The Detection of Discrete Regions of Hand-Object Contact Area and its Relationship to Quality of Grip in Persons with Tetraplegia

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Abstract

Contact area and the maximum holding force during tenodesis grasp in three subjects with spinal cord injury in the C_6 region were examined. Hand-object contact area was measured when a polycarbonate cylinder was grasped. Subsequently, a servomotor applied an increasing force to a similar object held by the hand until the object was displaced. The maximum holding force (N) of the hand was measured. Correlations were made between the measured object-hand contact area and the maximum object holding force. Additional correlations were performed between the contact area and the holding force whilst normalising for the subjects grip force. Both results are presented. Correlation of regional contact area and grasp holding force is likely to provide insight into the provision of grip with an optimised holding force via the manipulation of contact area.

Introduction

Physical parameters that influence the hand function of those with tetraplegia include joint range of motion, wrist extensor strength and contact area at the hand object interface. Preferred modes of hand grasp have been proposed using specific criteria in the non spinal cord injured population. These criteria include the object's shape and size on the grip [1], the intended action of the task [2] and hand object contact area [3].

The effectiveness of a particular mode of grasp depends on a number of factors operating together efficiently. Through the quantitative evaluation of these factors, a better understanding of effective grasp is possible. With improved understanding, parameters may be altered to increase the effectiveness of grasp. Such an alteration might be achieved with surgical modification or tweaking FES systems. In earlier work [4], the increased effective contact area at the hand object interface, through the manipulation of the object surface, improved hand grasp in persons with tetraplegia (C_5 and C_6). If one can improve hand grasp quality by altering contact area via manipulation of electrical stimulation configurations without needing to increase grasp force then the effects of fatigue may be minimised. The aim of this study is to identify the relationship of the measured contact area to hand grasp quality in persons with tetraplegia using a tenodesis grasp.

Materials and Methods

Three male subjects with motor level C_6 (ASIA classification) and International Surgical Classification [ISC, [6]] Group2/3, participated in the study to identify the influence of contact area on the hand grasp. All subjects retained voluntary wrist extension, which enabled them to use tenodesis [5] to hold objects.

Subject	Age	ISC	Hand Area (cm^2)
1	30	2/3	170.2
2	51	2/3	198
3	33	2/3	170

Table 1: Characteristics of subjects

Actual contact area was measured when subjects grasped a polycarbonate cylinder (5cm diameter). Subsequently, grip was evaluated by the measurement of the holding force as described below and in an earlier study [4].

Prior to, and at the completion of, testing, three grip strength measurements were taken with a strain gauge instrumented cylinder. These measurements were taken to provide assurance that the grasp wasn't unacceptably fatigued during the course of the experiment.

Hand length and breadth (metacarpal) were measured [7] on all subjects dominant hand. The total hand area equalled the length multiplied by breadth. This is shown in Table 1.

To measure contact area the subject's dominant arm (the right arm in each case) was placed in a splint to standardise position. This splint is pictured in Figure 2. The subjects hand was painted with water-soluble black paint and they were asked to grasp a cylinder that was covered in white paper and to hold the object briefly. This was repeated three to five times. After the resultant handprint was dry it was scanned (Epson Perfection 1200S) to a personal computer (Macintosh Power PC 9500/200). The hand print was divided into four areas. The 4 areas were:

- Palm
- Thumb

- Index finger
- Other fingers [ie Middle finger (MF), Ring finger (RF) and Little finger (LF)]

A shareware graphic programme was then used to determine the number of black pixels in each area. This was then multiplied by a calibration factor to provide the area in cm^2.

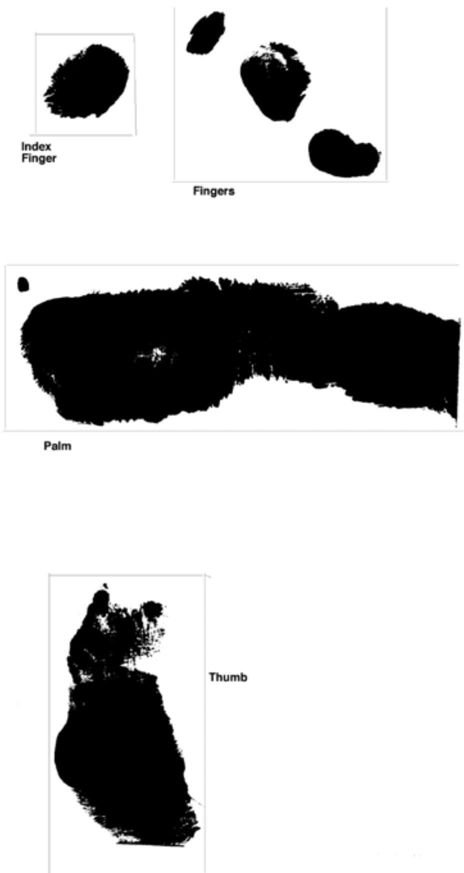

Figure 1: Example of hand print with segmented areas for analysis (Subject 3, trial 3).

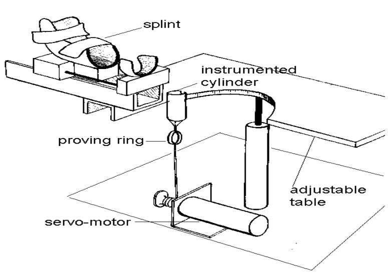

Figure 2: Experimental set-up

To measure the hands holding force in the second part of the experiment, a servomotor was positioned inferior to the subject's hand in which they held an instrumented aluminium cylinder. This cylinder was instrumented in a full wheatstone bridge strain gauge configuration, which enabled the grip force to be measured. The cylinder was connected to the motor via spectra rope. In series with the spectra rope was an instrumented proving ring (full wheatstone bridge strain gauge configuration) which measured the amount of force that the subject could resist before the cylinder was pulled from the hand. The signals measured were passed to an acquisition board (National Instruments PCI-MIO50XE). Data sampling was controlled by LabView software (National Instruments) running on a personal computer (Power Macintosh 9500) and sampled at 250 Hz. The holding force was measured from the proving ring. The maximum holding and grip forces were determined as the maximum forces generated before the cylinder slipped out of the hand.

Results

The contact area (cm^2) from each segmented area was divided by the subjects total hand area and the mean obtained. Correlations were performed firstly between the contact area and measured holding force. Subsequent correlations were performed on the contact area as described above, with the resultant holding force divided by the measured grip force. Results were normalised to subject 1 and are shown in figure 3 (Microsoft Excel).

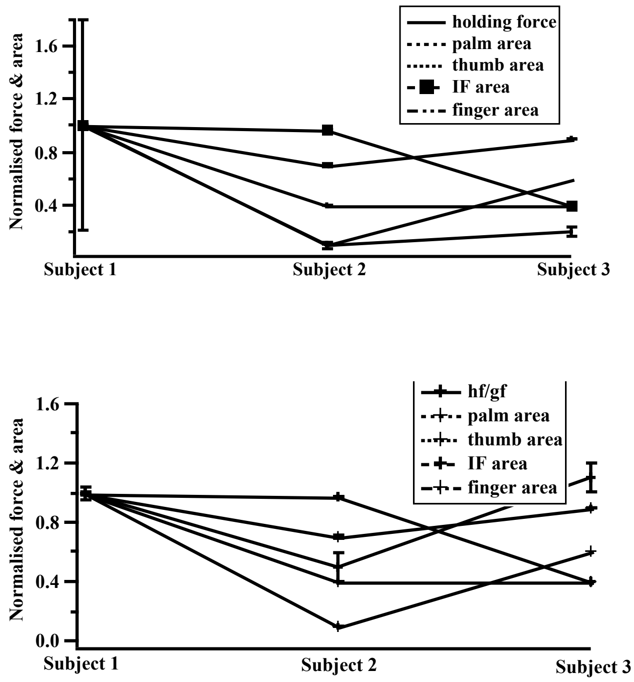

Figure 3: Normalised areas of the hand and holding force pictured (top) and (below) normalised areas with holding force/grip force

Area of hand analysed	Correlation of contact area and holding force	Correlation of contact area and [holding force ÷ grip force]

Palm	0.7	0.9
Thumb	0.9	0.8
Index finger	0.4	-0.7
Fingers	0.99	0.3

Table 2: Correlation between contact area (adjusted for subject hand size) and holding force.

The results in Table 2 list the correlations between the adjusted hand size contact area segments to the holding force in the first column and the holding force compensated by the grip force in the second column.

Discussion

Contact area has previously qualitatively been assessed in non spinal cord injured persons to identify which part of the hand is used to grasp objects [3]. Segmenting hand regions in the analysis of contact area in people with spinal cord injury has provided increased sensitivity in the measure of its influences with respect to tenodesis grasp. Correlation of the segmented contact area to the holding force indicates that holding force may have increased sensitivity to contact area in particular regions of the hand. Considering the shape and orientation of the cylinder held by the subjects in this study and the resultant contact area print, this pattern of grasp may be classified as a Power Grip [2, 3]. Kamakura et al [3] suggests not all grasps fit into this strict category as described by Napier but generally, "…a wide area of the hand, including part of the palm, makes contact with the object." p 440. In addition to visually classifying hand-object contact area, quantitative investigations as described here allows objective measurements and evaluation to be made.

Two forms of analysis have been considered in this study. The first correlation analysis where the thumb and finger areas were strongly correlated with the holding force may be related to Napier's description of the requirements of successful grasp. That is, the thumb is opposed to the pulps of one or all the fingers. This possibly indicates a dominance in the measurement of grip force as the opposing fingers transfer most of the grip force. Perhaps a better indication of hand ability may be achieved from the second correlation analysis where the holding force was compensated to the varying intersubject grip forces. For example, Subject 2 had the smallest palm contact area and holding force of the 3 subjects and his hand behaved not unlike a claw hand when the object was grasped. This type of claw hand action is described by Brand. Here the hyperextension of the metacarpophalangeal joints and the pushes the object out of the palm "…instead of surrounding it by the palmar surface and pulps of the fingers…"p 619. This may account for the small measured palm area and holding force.

This analysis method where the measured contact area is correlated to the hands holding force is shown to be a useful objective tool in understanding the contact area requirements needed for successful grasp in people with spinal cord injury.

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Acknowledgments: The authors would like to acknowledge the support of the Motor Accidents Authority of NSW, the Movement Disorder Foundation, The Spinal Research Foundation, the Cecilia Kilkeary Foundation and the Northern Sydney Area Health Service Research Grants Scheme. Special thanks also to Mr Kevin Brigden and Mr Mark Witcombe for their expertise.