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Short communication

The extent of altered digit force direction correlates with clinical upper extremity impairment in chronic stroke survivors

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ABSTRACT

Many stroke survivors suffer from impaired hand function. Biomechanics of hand grip suggests that abnormally directed grip force can hamper gripping abilities and hand function. This study examined the relation between the ability to precisely direct fingertip force and clinical hand function scores among individuals affected by stroke. Specifically, clinical hand function tests of the Fugl-Meyer, Chedoke McMaster, and Box and Block Test were used, since they involve various hand movements required for activities of daily living. Digit force direction during static grip was recorded using multiaxial load cells. Data for 59 chronic stroke survivors were analyzed. We found that larger angular deviation of digit force from the normal direction was significantly associated with lower hand functional levels ($p < .001$ for all three clinical tests). Particularly, stroke survivors whose digit force deviated more than 21° from the normal direction could not achieve the normal level of Fugl-Meyer or Chedoke or move more than 4 blocks in a minute. The biomechanics of the way digit force direction affects hand grip function is described. In addition, underlying mechanisms for altered digit force direction post stroke are postulated, including impaired somatosensation and abnormal neural input to muscles. In summary, this study identifies a new biomechanical marker for hand functional level and recovery. Future interventions may focus on correcting digit force direction to improve hand functional outcome.

1. Introduction

Many of 7 million stroke survivors in the U.S. (Roger et al., 2012) have impaired hand function (Trombly, 1989; Gray et al., 1990; Nakayama et al., 1994; Kamper et al., 2003). Stroke survivors' attempt at grasping an object often leads to the object slipping out of the hand. Not only reduced strength (Boissy et al., 1999) but also impaired grip coordination can affect grip function in daily living for people after stroke (Nowak and Hermsdorfer, 2005; Blennerhassett et al., 2006). One of the aspects of impaired grip coordination is altered force direction (Cole, 2006).

Altered digit force direction may hamper gripping abilities via biomechanics of hand grip. To grip an object without slippage, digit force must be directed to the object within an allowed angle range defined by the cone of friction (Fig. 1) (Fikes et al., 1994; MacKenzie and Iberall, 1994). For instance, to grip a rubber-finished object, digit force cannot deviate more than 42° (Seo et al., 2010). When the digit force direction lies outside the cone of friction, shear force becomes greater than maximum allowable friction force and the finger would slip against the object thereby resulting in loss of grip. If digit force is directed near the cone of friction, small perturbation to the finger or grasped object may lead to changes in digit force direction and loss of grip.

Chronic stroke survivors with severe hand impairment were shown to apply grip force far off from the direction normal to the grip surface, compared to age-matched adults without stroke, as illustrated in Fig. 1 (Seo et al., 2010). This large digit force angular deviation was associated with frequent slip between the finger and grip surface, observed for 55% of trials (Seo et al., 2010), which can result in grip loss and object dropping. Given the biomechanical basis by which digit force direction affects grip abilities, the extent of digit force angular deviation may be closely related to the ability to perform activities of daily living using the hand.

However, the direct quantitative relationship between the extent of digit force angular deviation and clinical functional ability is currently unknown. The previous study involved stroke survivors with severe hand impairment only. A larger dataset

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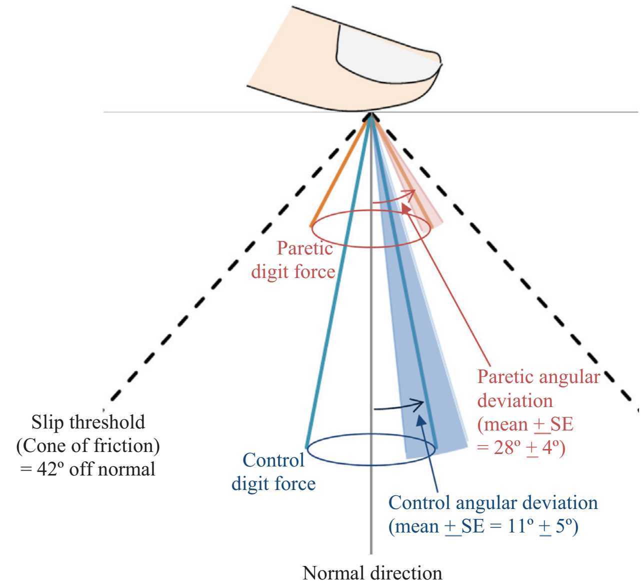

Fig. 1. Our previous study showed that chronic stroke survivors with severe hand impairment gripped with their paretic digit force directed further away from the normal/perpendicular direction compared to age-matched persons without stroke (control) (Seo et al., 2010). The mean angular deviation of digit force is illustrated as the width of the cone for each of the paretic and control hands. The paretic cone is shorter than the control cone, since the paretic hand is substantially weaker than the control hand, and thus produces less grip force. In addition to the mean values, ±1 standard error is shown as the shade around each cone. When the digit force deviation angle reaches the slip threshold (42° for rubber finish), the finger slips against the object surface (Fikes et al., 1994; MacKenzie and Iberall, 1994). The paretic digit force deviation angle is closer to the slip threshold compared to control, indicating greater likelihood of finger-object slippage, grip loss, and object drop.

involving stroke survivors with a wide range of hand functional levels is needed to determine the relationship between digit force direction and clinical hand function. Understanding this relationship would provide an insight for the way hand function is impacted by altered digit force direction post stroke, and enable development of assistive devices or therapeutic interventions that improve digit force direction and thus improve hand function for these individuals. Therefore, this study examined if the extent that digit force direction deviates from the normal direction relates to clinical hand function scores whose primary tasks involve dexterous and gross upper limb movements required by activities of daily living. The clinical hand function tests included: the Fugl-Meyer Assessment for the hand and wrist (Fugl-Meyer et al., 1975), Chedoke McMaster hand scale (Gowland et al., 1995), and Box and Block Test (Mathiowetz et al., 1985).

2. Method

2.1. Subjects

Fifty nine chronic stroke survivors' data were analyzed. The mean age was 58 and standard deviation was 12 years. Time since stroke ranged 1–21 years. They were 36 males and 23 females. Seventeen subjects' data were from previous studies (Seo et al., 2010, 2011a). Only data without any intervention was used from Seo et al. (2011a). The other 42 subjects' data were newly obtained. The hand impairment level of the 59 subjects ranged from mild to severe, as seen by the Stages 1–7 of the Chedoke McMaster hand scale determined by a therapist: Chedoke Stage 1 implies flaccidity, while people who can perform active movements with and without facilitation belong to Stage 2 and 3, respectively; Simple and complex synergy movements are possible at Stage 4 and 5, respectively; Stage 6 implies limitation in more complex or faster movements than needed in daily activities, while Stage 7 represents no evidence of functional impairment (Miller et al., 2008). All subjects signed written consent approved by IRB.

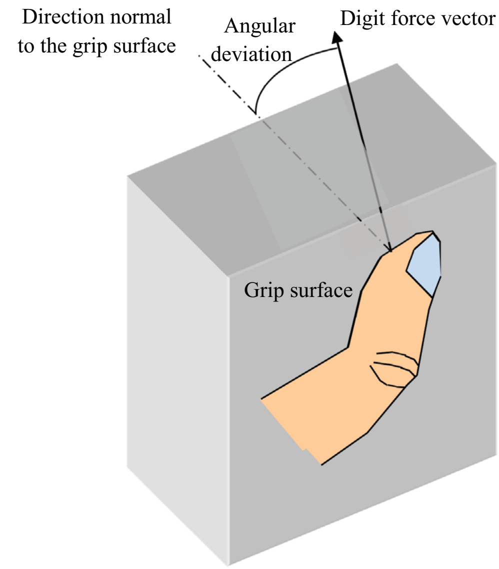

Fig. 2. The angle by which the digit force vector is deviated from the normal direction was computed as the arctangent of the ratio of total shear force to normal force.

2.2. Procedure

This study quantified digit force angular deviation from the normal direction during static grip for each subject (Fig. 2). Subjects rested their forearm on a table and placed the thumb and index finger on two fixed flat rubber surfaces. For subjects with severe impairment, the experimenter assisted with placing their fingers on the grip surfaces. Subjects were instructed to grip against the fixed surfaces for 5 s at the maximum effort, 5 N, and 2 N, at least three times each. The surfaces were instrumented with 6-axis load cells (ATI Industrial Automation, Apex, NC) to record normal and shear forces from each finger. For submaximal grips, visual feedback for normal force was provided to help subjects match their grip force to the target. The digit force deviation angle was computed as the arctangent of the ratio of total shear force to normal force over a one-second period in which the average normal force was the greatest for maximal grips or closest to the target for the 5 N or 2 N grips (Seo et al., 2010). As the deviation angle variation by digits or force levels within a person is slight compared to between-subject variance (Seo et al., 2010), an average deviation angle across both digits and force levels was used to characterize digit force direction for each subject for the correlation analysis.

In addition, clinical functional scores including the Fugl-Meyer for the hand and wrist (out of 24), Chedoke McMaster hand scale (out of 7), and Box and Block Test (number of blocks moved in 60 s) were recorded. Since this study involves retrospective data analysis, missing data exist. The Chedoke McMaster score was obtained for 59 subjects, whereas the Fugl-Meyer score was obtained for 46 subjects and the Box and Block Test score for 37 subjects. All data were for the affected hand.

2.3. Analysis

Pearson correlation was used to examine correlations between the deviation angle and the Fugl-Meyer upper extremity score, the deviation angle and the Chedoke McMaster hand score, and the deviation angle and the Box and Block Test. Three correlation analyses were used, since the functional scores were correlated with each other and thus cannot be combined in a single regression. Time since stroke, age, and gender did not influence the results of the regression analysis probably because all subjects were in the chronic stage (>9 months post stroke) and the age/gender effects, if there are any, are not as prominent as the effect of post-stroke impairment levels. Thus, the results without controlling for age, gender, and time since stroke are presented.

3. Results

The extent to which digit force direction deviated from the normal direction was negatively correlated with the Fugl-Meyer upper extremity score, Chedoke McMaster hand score, and Box and Block Test score as shown in Fig. 3A–C, respectively ($p < .001$, $R^2 \approx 0.6$ for all). Greater digit force deviation was associated with