EVALUATION OF HAND MOTOR FUNCTION BY CIRCUMFERENTIAL FORCE PRODUCTION OF THE THUMB

Daniel A. Harkness, Zong-Ming Li

Musculoskeletal Research Center
Department of Orthopaedic Surgery
University of Pittsburgh
Pittsburgh, PA

INTRODUCTION

Hand motor function can be described by activities involving precision handling and power grasps. These maneuvers necessitate digit force production and force control in multiple directions[1]. Thumb strength, based on the thumb's crucial anatomical and biomechanical role as the main proponent of opposition, has been the most common and convenient parameter used to assess the motor function of the hand [2,3]. Current clinical practices utilize key pinch and power grasp dynamometers[2,4-6], which are limited to a single force output insensitive to the direction of force application. Thus, a clinical need exists to provide a more comprehensive and descriptive means of assessing hand motor function based on multidirectional force measurement. Therefore, our objective was to design experimental procedures for measuring maximum voluntary contraction (MVC) forces produced by the thumb in a circumferential and continuous manner.

METHODS

Five subjects (age: 25.5 ± 3.9 yrs) sat with their shoulder in approximately 60^o abduction in the frontal plane, their forearm in a midprone position, elbow braced in 90^o flexion, and wrist braced in 20^o extension and 0^o ulnar deviation. The thumb was positioned within a metallic ring at the midpoint of the proximal phalange in approximately 10^o flexion at the metacarpophalangeal joint and fixed in extension at the interphalangeal joint (Figure 1). Each subject performed 40 circumferential MVC tasks that were grouped into 10 trial sets of 4 trials each. During circumferential trials, each subject produced MVC force against the inner perimeter of the ring following a counterclockwise path. The subjects were allotted 15 seconds to complete each task with 60 seconds of rest between each trial.

A Mini40 force transducer (ATI Industrial Automation, NC) was used to measure MVC forces. Output from the transducer generated Cartesian force coordinates (X_i, Y_i), which were transformed into polar coordinates (R_a, a), where R_a was the force magnitude at angular position a. A median (m_a) and maximum (M_a) were determined from a string of K data points along the radial line of each a_i where:

$$m_a = \text{median}\,(R_{a1}, R_{a2}, R_{a3}, \ldots R_{aK})$$
$$M_a = \max\,(R_{a1}, R_{a2}, R_{a3}, \ldots R_{aK})$$

The theoretical maximum force envelope (to be called *force envelope* in the ensuing text) F_a was formed by adding a constant C to the median force envelope, i.e., $F_a = m_a + C$ (a = 0, 1, 2, …, 359). The constant C was determined by averaging the differences between M_i and m_i around the 360 degrees, i.e., $C = \frac{1}{360}\sum_{a=0}^{359}(M_a - m_a)$.

After the force envelope was constructed, the area (A) enclosed by the force envelope was calculated using the following formula: $A = \frac{1}{2}\int_0^{2p} F_a^2\, da$. Throughout the progression of the experiment, accumulation of more MVC force data points along different angular directions caused the force envelope to enlarge. The area of this larger force envelope was subsequently reported as cumulative area.

RESULTS

The average force envelope from the 5 subjects is shown in Figure 2. The shape of the force envelope is asymmetrical and oblique, with the center shifted towards flexion. The average forces corresponding to adduction (0°), extension (90°), abduction (180°), and flexion (270°) are 52.1 N, 61.0 N, 55.2 N, and 82.2 N, respectively. The maximum radial force was 87.8 N at 286^o, a direction combining flexion and slight adduction. The highest forces were produced in the flexion/adduction quadrant; the forces produced in other quadrants were less than 75% of the maximum radial force. The lowest force was produced at 28° combined extension and adduction, only 53% of the maximum force.

The maximum cumulative area of 12,699 ± 4,773 N^2 occurred at the completion of 10th trial set. The force area envelope produced from the first trial set was 87.2% of the maximum. The percentage area of the cumulative force envelopes were 92.7%, 95.0%, 96.4%, and 99.1% after the 2nd, 3rd, 4th, and 5th trial sets, respectively. There were virtually no increases in force envelope area after the 5th trial set. However, the cumulative areas after the 3rd trial sets were significant higher than area of the 1st trial set ($P < 0.05$).

DISCUSSION

We have developed a novel concept of motor function quantification using a force envelope. The continuous circumferential measurement of hand motor function is parsimonious in comparison with previous studies when forces in specific directions were measured discretely [7-8]. The shape and size of the force envelope can be captured with only a few trials. About 90% of motor outcome, as quantified by force envelope area, was obtained after the first trial set, and more than 95% was achieved after the third trial set.

The methods developed in this study can be used to study neuromuscular function of the hand in a more advanced manner in contrast to the traditional measurement of hand strength using grip and pinch dynamometers. For diagnostic purposes, a specific hand disorder may cause a characteristic deviation of motor function because each muscle or tendon within the thumb has it own biomechanical role. A decrease in force in certain directions is correlated with the weakness of the associated muscles, suggesting certain underlying impairment. In addition, the methods can be used to evaluate the degree of motor deficit caused by known hand disorders, as well as to monitor the progression of a disorder and the efficacy of therapy and treatment [3].

Figure 1. Experimental station setup.

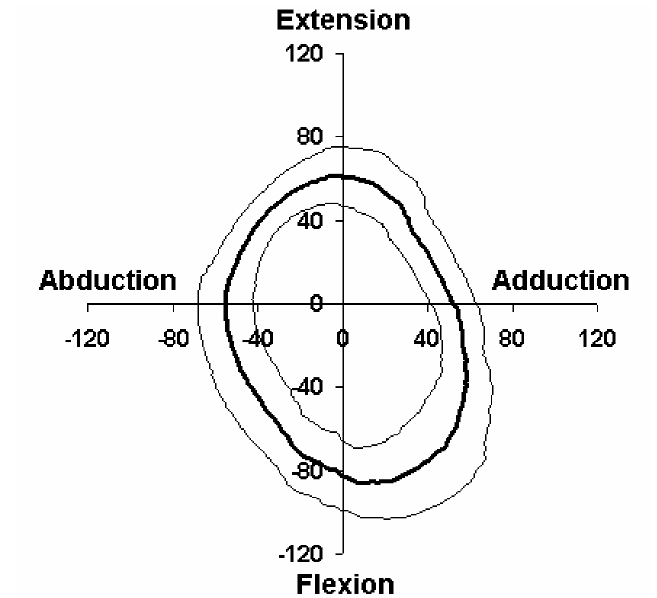

Figure 2. Average force envelope (N) of the 5 subjects (thick line represents the mean and thin lines represent SD).

REFERENCES

1. Johanson, M. E. et al. *J Hand Surg [Am]*, 26(4): 698-705, 2001.
2. Mathiowetz, V. et al. *J Hand Surg [Am]*, 9(2): 222-6, 1984.
3. Bohannon, R. W. *Clin Biomech*, 10(6): 283-292, 1995.
4. Ager, C. L. et al. *Am J Occup Ther*, 38(2): 107-13, 1984.
5. Goldman, S. et al. *Am J Phys Med Rehabil*, 70(6): 306-8, 1991.
6. Schreuders, T. A. et al. *J Hand Surg [Br]*, 25(6): 560-5, 2000.
7. Bourbonnais, D. et al. *J Hand Ther*, 6(4): 313-8, 1993.
8. Li et al., *Clin Biomech* (submitted 2002).

ACKNOWLEDGEMENTS

The support of the Aircast Foundation, Whitaker Foundation and Musculoskeletal Research Center is gratefully acknowledged.