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Test-retest reliability of laser displacement mechanomyography in paraspinal muscles while in lumbar extension or flexion

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ABSTRACT

This study investigated test-retest reliability of mechanomyography (MMG) on lumbar paraspinal muscles. Healthy male and female subjects (mean ± standard deviation, 25 ± 9.4 years, BMI 21.8 ± 2.99, n = 34) were recruited. Two test sessions (one week apart) consisted of MMG (laser displacement sensor (LDS)) muscle evaluations over the 10 lumbar facet joints, and 2 bilateral sacral sites, in anatomical extension and flexion. Two-way repeated measures ANOVA with Tukey's post hoc showed no significant differences between testing sessions for the same position ($p > 0.05$). The intra-class correlation coefficients (ICCs) in extension were classified as 'very good' (0.8–0.9) for maximal muscle displacement (Dmax), contraction time (Tc) and velocity of contraction (Vr). Half relaxation time (½Tr) and half relaxation velocity (½Vr) were 'poor' (0.4–0.5) and 'good' (0.7–0.8). In flexion, Dmax, Tc and Vr were 'excellent' (≥0.9) whilst ½Tr and ½Vr were 'fair' (0.6–0.7) and 'very good'. Comparing extension against flexion, significant ($p < 0.05$) differences in Dmax and ½Vr were found (L1/L2-L5/S1). Tc was significant ($p < 0.05$) for all sites whilst Vc was for L1/L2 on both sides ($p < 0.05$). ½Tr showed no significance ($p > 0.05$). Most MMG-derived parameters thus appear as reliable measures of muscle contractile properties in lumbar extension and flexion, with flexion providing more reliable results (ICCs).

1. Introduction

Mechanomyography (MMG) is a collective term for an assortment of similar non-invasive methods that all determine mechanical aspects of muscle contraction (e.g. contraction time). MMG operates through measuring the displacement of overlying skin following voluntary contraction, or involuntary transcutaneous neuromuscular stimulated (TNS) contractions (Orizio, 1993; Al-Mulla et al., 2011; Ibitoye et al., 2014). Recently there has been an increasing use of the laser displacement sensor (LDS) to record the contractile properties of muscles given the reputed accuracy and ease of use in experimental environments (Gorelick and Brown, 2007; Tosovic et al., 2012, 2015, 2016; Than et al., 2016). In addition, the technique is comparable to mechanomyographic tensiomyography (TMG) in that no extensive post-processing or filtering is required, lending to straightforward parameter extraction that is ideal for clinical studies (Krizaj et al., 2008; Seidl et al., 2017). From the MMG waveform can be derived variables that characterise muscle contraction. LDS MMG-derived contractile properties include the muscle's maximum radial displacement (Dmax), contraction time (Tc), contraction velocity (Vc), half relaxation time (½Tr), and half relaxation velocity (½Vr) (Kimura et al., 2008; Al-Mulla et al., 2011; Than et al., 2016). Overall, Gobbo et al. (2006) state MMG to be a summation of the single mechanical activities of the muscle fibers recruited by a stimuli.

Dmax, which is the signal amplitude, represents the maximal radial displacement (mm) the muscle belly is capable of achieving, without distortion, following TNS (Fig. 1) (Than et al., 2016). In the context of isometric involuntary contractions, Hunter et al. (2012) state Dmax to be a representative measure of muscle tone and contractile force from fibre recruitment.

Contraction time (Tc), defined as 10–90% of the MMG waveform's ascending limb, represents the time taken (ms) for the muscle to reach maximum displacement from a resting state (Fig. 1) (Dahmane et al., 2006). Simunic et al. (2011) state Tc to reflect the time of force generation, with capacity to readily distinguish slow and fast twitch fibre composition. Physiologically, this is inferred to be the time taken to complete the power stroke of contraction from actin-myosin cross bridging with reliance upon myosin ATPase activity (Bárány, 1967; Taylor et al., 1974; Maxwell et al., 1982; Gobbo et al., 2006; MacIntosh et al., 2012; Ce et al., 2013).

Abbreviations: ANOVA, analysis of variance; BMI, body mass index; Dmax, maximal displacement; ICC, intra-class correlation coefficient; LBP, low back pain; LDS, laser displacement sensor; MMG, mechanomyography; SEM, standard error mean; Tc, contraction time; TNS, transcutaneous neuromuscular stimulation; ½Tr, half relaxation time; Vc, contraction velocity; ½Vc, half relaxation velocity

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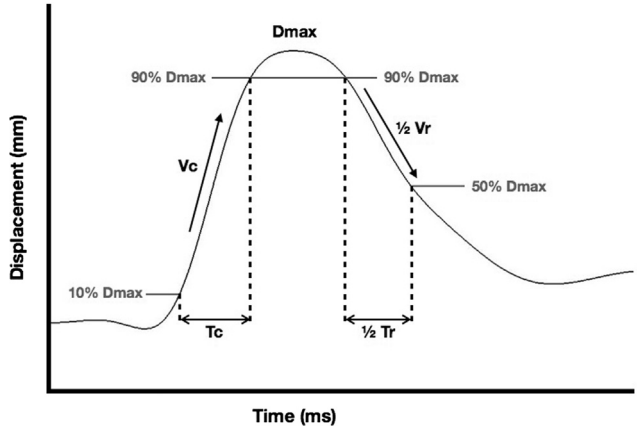

Fig. 1. Sample LDS MMG waveform after a PNS twitch stimulus. Tc calculated from 10 to 90% Dmax (ascending limb); ½Tr calculated from 90 to 50% Dmax (descending limb); Vc calculated as Dmax/Tc; ½Vr calculated as Dmax/½Tr. LDS: laser displacement sensor, MMG: mechanomyography, PNS: percutaneous neuromuscular stimulation, Dmax: maximum displacement (mm), Tc: contraction time (ms), ½Tr: half-relaxation time (ms), Vc: contraction velocity (mm/ms), ½Vr: half-relaxation velocity (mm/ms).

Vc (mm/ms) is the velocity of muscle contraction (Fig. 1) derived from Dmax divided by Tc (Than et al., 2016). As the term suggests, Vc is theorised to reflect the velocity output to achieve force generation. Physiologically, this is inferred to reflect the speed/efficiency of actin–myosin cross-bridge formation with respect to displacement (Tosovic et al., 2016; Than et al., 2016).

½Tr (ms), represents the time taken for the muscle to return to 50% of peak amplitude (Dmax) as it relaxes following stimulation (Fig. 1) (Tosovic et al., 2016). Seidl et al. (2017) state ½Tr to be related to the efficiency of Ca2+ reuptake during the relaxation phase. This in turn is physiologically inferred to reflect the termination of cross bridging by the re-uptake of Ca^{2+} into the sarcoplasmic reticulum (Klug et al., 1988; Gollnick et al., 1991; Hill et al., 2001; Ottenheijm et al., 2008; MacIntosh et al., 2012; Ce et al., 2013; Seidl et al., 2017).

½Vr (mm/ms) is derived from Dmax divided by ½Tr, and is the half velocity of relaxation (Fig. 1) (Tosovic et al., 2016). ½Vr is theorised to reflect the velocity of actin-myosin dissociation. Physiologically, this is inferred as half the rate of Ca^{2+} reuptake to maintain the ion gradient in the sarcoplasmic reticulum after contraction, causing dissociation of Ca^{2+}/troponin binding and subsequently actin-myosin cross bridging (Klug et al., 1988; Kimura et al., 2008; Krizaj et al., 2008; MacIntosh et al., 2012; Tosovic et al., 2016).

Signal interpretation of MMG is currently considered problematic due to a lack of generation models. However there have been studies performed to associate MMG characteristics and underlying physiology, with continued investigation broadening the applicability and literature base. In particular, Orizio et al. (1999) demonstrated using the human tibialis anterior that mechanical changes in muscle, due to localised fatigue, were reflected by MMG measures. The association between tension generated from oscillating muscle nerve stimulation and subsequent muscle displacement (Dmax) was further investigated by Orizio et al. (2000), who found tension generation and Dmax to match administered sinusoidal nerve stimulations. Additionally, Orizio et al. (2003) demonstrated that MMG waveforms anticipated and trailed accompanying tension waveforms within tendon. Whilst further literature is required to underpin the exact physiological mechanisms behind the acquired MMG waveform, these studies provide substantiation in that MMG can provide valid measures of tension generation within muscle using an in vivo model (Orizio, 1993; Orizio et al., 1999, 2000, 2003). Macgregor et al. (2018) follow on from this by stating muscle can be regarded as a near-constant volume system, with muscle fibre shortening and thickening detectable by surface displacement and tension at the tendon level, providing support for MMG as a useful tool to track muscle contractile features during contraction.

Regardless of the gaps in literature, MMG has been utilised in many human studies for physiological interpretations (Dahmane et al., 2006; Gorelick and Brown, 2007; Kimura et al., 2008; Al-Mulla et al., 2011; Hunter et al., 2012; Ce et al., 2013; Than et al., 2016; Tosovic et al., 2016; Macgregor et al., 2018). Recently, arising support for MMG as a potential diagnostic tool for identifying muscle injury has surfaced. This is based on the technique's ability to detect atrophic or fatigued muscles due to injury or over-use (Ibitoye et al., 2014; Tosovic et al., 2016; Than et al., 2016). While a range of muscles have been investigated with MMG, its applicability to the lumbosacral spine has not been investigated thoroughly. Before performing clinical or further physiological investigative studies, the test-retest reliability of LDS MMG requires elucidation as an unreliable technique would warrant no further utilisation. Whilst Seidl et al. (2017) have investigated the test-retest reliability of LDS MMG for the rectus femoris, Dahmane et al. (2001) have demonstrated evidence that each muscle of the human body should be considered its own entity. Furthermore, there is an absence in knowledge on the effects of joint positioning, in reference to the spine, on both test-retest reliability and MMG-derived contractile properties.

Consequently, the current study investigates the test-retest reliability of laser-based MMG, during anatomical extension (prone lying) and flexion (seated) of the spine, within a healthy participant cohort. It was hypothesized that MMG would provide reliable measures of low back muscle contractile properties regardless of spinal position. Based on the alteration of moment arms between extension and flexion, it was additionally hypothesized that there would be significant differences in muscle contractile properties between positions.

2. Methods

Bellberry Human Research Ethics Committee (HREC) (no. 2016-01-027) provided ethical clearance. Informed written consent was obtained from subjects. Healthy male (n = 16) and female subjects (n = 18) (mean ± standard deviation, 25 ± 9.4 years, BMI 21.8 ± 2.99, total n = 34) with no history of low back pain (LBP) were recruited for two separate testing sessions. No history of LBP was defined as no clinical diagnosis in the lifetime of the participant, with study sample size based on a previous LDS MMG test-retest reliability study (Seidl et al., 2017) and suggestions by Bonett (2002). Ten lumbar zygapophyseal joints, as well as two bilateral sites over the sacrum, were located via palpation and ultrasound using a 7.5 MHz linear transducer probe (Mindray DP-50). Participants were then placed prone on a padded plinth with a pillow underneath the anterior superior iliac spine to prevent excessive spinal lordosis during testing (Fig. 2A).

MMG was recorded from the erector spinae and multifidus muscles overlying the 12 low back muscle sites. Two TNS stimulatory electrodes (NeuroTrac TENS self-adhesive electrodes; 30 mm diameter), which were positioned 25 mm either side of the site (50 mm inter-electrode distance), were placed on the skin to activate muscles at each site (Tosovic et al., 2016; Than et al., 2016)

To measure radial muscle belly displacement following TNS, a LDS was positioned approximately 100 mm perpendicular to the muscle belly midway between the two stimulatory electrodes (Tosovic et al., 2016). Muscles were then maximally stimulated following a transcutaneous twitch stimulus (Tosovic et al., 2015). Stimuli of increasing current (mA) were delivered whilst maintaining a constant voltage (400 V) and duration (200 μs) (Digitimer DS7AH). This was conducted until a maximum muscle contraction was observed without deformation of the sinusoidal MMG waveform. Thirty second intervals were provided between stimuli to minimize fatigue from overstimulation. MMG contractile properties were calculated as mean values from five recordings of maximal MMG waveforms (Tosovic et al., 2015). The MMG waveforms were recorded in LabChart® 7 software