COMPARISON OF THE RELATIONSHIP BETWEEN LYING AND STANDING ULTRASONOGRAPHY MEASURES OF PENNATION ANGLE WITH ISOMETRIC PEAK AND RATE OF FORCE PRODUCTION

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INTRODUCTION: Ultrasonography is commonly used to assess muscle size and architecture (Hodges, Pengel, Herbert, & Gandevia, 2003; Miyatani, Kanehisa, Ito, Kawakami, & Fukunaga, 2004) and has been shown to be valid against gold standard magnetic resonance imaging (Hides, Richardson, & Jull, 1995) and dual energy X-ray absorptiometry (Ahtiainen et al., 2010; Dupont et al., 2001). Ultrasonography also provides a level of versatility (e.g. subject positioning) that other methods do not. Muscle morphology measures are important in attempting to passively estimate the performance capabilities of the muscle. A larger pennation angle (PA) is believed to have a positive effect on force-generation (Cormie, McGuigan, & Newton, 2011), but has been more commonly associated with rate of force development (RFD) ($r = 0.34$-0.44) (Gerstner et al., 2017; Maffiuletti et al., 2016; Zaras et al., 2016). However, it is plausible that the lying position in which most ultrasonography measurements are collected could influence the results of these investigations. Perhaps practitioners using ultrasonography should employ techniques that more closely reflect the positioning found in athletic manoeuvres. Standing measures provide the most logical application of such constructs. Therefore, the primary purpose of this study was to examine the relationships between lying and standing measures of muscle PA with isometric performance. This may be important for practitioners that work with athletic populations, as standing ultrasonography measures may capture the muscle in a state that more closely represents its functional architecture.

METHODS: Fourteen resistance trained subjects (age = 26.8 ± 4.0 years, height = 181.4 ± 6.0 cm, body mass = 89.8 ± 10.7 kg, back squat to body mass ratio = 1.84 ± 0.34) volunteered for the current investigation. All subjects gave informed consent and the procedures were approved by the university's Institutional Review Board. To determine anatomical landmark on the VL, subjects were positioned in the left lateral recumbent position with an internal knee angle of 160 ± 10° measured using a goniometer. A location half the distance between the greater trochanter and lateral epicondyle of the right femur was identified and marked. A distance 5-cm medial to the mid-femur marking was also identified and marked (Bazyler, Mizuguchi, Sole, et al., 2017). The same markings were used for both lying and standing measurements.

Subjects were assessed for PA of the right vastus lateralis (VL) in both lying and standing postures using ultrasonography (LOGIQ P6, General Electric Healthcare, Wauwatosa, WI) (Bazyler, Mizuguchi, Harrison, et al., 2017; Walker et al., 2016). The ultrasonography probe was then placed in the long-axis on the marked point 5-cm medial to the mid-femur, oriented parallel to the VL muscle. The probe was held at a 90° angle to the skin surface to maintain consistent images across subjects. Standing methods were consistent with lying measures with one exception: the subject was upright and bearing weight on the left leg, which was positioned on a

5-cm tall platform, unweighting the measured right leg and creating an internal knee angle of 160 ± 10°. Three separate images were saved for subsequent analysis (Wells et al., 2014).

The isometric squat (ISQ) testing used an adapted protocol from McBride and colleagues and Kraska and colleagues (Kraska et al., 2009; McBride, Cormie, & Deane, 2006). Data were collected using a dual force plate design (RoughDeck HP, Rice Lake, WI) with data sampled at 1,000 Hz. Participants' bar height was set on an individual basis so that each subject had an internal knee angle of 100° assessed using a goniometer (McBride et al., 2006). LabVIEW (version 7.1, National Instruments) was used for collecting and ForceDecks (NMP Technologies Ltd., London, UK) for processing kinetic data (Carroll et al., 2017). Isometric peak force (IPF), as well as rate of force development over the initial 50 ms (RFD50),100 ms (RFD100), and 200 ms (RFD200) were calculated.

Descriptive statistics using mean and 95% confidence interval were calculated. Within subject reliability for each PA collection posture was assessed using coefficient of variation (CV) and intraclass correlation coefficients (ICC). Due to the high reliability observed for each variable (CV_{LPA}=6.65%, CV_{SPA}=6.18%; ICC_{LPA}=0.90, ICC_{SPA}=0.84), the average of the three images was used for statistical analysis. A paired samples *t*-Test was calculated for standing versus lying measures to determine differences between the two subject positions. Correlations between all measurements of PA and isometric performance capabilities were calculated using Pearson's *r*. Based on the current sample size, correlation of at least 0.53 was needed to establish a statistically significant relationship. For practical significance, Pearson's *r* values were interpreted with magnitude thresholds previously established by Hopkins (Hopkins, Marshall, Batterham, & Hanin, 2009). Statistical analyses were performed using JASP (Version 0.8.1.2, Amsterdam, The Netherlands) and statistical significance was set at $p \leq 0.05$.

RESULTS: Paired-samples t-Tests revealed statistically significant differences between standing and lying measurements of PA ($p < 0.001$, LPA = 15.78 ± 1.44, SPA = 23.41 ± 2.25). The relationships between standing and lying measures of PA with isometric performance, as well as their practical interpretation, are displayed in Table 1.

Table 1. Relationships between muscle pennation angle with measures of isometric performance.

Measure	Outcome	IPF	RFD50	RFD100	RFD200
	Pearson's *r*	0.20	-0.04	0.02	-0.03
LPA	*p*-value	0.49	0.90	0.95	0.91
	Interpretation	Small	Trivial	Trivial	Trivial
	Pearson's *r*	0.49	0.59*	0.66*	0.54*
SPA	*p*-value	0.08	0.03	0.01	0.05
	Interpretation	Moderate	Large	Large	Large

LPA = lying pennation angle; SPA = standing pennation angle; IPF = isometric peak force; RFD50 = rate of force development at 50 ms; RFD100 = rate of force development at 100 ms; RFD200 = rate of force development at 200 ms; * = statistically significant relationship ($p \leq 0.05$).

DISCUSSION: The current investigation is the first study intended to determine the relationship between lying and standing measures of VL PA with isometric performance. Lying muscle measures have been commonly assessed; however, we hypothesized that standing measurement would provide a stronger relationship to measures of standing isometric force production abilities. Our results indicated that 1) collection position significantly altered ultrasonography measurements of VL PA and 2) standing ultrasonography measures strongly associate with measures of isometric performance compared to lying ultrasonography measures.

Measures of standing PA were statistically larger than the lying posture, providing evidence that body position substantially influenced the muscle size measurements. The observed increase in PA with standing measures indicate the potential effects of gravity on measures at the muscle belly. Most athletic actions are executed from standing postures. Therefore, lying ultrasonography measures may not accurately capture the muscle in its functional configuration due to the effects of gravity and the redistribution of neighbouring tissues on the muscle belly (Drakonaki, Allen, & Wilson, 2012).

Consideration of muscle architecture may give a unique insight into the influence of body position on muscle imaging and the resulting associations with physical output. Pennation angle indicates fascicle orientation with respect to the aponeurosis and has been previously associated with both maximal strength and RFD (Aagaard et al., 2001; Andersen, Andersen, Zebis, & Aagaard, 2010). The significantly larger SPA compared to LPA reflects the influence of gravity on muscle shape and resulting PA. Though the present investigation did not yield a significant relationship between SPA-IPF, the difference in relative magnitude of the relationships LPA-IPF and SPA-IPF should be noted. The difference in correlation coefficients suggests that lying measures may not be accurately capturing muscle architecture as it relates to its maximal strength.

Maximal strength is suggested to underpin RFD (Andersen & Aagaard, 2006; Suchomel, Nimphius, & Stone, 2016), as stronger athletes exhibit higher RFD and force at critical time points (Andersen et al., 2010). However, it may be valuable to assess RFD separately, as it has been found to correlate strongly with sport-specific tasks (Tillin, Pain, & Folland, 2013). Muscle architecture is one of the major contributors to an athlete's RFD capabilities (Aagaard, 2003), along with fibre-type distribution (Bottinelli, Schiaffino, & Reggiani, 1991; Harridge et al., 1996) and efferent neural drive (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Andersen et al., 2010). In the present investigation, SPA yielded significant and large correlations with all the considered spectrum of RFD timepoints, while lying measures yielded trivial relationships. Rate of force development during later time intervals (i.e. > 100 ms) are more closely interrelated to maximal strength (Andersen & Aagaard, 2006). The very strong correlation with SPA may be due to shorter observed fascicle length that would result from the greater pennation angle present in standing measures. Shorter fascicles create greater RFD potential due to a more compacted arrangement of series elastic elements (e.g. actin-myosin filaments, titin, cross-bridges) (Blazevich, Cannavan, Horne, Coleman, & Aagaard, 2009; Edman & Josephson, 2007; Lieber & Ward, 2011). The findings of the current investigation, especially considering the relationship between SPA-RFD50, suggests that standing fibre orientation may also be considered when investigating the intrinsic muscle properties influencing early-phase RFD (Andersen & Aagaard, 2006; Andersen et al., 2010). Therefore, lying measures of VL muscle architecture may misrepresent the functional configuration and RFD potential entirely, potentially limiting ultrasonography's usefulness as a monitoring tool for strength-power athletes. Because of RFD's implication for sporting success (Andersen et al., 2010), practitioners should instead consider standing measures of muscle architecture.

In conclusion, the results of the current investigation demonstrated that ultrasonography measurements of VL muscle architecture were significantly larger during standing ultrasonography imaging. This is valuable considering the desire for practitioners to capture the muscle in a state that more precisely represents its configuration during performance. Further, standing ultrasonography measures were overall more strongly associated with measures of isometric performance. This suggests that if practitioners intend to gain insight into strength-power potential based on ultrasonography measurements, performing collection with the athlete in a standing posture is preferred.

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