BIOMECHANICAL EVALUATION OF THE MOTOR FUNCTION OF THE INDEX FINGER

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INTRODUCTION
Assessment of motor function is an important aspect of the physical examination of the hand. However, existing tests of hand motor function are subjective, semiquantitative, or non-specific. Those tests often lack the sensitivity needed to identify subtle but meaningful changes in the deterioration of hand function. More quantitative, sensitive and discriminative methods are needed to detect changes in the motor function resulting from pathological conditions, disease progression, rehabilitation, or treatment. The purposes of this study were (1) to develop methods that provide objective, quantitative, systematic, and computer-assisted biomechanical evaluation of the motor function of individual digits, and (2) to establish motor function pattern of the index finger of asymptomatic hand using the developed methods.

METHODS
A novel experimental apparatus was designed to measure the maximum voluntary isometric contraction (MVIC) forces of a digit at various points along the digit. The direction of force application can be in any direction within the transverse plane of the longitudinal axis of the digit. The apparatus consists of a wheel, position control accessories, and a force transducer (Figure 1). MVIC force production of a digit is achieved by pulling on a plastic ring through a cable connected to a force transducer mounted on a metal wheel. Sixteen mounting holes for the transducer were evenly distributed around the rim of the wheel to allow force measurement in specific directions. Computer programs were used for force data acquisition and processing.

During testing, the hand was splinted in 20° of extension and 0° of ulnar deviation at the wrist, 20° of flexion at the metacarpophalangeal joint, and full extension at the interphalangeal joints. After the hand and forearm were in place, the position of the wheel was adjusted so that the longitudinal axis of the index finger was perpendicular to the wheel plane, with the middle of the proximal phalanx located at the center of the wheel (Figure 1).

Eight right-handed male subjects (age: 26.3 ± 4.9 yrs) with asymptomatic hands participated in the study. Each subject performed MVIC forces in 16 directions. Three consecutive sets of 16 trials were performed. Within each set, the sequence of 16 directions was randomized. For each trial, the subject was prompted to produce MVIC force within 4 seconds. A thirty-second break was provided between trials. The peak force produced in each trial was used for data analyses. One-factor ANOVA was used to compare force outputs, with a significance level set at α = 0.05.

RESULTS
Forces produced by the index finger were dependent on the direction of the force application (p < 0.001). The highest force, 110.7 ± 9.0 N, was generated at 270° in flexion, while the lowest force, 41.4 ± 14.8 N, was generated at 90° in extension. The index finger was able to generate more than 90% of the flexion force in the directions combined with abduction and flexion ranging from 157.5° to 315° (Figure 2). A polar plot was created by using a set of peak forces from the 16 directions. Based on this polar plot, the force envelope for each subject was constructed using cubic spline interpolation technique. The area formed by a force envelope was divided into two sets of force quadrants: (A) extension-adduction (northeast), extension-abduction (northwest), flexion-adduction (southwest), and flexion-adduction (southeast), and (B) extension (north), abduction (west), flexion (south), and adduction (east) (Figure 3). The area of the force envelope was 25,739 ± 3,688 N-N. For Division A of the force envelope, the percentage areas for extension-adduction, extension-abduction, flexion-adduction, and flexion-adduction quadrants were, on average, 12.9%, 20.4%, 36.0%, and 30.8%, respectively. For Division B, the percentage areas for extension, abduction, flexion, and adduction quadrants were, on average, 9.1%, 33.3%, 35.6%, and 22.1%, respectively.

DISCUSSION
We have developed an apparatus for the measurement of maximum voluntary isometric contraction force of a digit at various points along the digit and in any direction within the transverse plane of the longitudinal axis of the digit. The apparatus can be easily adjusted to measure motor function of other fingers and the thumb. For the index finger, it was found that the forces varied according to the direction of effort; and, the polar plot of force envelope demonstrates characteristic patterns. The methods described in this study provide an advanced level of quantification of hand motor function. The formation of the force envelope allows visualization of the motor function pattern and calculation of envelope area and quadrant areas, furthering our understanding of hand motor function results from global musculature and functional muscle groups.

A specific hand problem may cause a characteristic deviation of motor function because each muscle or tendon within a digit has it own biomechanical role and hand muscles are innervated by several distinct nerves. Weakness in certain directions may provide valuable information on relevant muscles, and hence, the source of the problem. Therefore, our methods may provide sensitive measures to help detect hand problems in the earliest stages, when therapies are most efficacious. In addition, our methods can be used to objectively quantify the degree of motor function impairment for individuals already diagnosed with a hand problem, as well as to monitor the progress of the disorder and/or the efficacy of therapy and treatment.

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