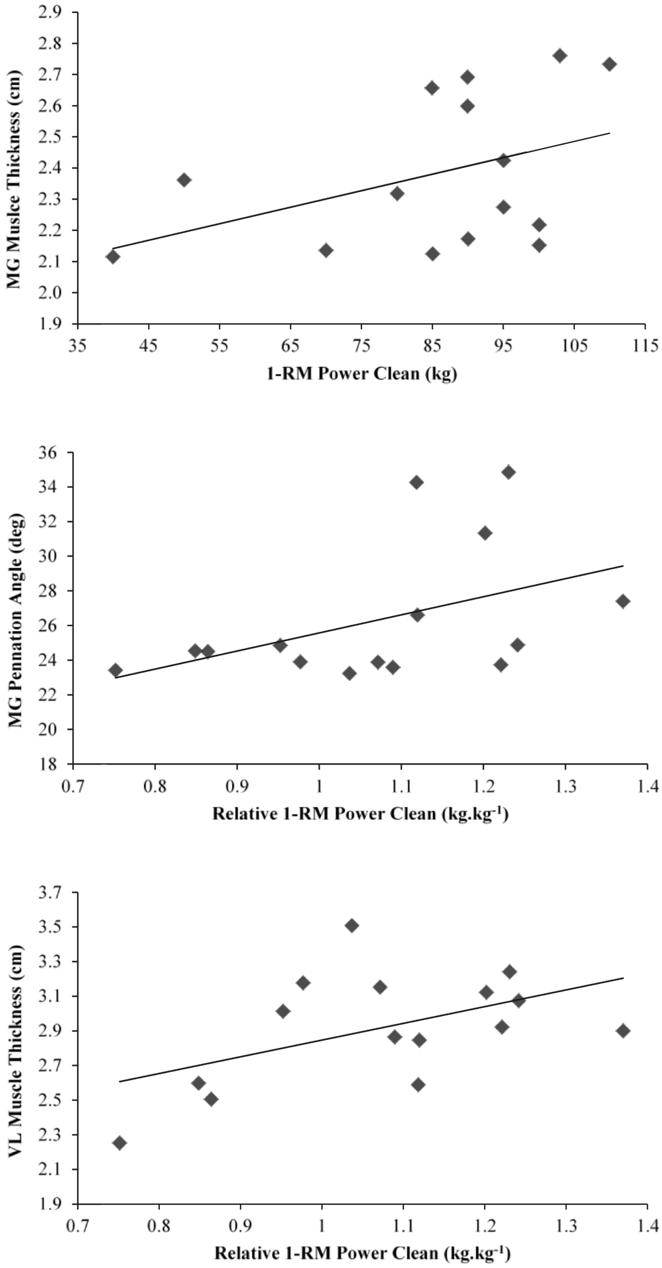

Figure 1 Relationships between power clean performance and MG muscle thickness (top), MG pennation angle (middle) and VL muscle thickness (bottom).

Table 1 Mean ± standard deviation muscle architectural properties for the right and left legs.

	MG MT (cm)	MG PA (deg)	VL MT (cm)
Right Leg	2.39 ± 0.20	25.7 ± 4.0	2.90 ± 0.36
Left Leg	2.38 ± 0.31	27.0 ± 4.3	2.94 ± 0.34

Where MG = medial gastrocnemius, VL = vastus lateralis, PA = pennation angle, and MT = muscle thickness

DISCUSSION

The aims of this study were to explore relationships between aspects of lower body muscle structure (VL muscle thickness, MG muscle thickness and MG pennation angle) and 1-RM power clean performance in resistance trained subjects. In line with the hypotheses and as shown in Figure 1, significant positive moderate relationships were found between the following variables: VL muscle thickness and relative 1-RM power clean ($r = 0.506$, $p = 0.027$), MG muscle thickness and absolute 1-RM power clean ($\rho = 0.476$, $p = 0.036$) and MG pennation angle and relative 1-RM power clean ($\rho = 0.543$, $p = 0.018$). To the authors' knowledge, this is the first study to demonstrate a link between distinct lower body muscle structural properties and weightlifting performance.

The correlation coefficient between VL muscle thickness and relative 1-RM power clean ($r = 0.506$, $p = 0.027$) is similar to that observed between elite female softball players' percentage increase in VL muscle thickness and relative 1-RM back squat performance ($r = 0.57$, $p = 0.18$) across a competitive season.[4] Relative 1-RM performances in the power clean and back squat have been shown to share a very high association ($r = 0.923$, $p \leq 0.05$) [9] which may explain the similarities in the magnitude of the correlations reported between studies. These results suggest that a greater thickness of the VL muscle is beneficial for relative strength and power performances. Indeed, previous research found that VL muscle thickness was related to vertical jump performance which requires the acceleration of body mass alone.[5]

Although there was a trend towards VL muscle thickness being correlated with absolute 1-RM power clean in the present study, the resultant correlation coefficient did not reach statistical significance ($\rho = 0.428$, $p = 0.056$). Similar to relative performances, however, absolute 1-RM power clean and back squat performances exhibited an excellent relationship ($r = 0.945$, $p \leq 0.05$).[9] Furthermore, elite male powerlifters' VL muscle thickness was strongly correlated to their absolute 1-RM back squat performance ($r = 0.82$, $p < 0.01$).[2] The reasons for differences in results may be due to the subjects tested by Nuzzo et al.[9] having had ≥ 4 years' experience of performing strength and power exercises and/or the elite powerlifters tested by Brechue and Abe [2] demonstrating a broad range of VL muscle thickness (~2.8-3.7 cm) and 1-RM back squat (~180-400 kg) values across the groups (light-heavy weights) tested.

The relationship between MG muscle thickness and absolute 1-RM power clean ($\rho = 0.476$, $p = 0.036$) was similar to the moderate relationship between LG muscle thickness and CMJ peak power ($r = 0.45$, $p \leq 0.05$) reported in a previous study.[6] In a previous study, absolute 1-RM power clean was reported to be strongly correlated to CMJ peak power ($r = 0.86$, $p \leq 0.05$) [9], which, like for VL muscle thickness, may explain the relationships observed in the present study. The greatest correlation found in the present study was between MG pennation angle and relative 1-RM power clean ($\rho = 0.543$, $p = 0.018$). The magnitude of this relationship is in line with previously reported relationships between LG pennation angle and both CMJ relative peak power ($r = 0.43$, $p \leq 0.05$) and CMJ peak velocity ($r = 0.63$, $p = 0.01$).[6] Similar to the results mentioned earlier, a previously conducted study found relative 1-RM power clean to positively correlated to both relative peak power ($r = 0.706$, $p \leq 0.05$) and peak velocity ($r = 0.698$, $p \leq 0.05$) attained during the CMJ.[9]

The results above suggest that a thicker MG muscle is beneficial for absolute 1-RM power clean performance, whereas a larger MG pennation angle is advantageous for relative 1-RM power clean performance. The former suggestion is in line with the widely accepted notion that a larger muscle is generally capable of producing greater forces.[18] The latter suggestion may fall in line with previous research concerning stretch-shortening cycle (SSC) utilization, which is important during the transition phase of the power clean.[19] For example, larger pennation angles within the MG allows this muscle to remain in a relatively isometric state during SSC actions which improves both force production and the recycling of elastic energy within the Achilles tendon.[20] As ground reaction forces increase (as seen when system mass increases during power clean performance [21]) muscles are less able to produce force isometrically and instead they may lengthen which can inhibit SSC utilization.[20] The present results suggest that subjects with greater MG pennation angles are better able to utilize the SSC during 1-RM power clean performances. Increasing lower limb muscle thickness and pennation angles can be achieved through heavy resistance (i.e. strength) training.[23] A particular emphasis should be placed on improving rate of force development (RFD) as part of strength training programs, however, given that a greater pennation of the LG muscle was found to be related to early RFD during high force SSC actions [24] and that RFD is synonymous with power clean performance.[7]

Although previous research showed that males demonstrated significantly greater muscle thicknesses and pennation angles of the VL and MG when compared to females [22], this notion should not influence the interpretation of the results presented within this study given that the primary aim was simply to explore whether or not greater muscle thickness (VL and MG) and pennation angle (MG) related to better 1-RM power clean performances, irrespective of sex. Future research should, however, focus on exploring the relationships reported in the present study within a larger cohort of subjects (for both sexes) and across a broader spectrum of 1-RM power clean performances. Furthermore, as correlations do not describe cause and effect, it would be prudent for future studies to investigate the effects of training-induced increases in lower limb muscle thickness and pennation angles on 1-RM power clean performances.

CONCLUSION

The results suggest that developing thickness of the knee extensor musculature and both thickness and pennation angles of the plantar flexor musculature may augment 1-RM power clean performance. This in line with the notion that the power clean performed with ≥ 70% of 1-RM is reflective of strength-speed exercise with more emphasis placed on training the force end of the force-velocity curve [7], and so one would expect greater muscle thickness and pennation angles to be positively related to this exercise given their combined effect on force output.[18,20]

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