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Validation of an Adjustment Equation for the Burst Superimposition Technique in Subjects Post-Stroke

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Abstract

Introduction—Deficits in voluntary force generation may be due to incomplete activation or decreased maximum force generating ability (MFGA) of the targeted muscle. The validity of techniques used to measure MFGA in individuals post-stroke has not been assessed. The objective of this study is to determine the reliability of the MFGA predicted using an adjusted burst superimposition method within a post-stroke population.

Methods—Differences in paretic-side plantar flexor muscle MFGA between two trials was calculated using the standard and adjusted burst superimposition technique for 17 individuals post-stroke (15 men, 58.7 ± 10 yrs, 6+ months post-stroke) to assess reliability of the techniques.

Results—The adjusted measurement was shown to be more reliable ($p=0.03$), especially when volitional effort differed by more than 40 N.

Discussion—Reliable measurement of the MFGA in individuals who have sustained a stroke is of clinical importance. These results suggest that the adjusted burst superimposition method may be useful when performing multiple measurements of muscle performance.

Keywords

Maximum force generating ability; Burst superimposition; Plantar flexors; Stroke; Functional Electrical Stimulation

INTRODUCTION

Deficits in the voluntary force generating ability of an individual may be due to incomplete voluntary activation, a decrease in the maximum force generating ability (MFGA) of the muscle, or both. Quantifying the source of muscle weakness in individuals with upper motor neuron pathologies is important for both clinical rehabilitation and musculoskeletal modeling.^{1–3} Various techniques exist to obtain estimates of the MFGA of a muscle or muscle group in individuals with no neurological impairments.^{4–7} However, in individuals post-stroke, neurological impairments may limit the volitional force that can be produced, and the validity of techniques to estimate MFGA in this setting has not been assessed.

Recently, a study by Flynn and colleagues evaluated the accuracy and reliability of several methods in determining the MFGA of the ankle plantar flexor muscles of able bodied subjects performing submaximal volitional contractions.⁸ They found that an adjusted burst

superimposition method was the most accurate and reliable method. The adjusted burst superimposition test, however, has not been assessed in a neurologically impaired population. The objective of this study was to determine within a post-stroke population the reliability of the MFGA predicted using the adjusted burst superimposition method. Unfortunately, because many individuals post-stroke cannot fully activate their muscles volitionally and the intensity needed to activate a large muscle group like the plantar flexors fully for the duration needed to produce a plateau in force is not easily tolerated, we are unable to assess the accuracy of this method. Thus, only reliability, defined as the ability of repeated measurements to yield the same results, can be assessed.

MATERIALS AND METHODS

Seventeen individuals post-stroke (15 men, 58.7 ± 10 yrs., 6+ months post-stroke involving cerebral cortical regions) were recruited to participate in this study. Subjects were excluded under the following conditions: severe aphasia, substantial cognitive deficits, cerebellar involvement, or preexisting conditions affecting walking function. Each subject signed an informed consent approved by the University of Delaware Human Subjects Review Board. Muscle force of the paretic-side plantar flexor muscle group was evaluated using the burst superimposition test as recently described.⁸

During testing, subjects lay supine on a KIN-COM III dynamometer (Chattecx Corp, Chattanooga, Tennessee) with the knee in extension and ankle at neutral. A Grass S8800 stimulator (Grass Technologies, Warwick, RI) with an SIU8T stimulus isolation unit and two self-adhesive surface electrodes (Versa-Stim 3"×5", CONMED Corp., New York, USA) were used to deliver electrical pulses. During the burst superimposition test, an initial maximal single pulse (600μs, 135V) was delivered to the resting muscle. After this pulse, subjects had 5 seconds to reach their maximum volitional effort. Five seconds after the first pulse, a maximal electrical stimulation burst (600μs pulse duration, 100ms train duration, 135V, 100Hz train) was delivered while subjects produced a maximum volitional force. Predicted MFGA using the burst superimposition test ($MFGA_{burst}$) was calculated using the following equation:

$$MFGA_{burst} = F_{vol} + F_{stim} \quad (1)$$

where F_{vol} is the volitional force produced by the subject and F_{stim} is the additional force produced by the stimulation. An adjustment was applied to the MFGA value predicted by the burst superimposition test to obtain an adjusted MFGA ($MFGA_{adj}$), using the equation developed by Flynn et al., 2011⁸:

$$\%Error = 105 \left(\frac{F_{vol}}{MFGA_{burst}} \right)^3 - 157 \left(\frac{F_{vol}}{MFGA_{burst}} \right)^2 + 103 \left(\frac{F_{vol}}{MFGA_{burst}} \right) - 52.0752 \quad (2)$$

To calculate $MFGA_{adj}$, the observed MFGA is multiplied by a correction factor, C, where:

$$MFGA_{adj} = MFGA_{burst} \times C \quad \text{where} \quad C = \frac{1}{\left(1 + \frac{\%Error}{100}\right)} \quad (3)$$

Data Analysis

Two successful trials of the burst superimposition test were collected per subject during a single test session. A successful trial was defined as a trial in which the subject maintained a constant force for at least 100 ms prior to the delivery of the maximal electrical stimulation

burst. Constant force prior to stimulation was assessed visually during the collection. The average standard deviation in force over the trials that were used is 1.59 ± 1.49 N. All subjects were able to achieve 2 successful trials in no more than 3 attempts. To assess the reliability of the data, the difference in the predicted MFGA values between the 2 trials was calculated for both the MFGA_{burst} and MFGA_{adj} methods. With perfect reliability, the difference between repeated trials would be zero. Paired t-tests were used to evaluate the differences in reliability between the 2 methods. Additionally, paired t-tests were used to evaluate differences between the predicted MFGA of lower and higher MVC trials for both the MFGA_{burst} and MFGA_{adj} techniques.

RESULTS

The MFGA_{adj} was more reliable for all subjects with differences in F_{vol} greater than 40 N (Figure 1). Overall, the average MFGA_{adj} was 96.6 ± 42.7 N greater than the MFGA_{burst} ($p < 0.001$). The absolute differences between repeated trials using the MFGA_{adj} to calculate forces (17.9 ± 19.6 N) were less than using the MFGA_{burst} (24.5 ± 21.3 N) ($p = 0.03$). The MFGA_{burst} for the lower F_{vol} trials were lower (-23.3 ± 22.8 N) than the MFGA_{burst} for the greater F_{vol} trials ($p < 0.001$); In contrast, the MFGA_{adj} trials were not different ($p > 0.05$) (Figure 1).

DISCUSSION

Reliability of the predicted MFGA when a wide range of voluntary forces are produced is of particular importance for subjects post-stroke, as a consistent volitional effort cannot be assumed within or between sessions. The error adjustment used in the MFGA_{adj} technique is dependent on the volitional effort (F_{vol}) that a subject produces, and greater adjustments are made when the subject's volitional activation is lower. In addition, because the MFGA_{adj} was greater than the MFGA_{burst}, using the adjusted method would result in a lower predicted volitional activation ratio, where the volitional activation ratio is the ratio of the volitional force to the MFGA. Using criteria set by Kent-Braun and colleagues⁴, MFGA_{adj} would be considered more sensitive to impairment than MFGA_{burst}, as it reveals a greater amount of volitional impairment.⁴ Sensitivity to impairment is crucial when measuring muscle performance, as it provides clinical insight that can help guide rehabilitation protocols. For example, a subject with significant deficits in MFGA and minimal activation impairment may benefit more from a rehabilitation protocol focused on strength training. In contrast, individuals with considerable deficits in activation may benefit more from interventions such as biofeedback or EMG-triggered electrical stimulation⁹, which are designed to increase volitional control of muscles. Additionally, more sensitive measurements of muscle performance are important for accurately tuning musculoskeletal models to reflect subject-specific capabilities. This is of substantial importance, as results of musculoskeletal models have been shown to be sensitive to differences greater than 10% in maximum isometric force.¹

Although we did not assess the accuracy of the estimated MFGA_{adj} in individuals post-stroke, we believe that the superior reliability of the MFGA_{adj} technique demonstrated in this study, combined with validation of this technique in a healthy population, suggests that the MFGA_{adj} may be a useful technique to estimate MFGA and volitional activation in a post-stroke population.

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ABBREVIATIONS

MFGA	maximum force generating ability, represents the force the muscle is capable of generating with full muscle activation
F_{vol}	force of the volitional contraction
MFGA_{adj}	The maximum force generating ability calculated using the adjusted burst superimposition technique
MFGA_{burst}	The maximum force generating ability calculated using the burst superimposition technique

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Figure 1.

(A) Volitional forces (F_{vol}) and predicted maximum force generating abilities (MFGA) for 2 trials of the burst superimposition test with ($MFGA_{adj}$) and without ($MFGA_{burst}$) adjustment for 17 individuals post-stroke. (B) Difference between MFGA predictions versus differences in voluntary forces (ΔF_{vol}) for 2 trials of the burst superimposition test. The adjusted MFGA value is more reliable (closer to zero) for all individuals with ΔF_{vol} greater than 40 N.