MEASUREMENT OF INTRAMUSCULAR PRESSURE, FORCE, AND ELECTROMYOGRAPHY IN THE TIBIALIS ANTERIOR MUSCLE DURING RAMPED ISOMETRIC CONTRACTIONS

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INTRODUCTION
Quantifying individual muscle force will enhance our understanding of musculoskeletal mechanics and motor control, and advance the efficacy of diagnostic tools and targeted therapies in musculoskeletal and neurologic pathologies. Although efforts have been made to quantify force through electromyographic (EMG) measurements, these methods do not directly capture mechanical output. In contrast, intramuscular pressure (IMP) is the fluid pressure generated within skeletal muscle and is a direct reflection of muscle tension [1]. Thus, the purpose of this study was to investigate the development of force, IMP and EMG in the tibialis anterior (TA) muscle during ramped isometric contractions. We hypothesized that (1) the relationships between normalized EMG amplitude or IMP and force do not depend on contraction rate, and (2) the electromechanical delay (EMD) between force and EMG would be greater than the EMD between IMP and EMG.

METHODS
Eight young healthy adults (3 females; mean ± SD age: 26 ± 2 years; BMI: 22 ± 2 kg/m²) with no prior history of neurologic or musculoskeletal disease participated in this study.

Experimental set-up: While subjects were supine, the right ankle was raised until the foot was perpendicular and the shank was parallel to the ground. A foot strap was secured around the metatarsals and connected to an external load cell (SM-100, Interface Inc., Scottsdale, AZ) in line with the load cell axis and perpendicular to the ankle rotation axis. A fiber optic pressure sensor (FOP-M260, FISO Technologies, Inc., Quebec, Canada) was inserted into the TA under ultrasound guidance using a 22-gauge I.V. catheter. The catheter was oriented toward the distal TA tendon and inserted through the skin at a 30° angle until the tip was mid-depth in the TA superficial compartment. The needle was withdrawn and the sensor was advanced through the catheter lumen into the muscle. A bipolar stainless steel surface electrode (12 mm disks, Motion Lab Systems, Baton Rouge, LA) was placed on the skin surface near the pressure sensor tip. Force, IMP, and EMG were simultaneously acquired and digitized at 2500 Hz per channel (NI USB-6225, National Instruments, Austin, TX) using custom software (LabVIEW, National Instruments).

Protocol: Subjects performed three maximum voluntary contractions (MVC) and the greatest value was selected. Subjects performed ramped isometric contractions from zero to 50% MVC at rates of 5, 10, and 15% MVC/second guided by visual feedback. Fifteen trials were performed at each contraction rate, with at least 30 seconds of rest between trials to prevent fatigue.

Data processing and analysis: All data processing was performed offline using custom MATLAB software (The MathWorks, Natick, MA). The following outcome variables were assessed:

(1) Force, IMP, and EMG relationship: Data were normalized to the maximum value of each trial (IMP, EMG) or the MVC (force) and averaged across all trials for each subject at each contraction rate. A linear fit was developed for each contraction rate between the normalized IMP and EMG vs normalized force, and the slopes of each linear fit were compared.

(2) Electromechanical delay: The onset of activity was defined as the time when the signal was greater than three standard deviations above the mean signal value during rest. The delay between the force or IMP activity onset relative to the EMG activity onset was quantified for each trial.
Statistical analysis: A standard least squares model was performed in JMP software (SAS Institute, Inc., Cary, NC). Tukey-Kramer post-hoc analysis was applied to test significant differences ($\alpha = 0.05$).

RESULTS AND DISCUSSION

(1) Force, IMP, and EMG relationship: No statistically significant difference was found between the normalized force-EMG linear fit slopes across contraction rates, which is in agreement with the findings from previous studies [2]. Additionally, no statistically significant difference was found between the normalized force-IMP linear fit slopes across contraction rates. (Figure 1)

![Figure 1](image1.png)

Figure 1. Effect of force on normalized RMS EMG (top) and normalized IMP relationship (bottom) in a representative subject, averaged over n trials, for three different contraction rates. No significant difference was found between the slopes for either the force-EMG or force-IMP relationship across the contraction rates.

(2) Electromechanical delay: Force generation rate did not have a significant effect on onset delay times. A statistically significant difference ($p < 0.05$) was found between the mean force-EMG EMD (36 ± 31 ms) and the mean IMP-EMG EMD (3 ± 21 ms). The force-EMG EMD is attributed to the time required to stretch series elastic elements [3], and our findings agree with reported delays of 20 – 125 ms in lower extremity muscles [4, 5]. The statistically significant shorter IMP-EMG EMD suggest that IMP measurements are not affected by the transduction of force along series elastic components, and thus, reflect local instantaneous changes in muscle tension.

![Figure 2](image2.png)

Figure 2. Boxplots showing distribution of measured electromechanical delay (EMD) of force and IMP signals. The mean force EMD was greater than the IMP EMD ($p < 0.05$).

CONCLUSIONS

The results from this study demonstrate that (1) a linear relationship between force, IMP and EMG exists and and is independent of contraction rate, and (2) the EMD between IMP and EMG is shorter than the EMD between force and EMG. Taken as a whole, these findings suggest that IMP reflects changes in muscle tension due to the contractile muscle elements.

REFERENCES


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