Maximal grip force in chronic stroke subjects and its relationship to global upper extremity function

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ABSTRACT

Objectives: Previous studies have shown that recovery of recordable grip strength in acute stroke subjects (SS) is one of the most sensitive assessment of initial upper limb recovery and a good prognostic for latter recovery. The objectives of this study were to test the reliability of maximal voluntary grip force (MVGF) measures and evaluate the relationship between paretic grip strength deficit and paretic upper extremity function in chronic SS. Design: Over a three week period, bilateral MVGF were assessed repeatedly (n=3) with a modified strain gauge dynamometer in 15 chronic SS and 10 control subjects (CS). The paretic MVGF deficit was expressed in relation to the MVGF of the non-affected hand. Outcome measures: Upper extremity function in SS was measured using the Fugl-Meyer, TEMPA, Box and Block and finger to nose tests. Results: MVGF measures in both groups of subjects demonstrated good reliability (ICC>0.86) and low standard error measurements (SEM). The paretic MVGF was greatly impaired in comparison to the CS. This impairment was significantly correlated (p<0.01) with the performance of the SS on the four upper extremity function tests. The percentages of variances explained by the MVGF deficit on all four upper extremity tests varied from 62% to 78%. Conclusions: These results suggest that the paretic maximal grip strength normalized with the maximal grip strength on the non-affected side appears to be a valuable outcome measure of upper extremity function of chronic stroke subjects.

INTRODUCTION

The ability to generate muscle tension for the purpose of posture and movement is an obvious prerequisite to normal human functions. Weakness or a subject's inability to generate normal levels of muscle tension, is now being recognized by an increasing number of rehabilitation professionals as a vital impairment leading to disability in stroke patients [1-3]. Although strength testing has not always been part of the conceptual framework in the evaluation and rehabilitation processes of the hemiparetic patients, a new paradigm justifying its use is now emerging. Studies linking strength deficits of different muscle groups in hemiparetic patients and their performance on functional tasks have been presented and discussed extensively in the literature [4-6]. However, with the exception of a few [7-11], most of these studies have focused on the relationship between lower limb muscles strength and gait performance [7, 12-15]. Strength deficits of upper limb muscles and their potential relationship to upper limb performance have not been studied at length.

Assessment of handgrip strength has been used as a predictor of the motor performance and functional independence of acute stroke subjects [10, 11]. Heller et al. (1987) compared handgrip strength measurements with arm function tests in 56 acute stroke patients. They observed that failure to recover measurable grip strength before 24 days was associated with absence of useful arm function at three months[10]. Sunderland et al. (1989) observed that improvement in grip strength scores in a group of 38 acute stroke patients closely paralleled improvements on more complex motor tasks. This finding suggests that grip strength may be a valuable marker for recovery of arm function in acute stroke patients [11]. While a grip strength assessment is easy to administer, its reliability with hemiparetic subjects has not been examined. Moreover, it has not been established whether grip strength deficits in chronic hemiparetic subjects parallel their motor recovery status. The objectives of this study were thus to: 1) assess the reliability and consistency of maximal hand grip strength measurements in stroke subjects, 2) examine the relationship between the hand grip strength deficits on the affected side of chronic stroke patients and the performance of their affected upper limb on various clinical tests. A portion of these results has been presented in abstract form [16]

METHODS

Subjects

Fifteen chronic stroke subjects [SS] and 10 control subjects [CS] participated in this study. The SS were recruited from a secondary care rehabilitation center patient database and were included in the study if they i) had sustained a single cerebro-vascular accident (CVA) leading to upper limb paresis at least one year prior to the experiment, ii) lived within 30 km of the research center, iii) were able to understand simple commands (no receptive aphasia) and, (iv) showed no severe cognitive or comprehension deficits. Patient with troncular lesions as documented in their medical history were not considered. The demographic characteristics for both subjects group appears in Table 1. The control group was composed of five men and five women between 25 years and 67 years of age (mean ± SD age : 44,1 years ± 11,3). The hemiparetic group consisted of 10 men and 5 women between the ages of 29 years and 65 years (mean ± SD age : 47,1 years ± 13,7). All of the control subjects, with the exception of one left handed subject showed strong (90 % or more) right hand dominance on the Edinburgh Inventory [17]. Handedness for all the hemiparetic subjects as reported before their cerebro-vascular accident using the Edinburgh Inventory also showed strong right hand dominance (90 % or more). Both groups were statistically comparable in term of gender (x^2 = 0.15, p =0.70) and age (t-test=- 0.268, p= 0.79).

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Maximal voluntary grip forces

Maximal voluntary grip forces (MVGF) were assessed bilaterally using a modified hand grip dynamometer interfaced with a computer (Figure 1). Grip forces were recorded using a modified prehension dynamometer [Lafayette Instrument, Model 78001] instrumented with a universal tension adaptor. The tension adaptor was coupled to a transducing cell [Gould Statham, UC3] interfaced to a computer. This transducing cell unit was excitable to a maximum of 10V and had a sensitivity of 12mV/V. It allowed maximum grip force measurement of 2225 N with a sensitivity of 2.67N. The voltage from the transducing cell was sampled at 50Hz and converted on line in N from known calibration factors and displayed on a monitor. Subjects were seated in a wheelchair. The testing position was standardized. The shoulder was placed at approximately 30° of abduction and 0° of flexion. The elbow was flexed at 90° with the wrist in neutral position. MVGF were established as the highest values recorded during three maximal voluntary exertions separated by two-minute rest intervals. For each subject, three measurement sessions were held one-week apart at approximately the same time of day.

Hand grip strength deficit

The hand grip strength deficit was represented by the hand ratio (HR). The HR in SS was calculated by taking the ratio of the MVGF of the affected hand (AH) to the MVGF of the non-affected hand (NAH). For CS, the left hand (LH) was considered to be the equivalent to the NAH of SS and the the right hand (RH) was the equivalent of the MVGF of the AH of SS.

Upper extremity function

The performance of the upper limb of each SS was characterized using a battery of standardized clinical tests. These evaluations were performeddone by a trained therapist blind to the study. They included the Fugl-Meyer test [18], the TEMPA test [19] the finger to nose test [20] and the Box and Block test [21]. The performance on the Fugl-Meyer test was computed only for the upper limb portion of the test. The total score for the TEMPA test was computed using the functional cotation score of the TEMPA in the four unilateral and the four bilateral functional tasks. The finger to nose test and the Box and Block test were performed using only the affected upper limb.

The Fugl-Meyer scale assesses the ability of the subject to make isolated movements both within and outside of the pathological synergy patterns. It also measures sensory function, reflexes, hand function and coordination. Several investigators have demonstrated the validity and reliability of this assessment in hemiparetic patient populations [22, 23]. The TEMPA test consists of four unilateral and four bilateral functional tasks that range in difficulty from carrying a pot to addressing and posting an envelop. The performance of each of these tasks was scored on a four point negative ordinal scale. Zero corresponded to successful completion of the task without hesitation or difficulties as demonstrated, -1 corresponded to successful completion of the task with hesitation or difficulties, -2 corresponded to partial execution of the task (at least 25 %) in which certain parts of the task were modified or where the subject needed assistance to execute it, -3 corresponded to unsuccessful execution of the task (less than 25%) even with assistance or modification. The 4 unilateral tasks were scored for both the affected and non-affected upper limb and summed with the score of the 5 bilateral tasks. The total functional scores ranged from 0 to -39. The distribution of maximal points deduction for the functional tasks was -12 points for 4 unilateral tasks executed on the affected side (i.e. 3 points scale x 4 tasks), -12 for the same tasks executed on the non-affected side and -15 points for 4 bilateral tasks. A score near 0 indicates normal non-disturbed functional performance in both unilateral and bilateral tasks. The reliability and validity of this test have been demonstrated in elderly subjects [24, 25]. The Box and Block test consisted of moving, one by one, a maximum number of one inch block, from one compartment of a box to another of equal size in a sixty seconds period. The administration of the test was done in accordance with the standardized procedure of Mathiowetz [26]. The reliability of this test for use in both young and elderly populations has been demonstrated and its construct validity established [27].

The finger to nose test consisted of counting how often the subject touched alternatively his or her nose and the target in a 20 second period using the finger of the affected upper limb. In this test, the subject sat in a regular chair facing a wall. A red target 2 cm in diameter was fixed vertically on the wall at the subject's eye level. The chair was positioned so that the subject's nose was 45 cm from the target. Imprecise movements between the nose and the target were not acccounted for in the total score. A high test-retest score for this evaluation has been documented in traumatic brain injured patients [28, 29].

Statistical procedure

Intraclass correlation coefficients (ICC) [30, 31] were computed for each group of subjects to determine the reliability of the MVGF measurements. The consistency of each MVGF measurement was estimated using the standard error of measurement (SEM) [32, 33]. The SEM expresses measurement error in the same unit as the original measurement and can be used to distinguish a true difference between measures and an error of measurement. All of the statistical analyses were performed on the GENOVA* program developed specifically for the generalizability analysis [34]. HRs and bilateral MVGF recorded in the second measurement session were then compared between groups (SS vs. CS) with unpaired t-tests. Linear regression analyses were performed on scores obtained with the clinical tests (Fugl-Meyer, TEMPA, Box and Block and Finger to Nose) and HR measurements of SS. Alpha values were fixed at 0.05. Analyses were performed on the Statview statistic package from Abacus Concepts.

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RESULTS

Reliability of MVGF measurement

The mean and standard deviations of bilateral maximal voluntary grip force (MVGF) taken in three separate measurement sessions for fifteen SS and ten CS are illustrated in Figure 2. Results of ICCs and SEM estimates for each group and each measurement of MVGF are summarized in Table 2. Results of ICCs and SEMs indicate that repeated measurements of the MVGFs of SS appear more reliable and consistent on the AH than on the NAH. In contrast to SS results, repeated MVGF measurements on the left hand of CS (i.e. non dominant hand) are more reliable and consistent than repeated MVGF measurements on the righ hand (i.e. dominant hand).

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The ICCs for repeated measurements of MVGFs were higher in the CS than in the SS. The ICCs values for repeated measurements of MVGF of the non-affected hand (NAH) and MVGF of the affected hand (AH) of the SS were respectively 0.86, and 0.91. The ICC values for repeated measurements of MVFG of the left hand (LH) and MVGF of the right hand (RH) of the CS were respectively 0.98 and 0.95. The SEM values for the measurement of MVGF on each side of both groups ranged from 15.9N to 33.4N. Results of the SEM values expressed in relation to the mean of a given measure are presented in the right hand portion of Table 2. The SEMs of the MVGF measurements in SS, for one experimental session and one repetition, represent 8.73 % of mean MVGF of the non-affected hand and 19.21 % of the mean MVGF of the affected hand. In comparison, the SEMs of MVGF measurements in CS represent 4.86 % of mean MVGF of the left hand and 23.71 % of the mean MVGF of the right hand. This indicates that in order to assess the efficiency of any therapeutic intervention aimed at decreasing hand grip strength deficit in SS, increases representing more than 19,21 % of the initial MVGF of the AH value recorded are necessary to reflect changes other than the measurement error of MVGF of the AH.

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HR group differences

The distribution of hand ratio [HR] for 15 SS and 10 CS computed from the second measurement session is shown in Figure 3. The HR of the CS ranged from 11 % to 82 % with a mean of 34 % ± 20 % (Std). The hand ratio of SS group ranged from 72 % to 116 % with a mean of 103 %± 13 % (Std). A significant HR difference [mean difference = -70.33, $t(23) = -10.11$ $p< 0.0001$] was found between the two groups. While no significant differences between MVGF recorded on each side of the CS were observed (mean differences 12.42, $t(9)= 0.98$, $p=0.35$), significant differences between MVGF recorded on each side of the SS were found (mean difference=-253.07, $t(14)=-10.59$, $p<0.0001$). Furthermore, no significant differences were observed for MVGF recorded on the non-affected side of SS and the left side of CS (mean difference =58.76, $t(23)=1.57$, $p=0.13$). These results indicate that the hand grip strength deficit observed in SS (i.e. low HR) is attributable to the performance of the affected hand.

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Clinical correlates of HR

Individual HR results of fifteen SS, taken from the second measurement session and their corresponding clinical scores on the Fugl-Meyer, TEMPA, Box and Block and finger to nose tests are illustrated in Figure 4. Low HR scores (i.e. HR<35) were associated with poor performance on the various clinical upper extremity function tests. The highest HR score (83 %) was associated with a near normal or maximal performance on the upper extremity function tests. The results of linear regressions between HR scores of SS and their scores on each upper extremity function test appear in Table 3. Significant correlations ($p<0.01$) were observed between HR scores of SS and their performance on all four of these tests. The percentages of variances on the tests explained by the HR score varied from 62 % to 78 %. The highest percentage of variances explained by the HR score was for the TEMPA upper limb functional score (78%).

DISCUSSION

Assessment of MVGF is one of the most common measure in the quantification of muscle function. A plethora of studies have looked at the effects of numerous measurement parameters of MVGF and large-scale investigations have provided detailed norms for different populations. In acute stroke subjects, recovery of recordable grip strength was found to be one of the most sensitive assessments of initial upper limb recovery [10] and a good prognostic for latter functional recovery [11]. It has also been suggested that upper limb motor impairment in stroke is best assessed using grip strength measurements [35]. The objectives of the present study were to appraise the reliability and sensitivity of this measure and the information it can provide in relation to impairments affecting upper extremity function in chronic SS. MVGF were measured on three separate occasions bilaterally in both SS and CS. MVGF measurements in both groups showed good to excellent reliability (ICC >0.85) and acceptable SEMs (mean SEM=14 % of mean MVGF). MVGF deficits in chronic SS on the paretic side were characterized in relation to MVGF on the non-paretic side.

Controversy exists regarding the use of the motor performance of the non-affected limb as an index of normal function in stroke patients. Arguments against such use are based on the belief that the non-hemiparetic extremities (i.e. limbs ipsilateral to the lesion) may not be functioning at a normal level [36, 37]. While contradicting evidences on ipsilateral grip strength deficits in SS have been presented [36, 38-41], a recent study by Desrosiers et al., (1996) has shown conclusively that ipsilateral grip strength in SS following a stroke is not significantly altered [42]. Our results also show no significant differences for MVGF recorded on the non-affected side of SS and MVGF recorded on the left hand of CS.

Reliability issues pertaining to the measurements of force obtained in the non-hemiparetic extremities in comparison to those on the paretic side have also been raised. Riddle et al., (1989) observed that repeated intersession force measurements on the non-hemiparetic extremities generally have poor to moderate reliability (ICC<.78). They argued that this level of reliability warrants against their use for comparison with the paretic side [43]. While this may hold true for certain force measurements, it appears not to be the case for MVGF measurements. Although there was a slight difference in reliability levels between MVGF measurement in SS on the NAH and the AH (ICC of 0.86 and 0.91 respectively), both measurements demonstrated good reliability and similar SEMs.

MVGF deficits were associated with motor and functional upper limb performance in chronic SS. While the sample size of SS in this study is small (n=15), a large proportion of variance on all four upper extremity tests were explained by MVGF deficits. Chronic SS with strong MVGF deficits tend to demonstrate significant motor and functional upper limb impairments. These results corroborate previous observations on acute stroke subjects [10, 11] and suggest that the prognostic value and the sensitivity of this measure remain after the initial recovery (i.e. first six months). Interestingly, the slopes and intercepts of these relationships indicate that patients with a unitary hand ratio (i.e. 100 % hand ratio), representing no MVGF deficit, would score 76 on the FM, O on the TEMPA, 68 on the Box and Block test and 32 on the finger to nose test. These scores are close to those obtained for subjects without neurological deficits [25, 44, 45]. This suggests that in addition to being closely correlated with performance on upper extremity function tests, MVGF deficits in chronic SS are also scaled to normal / healthy performances. The strength of these relationships was maintained when clinical data for upper extremity function tests of another cohort of 8 chronic SS participating in another study was examined. Their hand ratio scores computed from MVGF using a sphygmomanometer, were added to the regression analysis [16]. The proportion of variance in the clinical test explained by the HR scores with these additional subjects (n total =23) was 76% for the Fugl-Meyer test, 85 % for the TEMPA test, 82 % for the Box and Block test and 74 % for the finger to nose test.

MVGF deficit is by no means the most important contributor to upper extremity dysfunction in SS. However, the magnitude of the relationship observed between MVGF deficit and the performance on selected clinical tests of affected upper extremity function, raise some interesting questions. These include the clinical value of MVGF measures and the relationship with the status of upper extremity function in SS. Kraft et al, (1992) observed significant improvement on Fugl-Myer scores following electrical stimulation (EMG-stim) of paretic wrist extensor muscles in chronic SS [46]. Interestingly, this improvement was also accompanied by a significant increase in paretic grip strength. Both improvements were maintained at three-month and nine-month followups. In contrast, the control group receiving no treatment showed no significant change in either Fugl-Meyer scores or grip strength.

Interpretations of the relationship between MVGF deficits and upper extremity function must be proposed cautiously when considering the design limitations of this study as well as its descriptive nature. In the normal population, MVGF is generally considered to be one of the best indicators of overall upper limb strength [47-49]. Considering that the ability to produce an efficient muscle contraction is the basis for any movement [50], MVGF deficit in SS could reflect force production deficits in the paretic upper extremity.

However, muscle weakness in SS is generally more profound in the distal segments than in the proximal upper limb segments [51]. Therefore, it may be that upper extremity function depends to a large extent on hand function and that this hand function requires a minimum recovery of MVGF. Interesting evidence supporting this hypothesis is the observation that SS with low hand ratios (HR<35) were unable to perform or performed poorly in tests requiring manual manipulation (i.e. TEMPA and Box and Block test). Grip strength deficits on the paretic side appear to be good representation of the potential for paretic upper extremity function. They could be used to guide and evaluate the effectiveness of treatment strategies for upper limb rehabilitation in stroke .

CONCLUSION

Bilateral maximal voluntary grip forces (MVGF) were assessed repeatedly over a three week period in 15 chronic SS and 10 CS. Reliability of MVGF measurements over this period was similar for both groups. Bilateral MVGF measurements in SS were found to be highly reproducible. The grip force of SS on their affected side expressed as a % of the MVGF on the non-affected side (i.e. hand ratio) was found to be greatly impaired in comparison to the CS. This impairment was highly correlated with the performance on upper extremity function tests. These results suggest that maximal grip strength, expressed as a ratio between the affected and non-affected sides, appears to be a valuable marker of hand and arm function in chronic stroke subjects.

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FIGURE CAPTIONS

FIGURE 1. Hand grip dynamometer used to measure maximal voluntary grip force.

FIGURE 2. Box plots illustrating hand ratios [HR] of SS (n=15) and CS (n=10) computed from the second measurement session. HR in CS are expressed in % of the maximal voluntary grip force (MVGF) on the left side. HR in SS are expressed in % of the MVGF of the non-affected side.

FIGURE 3. Stability of hand ratios (HR) and maximal voluntary grip force measurements across three measurement sessions (S1, S2, S3) for 15 SS and 10 CS.

FIGURE 4. Linear regression between hand ratio scores of SS taken from the second measurement session and the performances on the Fugl-Meyer, TEMPA, Box and Block and finger to nose tests.