ASMFA ADVANCES IN SKELETAL MUSCLE FUNCTION ASSESSMENT

CONTRACTILE RATE OF MUSCLE DISPLACEMENT ESTIMATED FROM THE SLOPE OF THE DISPLACEMENT-TIME CURVE USING TENSIOMYOGRAPHY

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KEY WORDS:
Muscle function; Contractile rate of force development; Tensiomyography

ABSTRACT

Tensiomyography (TMG) can estimate the intrinsic contractile potential of a muscle using data between 10 and 90% of the displacement-time curve. However, it is yet to be determined whether this data represents the greatest rate of displacement i.e. the most valid estimate of the maximal shortening velocity of a muscle. The aim of this secondary analysis of data gathered from 10 participants who had maximal displacement (Dm) of the rectus femoris assessed using TMG, was to compare the rate of displacement using data from 0 – 100% of Dm; 10 – 90% of Dm and the most linear phase of the displacement-time curve. One-way analysis of variance (ANOVA) indicated that rate of displacement increased as data bands narrowed towards the most linear phase of the displacement-time curve (P<0.001). Rate of displacement explained the greatest proportion of variance in total Tc when estimated from the linear phase (R^2=0.601; P=0.008). Rate of displacement estimated from data points between 10 – 90% of Dm had a strong association with rate of displacement estimated from the linear phase (r=0.996; P<0.001). The most valid estimate of maximal rate of displacement comes from the linear phase of the displacement-time curve.

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INTRODUCTION

Tensiomyography (TMG) is a non-invasive method for measuring skeletal muscle contractile properties **[1]**. A pulsed electrical current is delivered via two electrodes applied to the surface of the skin to evoke a phasic contraction of underlying skeletal muscle **(Figure 1)**. The muscle contraction displaces a probe positioned perpendicular to the skin to record muscle displacement, from which maximum displacement (Dm) has been described as a surrogate measure of contractile force **[2]**. A characteristic waveform is produced when displacement is plotted against time from which contraction time (Tc) can be determined **(Figure 2)**. Contractile rate of force development (RFD) is defined as the slope of the force-time curve and is a representative measure of the rate of force generated by the neuromuscular system **[3]**. Typically, RFD is obtained from a voluntary isometric contraction or via an involuntary twitch contraction and is normally used to provide information about the intrinsic contractile properties of a muscle which cannot be inferred from maximal force or Dm **[4, 5]**. RFD is thought to be an important determinant of the maximum force and velocity that can be exerted by an individual during functional tasks such as sprint running or recovering from a postural perturbation to avoid a fall. These contractions require 50 – 200 ms which is considerably shorter than the time to reach maximum force (~300ms).

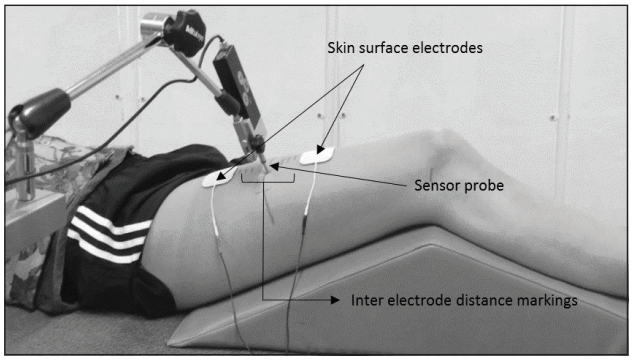

Figure 1. TMG set up.

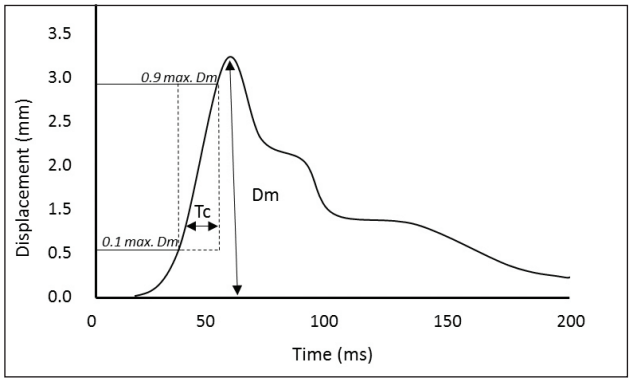

Figure 2. TMG waveform characteristics for contraction time (Tc) and maximum displacement (Dm).

The TMG system software uses an algorithm to calculate Tc using predetermined data points (10% and 90% of Dm) extracted from the rising waveform [6-9]. The rationale for using 10% and 90% as cut off points is apparently based on the assumption that this will encapsulate the linear phase of the contraction, and will exclude the initiation of contraction and the plateau when reaching maximum contraction. A strong association between Tc and the percentage of type 1 muscle fibres (r=0.930), measured using histochemical techniques, has been demonstrated [10]. However, it is yet to be determined if the data between 10 – 90% represents the greatest rate of displacement i.e. the most valid estimate of maximal shortening velocity during muscle contraction. Furthermore, the effect of widening the data range sampled (0 – 100%) or narrowing the data ranged sampled (the linear phase of contraction) on the rate of displacement has not been investigated. Therefore, the aim of this technical report is to describe a comparison of three estimates of the rate of displacement using data from 0 – 100% of Dm, 10 – 90% of Dm, and the linear phase of the displacement-time curve. The association between the three estimates of rate of displacement, Dm and total Tc (0 – 100% Dm) was also determined. We hypothesised that Dm would explain a greater proportion of the variance in rate of displacement when sampled from wider time points e.g. 0 – 100%, due to both measures being dependent on factors influencing maximal strength. Conversely, we hypothesised that total Tc would explain a greater proportion of the variance in rate of displacement when sampled from narrower time points i.e. the linear phase of the displacement-time curve.

MATERIALS AND METHODS

This technical report describes a secondary analysis of data that was collected as part of a study that evaluated the effect of kinesiology taping and a no tape control on Dm and Tc. The study used a within-subject repeated measures design, with each participant undertaking one 60 minute experiment during which Dm and Tc data were collected before, during and after the application of either kinesiology tape or no kinesiology tape **(control, Figure 3)**. Study participants were a convenience sample of 62 healthy (mean + SD age 23.55 ± 5.60 years; height 169.68 ± 17.03 cm; body mass 69.16 ±13.40 kg) staff and students from Leeds Beckett University, recruited via word-of-mouth and posters displayed within the University. Exclusion criteria included: ≤18 years; pregnant; taking medication; those wearing an implantable medical device (i.e. pacemaker); those who do not consider themselves as healthy; have major long-term illness; have lower limb and/or lower back injury; experience disturbances to skin sensation (i.e. numbness, sensitivity or tingling) or have a dermatological condition(s) (i.e. dermatitis, eczema, bacterial/ fungal infection or allergy to adhesive plasters). Participants were asked to refrain from participating in vigorous activity 72 hours prior to the laboratory visit and to refrain from consuming stimulants (i.e. caffeinated products) or exercising within 12 hours of the laboratory testing session. Participants provided written informed consent and all procedures were performed in accordance with the most recent version of the Declaration of Helsinki. The study was approved by the Research Ethics Committee of Leeds Beckett University.

Data used in the secondary analysis described in this technical report was extracted from 10 of the 62 partici-

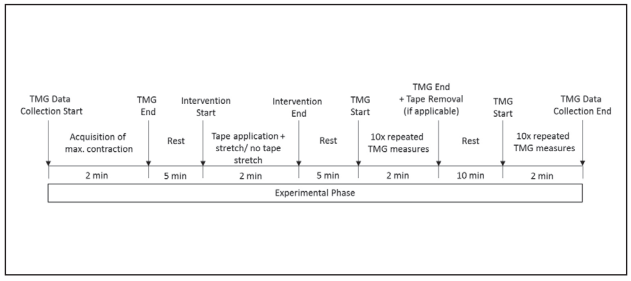

Figure 3. Time-line of experimental procedures used in the study from which data was collected for this secondary analysis.

pants (mean + SD, age 22.40 ± 4.53 years; height 173.02 ± 9.51 cm; body mass 70.65 ±13.69 kg). Data was selected by allocating each participant a code, noting it on a piece of paper, and selecting 10 of these from a bag containing all 62 participants. If the TMG wave met the criteria for acceptance (see below) it was entered into the secondary analysis. If not, then the data was 'rejected' and another piece of paper was selected from those remaining in the bag. A total of two data points were rejected before a sample of 10 was achieved.

Assessment of Muscle Contractile Properties

Participants were positioned quietly resting supine on a plinth to ensure recording took place under static and relaxed muscular conditions **(Figure 1)**. A triangular pad was placed under the dominant knee to maintain the knee joint at an angle of 120˚ (180˚ corresponded to knee full extension). A TMG-S1 stimulator (EMF-Furlan and Co. d.o.o., Ljubljana, Slovenia) was used to deliver a single monophasic 1-ms electrical pulse via two square (5 x 5 cm, Med-Fit) self-adhesive electrodes placed on the skin overlying the rectus femoris. A sensor probe (GK40, Panoptik d.o.o., Ljubljana, Slovenia), positioned perpendicular to the muscle belly recorded muscle displacement using a sampling rate of 1 kHz. Probe location was determined using anatomical landmarks of the greater trochanter and lateral condyle. A horizontal line was marked across the thigh using a dermatological pen, at the midpoint between the two landmarks. Rectus femoris borders were identified manually by the tester via resisting an isometric knee extensor contraction. The sensor was positioned at the midpoint between the borders, along the marked horizontal line, representing the midpoint of the greater trochanter and lateral femoral condyle. The electrodes were positioned 2.5 cm distal and proximal to the probe position, along the vertical axis, creating a 5 cm inter electrode distance.

Criteria for acceptance of a displacement-time curve

Baseline, pre-intervention displacement-time curves were used for this secondary analysis. The criteria for exclusion of a displacement-time curve were a) an incomplete wave-form or b) a double peak of which the the second is higher. Examples of accepted and excluded waveforms are shown in **Figure 4**.

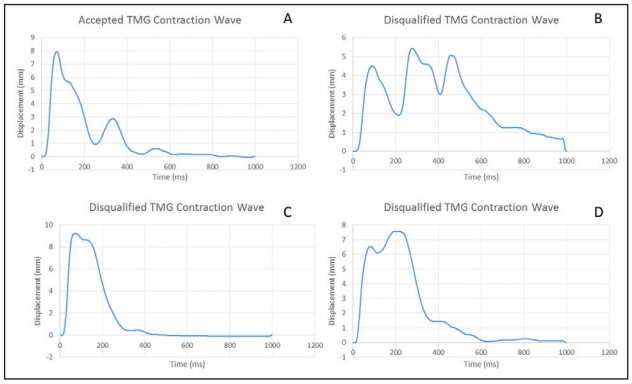

Figure 4. Examples of included (accepted) and excluded (disqualified) displacement-time curves. A: Accepted TMG contraction wave; B: Disqualified TMG contraction wave due to the second peak of the displacement-time curve exceeding the first peak; C: Disqualified TMG contraction wave due to the lack of the full wave development; D: Disqualified TMG contraction wave due to the second peak of the displacement-time curve (Dm, mm) exceeding the first peak as well as the lack of the full wave development.

Secondary Analysis

The following data were extracted for each displacement-time curve:

- The slope of the displacement-time curve between 0 – 100%.
- The slope of the displacement-time curve between 10% and 90%
- The slope of the displacement-time curve between the lower and upper bounds of the most linear contractile phase.

The process of identifying the most linear phase of the line through visual inspection, involved plotting 0-100% of Dm graphically **(Figure 5)**. The linear phase was identified using the line function on Microsoft Excel. Subsequently, a straight line was drawn and manipulated such that the straight line overlay the maximum number of data values along the contractile wave. Contractile rate of displacement was extracted from the slope of the line equation, where 'm' represents the rate of development (mm/ms) in the line equation; y = mx + c. A Shapiro-Wilk test was conducted to assess whether variables were normally distributed. Mean and standard deviation (SD) values are reported.

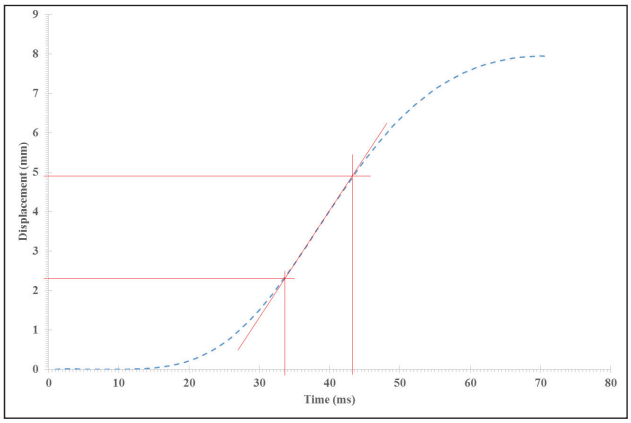

Figure 5. Process for determining the slope of the displacement-time curve between the lower and upper bounds of the most linear contractile phase. Raw data was extracted and plotted for the upward phase of the maximal contraction wave between 0% and 100% Dm using the X Y scatter plot command in Microsoft Excel. Visual inspection was used to identify the greatest linear phase of the wave and data extracted between the lower and upper boundaries (solid lines). This data was plotted on a separate X-Y scatter and a trend line added and line equation calculated.

Statistical Analysis

Differences between methods were assessed using a one-way analysis of variance. Linear regression was used to determine the proportion of variance in rate of displacement explained by Dm and total Tc. Statistical significance was defined as $P < 0.05$. Statistical analysis was conducted using IBM SPSS statistical package for Windows, Version 23.0 (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.).

RESULTS

Descriptive statistics are displayed in **Table 1**.

Table 1. Maximal displacement (Dm), total contraction time (Tc) and rate of Dm calculated from three separate time points (n=10).

Participant code	Dm (mm)	Tc (ms)	Dm/Tc (mm/ms)	Data Range: 0 – 100%. Rate of displacement development (mm/ms)	Data Range: 10 – 90%. Rate of displacement development (mm/ms)	Data Range: Linear phase, lower bound to upper bound. Rate of displacement development (mm/ms)
2	7.81	79	0.10	0.13	0.18	0.19
4	10.65	55	0.19	0.23	0.41	0.46
5	6.93	57	0.12	0.14	0.24	0.28
16	4.02	71	0.06	0.08	0.17	0.21
27	5.34	62	0.09	0.19	0.38	0.43
34	10.58	65	0.16	0.21	0.33	0.38
38	11.35	73	0.16	0.10	0.15	0.18
44	7.31	59	0.12	0.15	0.21	0.28
49	10.96	53	0.21	0.24	0.43	0.48
50	10.67	64	0.17	0.21	0.34	0.38

Rate of displacement was associated with maximal Dm when estimated between 0 – 100% of contraction **(Table 2)**. Rate of displacement increased as the data sampled approached the linear phase of contraction (P <0.001) and is illustrated by box plots in **Figure 6**. Rate of displacement explained a greater proportion of the variance in total Tc as the data sampled became closer to the linear phase **(Table 2, Figure 7, 8)**. Rate of displacement estimated from the linear phase was not associated with rate of displacement estimated between 0 – 100% but had a strong association with rate of displacement estimated between 10 – 90% of contraction **(Table 2)**.

Table 2. The association between rate of displacement at different time points, displacement, contraction time and the linear phase of the displacement-time curve. Abbreviations: maximal displacement (Dm), total contraction time (Tc).

	Mean ± SD (mm/ms)	Dm	Tc	Rate of discplacement Linear Phase
		r^2 (p-value)	r^2 (p-value)	r^2 (p-value)
Rate of displacement (0 – 100% Dm)	0.14 ± 0.05	0.851 (<0.001)*	0.285 (0.112)	0.349 (0.072)
Rate of displacement (10 – 90% Dm)	0.28 ± 0.11	0.128 (0.310)	0.525 (0.018)	0.985 (<0.001)
Rate of displacement (Linear Phase)	0.33 ± 0.12	0.108 (0.353)	0.601 (0.008)	

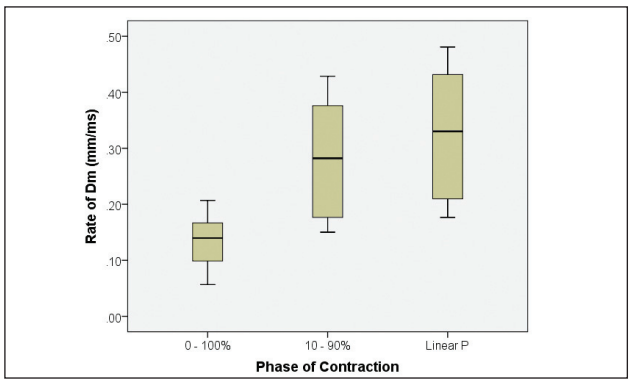

Figure 6. The increase in rate of displacement approaching the linear phase of the displacement-time curve (Linear P = Linear Phase).

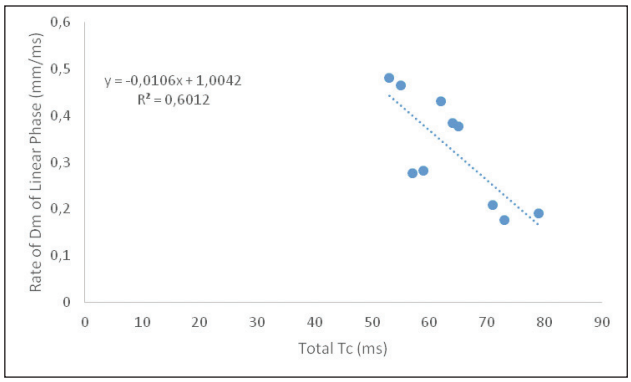

Figure 7. The association between the rates of displacement from the linear phase against total Tc.

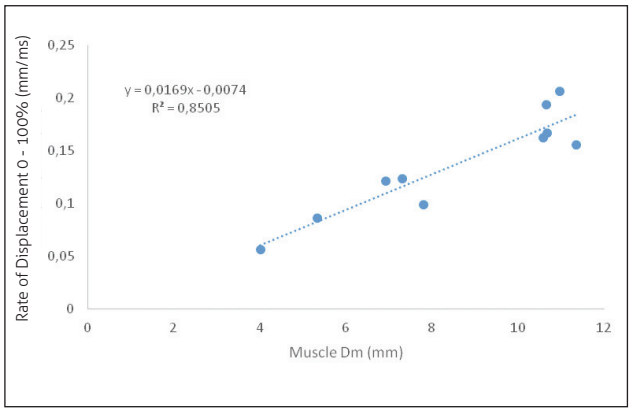

Figure 8. The association between rate of displacement (0-100%) and Dm.

DISCUSSION

This secondary analysis estimated rate of displacement using data from 1) the onset of contraction to Dm (0-100%) 2) between 10 and 90% of Dm and 3) from the linear phase of the displacement-time curve. The findings support our hypothesis that the rate of displacement was greatest when estimated from the linear phase rather than the 10 – 90% of contraction parameter suggested by TMG manufacturers to calculate Tc. Rate of displacement was only associated with Dm when estimated between 0 – 100% of the displacement-time curve which suggests that data within 10 – 90% of contraction is not dependent on physiology associated with Dm. Rate of displacement estimated from the linear phase had the strongest association with total Tc although this association was similar when estimated between 10 – 90%. Furthermore, while rate of displacement between 0 – 100% was not associated with rate of displacement estimated from the linear phase, rate of displacement estimated between 10 – 90% was strongly associated with that of the linear phase.

Our results indicate that investigators who seek to quantify the greatest rate of displacement should use the most linear phase of the displacement-time curve. Depending on the physiological component of muscle contraction under investigation this is a potentially important finding. Rate of displacement is greatest and demonstrates a stronger association with total Tc when estimated from the linear phase of contraction compared to that estimated between 10 and 90% of contraction. However, the correlation between methods is excellent (r=0.993, p<0.001) and therefore either may be used to estimate rate of displacement. There are parallels in our estimation of rate of displacement and that of rate of force development (RFD) estimated from an isometric contraction. RFD becomes increasingly dependent on factors associated with maximal strength as the time from the onset (wider sampling frame) of contraction increases. In fact, maximal strength can explain 80% of the variance in voluntary RFD when estimated from later phases (150 – 250 ms) of the contraction (Andersen and Aagard, 2006). Dm in the present report could explain 85% of the variance in rate of displacement when estimated between 0 – 100% but could not explain any of the variance when estimated at intervals between 10 – 90% of the displacement-time curve. Our involuntary contractions required <80 ms and the early phase of contractions (<40ms) are highly dependent on the rate of cross-bridge cycling which is highly dependent on the myosin heavy chain composition of a muscle. This may help to explain the lack of association between Dm and rate of displacement at time points less than 90% of the displacement-time curve. Furthermore, rate of displacement between 0 – 100% although strongly associated with Dm was not associated with total Tc, or rate of displacement at any point between 10 – 90% of the displacement-time curve. These findings combined may suggest that physiological factors associated with Dm (i.e. force) and rate of displacement estimated from the entire contraction may be different from those responsible for total Tc and rate of Dm estimated at different time points between 10 – 90% of contraction.

In conclusion, this secondary analysis provides preliminary evidence that the most valid estimate of rate of displacement comes from the linear phase of the displacement-time curve. Nevertheless, our analysis raises more questions than it answers such as:

a) What are the alterations that occur in the relationships described above when a greater sample size is used?
b) What is the reliability of estimate for rate of displacement at varying time points along the displacement-time curve?
c) What is the rate of displacement at specified time points from the onset of contraction e.g. 0 – 10%; 0 – 20% etc.?
d) What is the variance in the number of data points used to obtain the linear phase?
e) What is the variance around the upper (90%) and lower (10%) boundaries used to estimate Tc?

We hope that this technical report catalyses further research in this field.

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