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Evaluation of Sustained Grip Strength for a Stroke Patient with a Mild Paresis

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ABSTRACT

The purpose of this study was to investigate whether a sustained grip strength test is workable as an accurate assessment of activity limitation related to muscle weakness of the paretic hands of stroke patients with mild pareses. Sixty-one stroke patients with mild pareses participated in this study. The maximal grip strength and an ability to sustain grip strength were examined with the Sustained Grip Strength Test. The latter ability was measured by the sustained period of the maximal grip strength (a period that exhibited more than 80% of the peak force during a six-seconds trial). The activity limitation of squeezing an object was evaluated in four ADL tasks, and the difficulties were rated according to three scores. We found that there was a significant positive relationship between the degree of the task difficulty and the maximal grip strength for paretic hands whose sustained period was over three sec, in all four assessments ($p < 0.05$). However, for paretic hands whose sustained period was under three sec, no such relationship was found. Consequently, measuring both the maximal grip strength and the sustained period was needed to assess accurately an activity limitation related to muscle weakness of the paretic hands of stroke patients with mild pareses.

Key words: *Stroke, Hand, Strength, Activities of daily living*

Stroke accounts for the largest number of patients receiving occupational therapy[39] and physical therapy in Japan[40]. An exercise regime to enhance recovery of the paretic hands is usually prescribed[35–38]. Since therapeutic intervention aims to reduce activity limitation (disability), a hand test that indicates the level of disability is needed to help determine the best exercises to be provided.

There are few evaluations that can accurately assess a disability of the paretic hands of stroke patients with mild pareses. Wade and colleagues[34,41] recommended a timing test to measure manual dexterity (ex. the Nine Hole Peg Test[15]) as one test of specific hand abilities (focal disabilities). However, it is not known whether other hand tests can be utilized for an assessment of slight disabilities.

Muscle weakness is another feature of motor impairment of paretic hands due to stroke[2,4,5,7,41,43]. It is usually measured by a grip strength test. Previous researchers have shown that the maximal grip strength of the paretic hands was inferior to that of the healthy subjects[14,30]. It has also been shown that the grip strength of paretic hands is a useful indicator to assess the recovery of the impairments[3,10,15,33]. There are, however, few studies about a relationship between the grip strength of paretic hands and hand disturbance during activities of daily living (ADL).

It is likely that low maximal grip strength causes a disturbed grip function, which includes squeezing an object during ADL (ex. difficulty in lifting a weighty container, and in fixing a jar firmly). This assumption was supported by previous research, with regard to patients with rheumatoid arthritis[11,26,28,29]. As a result, whether it is appropriate to apply this assumption to stroke patients with mild pareses was investigated here.

At the other hand, it has been suggested that weakness as a symptom of a upper motoneuron syndrome goes beyond the simple loss of maximal force[7,43]. For example, during a short-lasting squeeze, a loss of dynamic peak, slow build-up, and reduction of force can be noted[43]. If these abnormalities exist, they are likely to affect functional hand squeeze. Therefore, the Sustained Grip Strength Test (SGST)[16,17] was administered, to evaluate muscle weakness of paretic hands due to stroke. It is a measurement of isometric grip strength while a subject continuously exhibits maximal effort for six seconds. Both the maximal grip strength and the ability to sustain grip strength were evaluated.

The purpose of this study was to investigate whether the Sustained Grip Strength Test (SGST)

is workable as an accurate assessment of activity limitation related to muscle weakness of the paretic hands of stroke patients with mild pareses. The research question to be answered was whether the SGST could be used as one focal disability measure to evaluate the difficulties in squeezing objects by the paretic hands of stroke patients with mild pareses. Before approaching this question, in order to interpret the results correctly, the maximal grip strength and ability to sustain grip strength of paretic hands were compared with those of the non-dominant hands of healthy control subjects. Also investigated was whether the demographics of stroke patients correlate with the results of the SGST.

MATERIALS AND METHODS

Subjects

Sixty-one stroke patients with mild pareses (36 males and 25 females, 19–81 years) and the same number of healthy control subjects, matched in age and sex, participated in this study (Table 1). Each stroke subject was receiving occupational therapy in one of six rehabilitation hospitals at the time of the experiment. We enrolled stroke patients who met the following criteria: (1) hemiparesis due to stroke which had been sustained at least 2 weeks prior to the experiment; (2) the paretic hand could perform tip pinch, full-range voluntary extension of the digits, and individual finger movements, although less accurately than the opposite side; (3) the paretic arm was at Brunnstrom Recovery Stage (BRS) VI or V[31]; (4) maximal grip strength on the paretic side ranged from 5 to 20 kgf; (5) there was no severe sensory loss; (6) none had severe contractures, pain, nor complications which prevented them from performing the test; (7) maximal grip strength on the non-paretic side was more than 15 kgf and stronger than the paretic side; and (8) no cognitive dysfunction prevented them from following the test instructions. The demographic data for the stroke patients appear in Table 2. The entry criterion for the control subjects was the absence of active neurological and/or orthopedic disease. All subjects were informed of the details of this experiment, and consented to participate in it.

Table 1. Age and sex of the subjects

Age/Sex	Male(n=36)	Female(n=25)
Under 50years	4	3
50–59 years	13	2
60–69 years	4	7
over 69 years	15	13

Table 2. Demographic data for stroke patients

Demographics		(n=61)
Types of stroke		
	Infarction	31
	Hemorrhage	25
	SAH#	2
	AVM## + Hemorrhage	3
Intervals after stroke		
	within 1 month†	10
	over 1 month	51
	(1–3 months 19)	
	(3–6 months 17)	
	(over 6 months 15)	
Paretic side		
	Right	38
	Left	23
Brunnstrom Stage (arm)		
	VI	55
	V	6

subarachnoid hemorrhage
arteriovenous malformation
† None whose intervals after stroke was within 2 weeks

The Sustained Grip Strength Test (SGST)

Previous literature stated that when a healthy subject squeezed a dynamometer with maximal effort for five, six or ten seconds, a typical strength-time curve was gained. This curve is relatively smooth and consists of an initial rapid rise of force and an early peak height[1,9,16,18,23,24,32,42] followed by a gradual decrease in height[1,16,18,23,24,42].

According to our examination of the momentary strength for every second during a sustained grip strength test, the reproducibility of the strength-time curves during the six seconds trial was higher than that of the ten seconds trial[18]. Assuming that a more reliable strength-time curve is necessary for an analysis of the ability to sustain grip strength, the six seconds trial was adopted as the SGST.

Both the maximal grip strength [kgf] and the ability to sustain grip strength were evaluated during the test. The latter ability was assessed with the sustained contraction period (sustained period) ($0 \leqq t \leqq 6$ [sec]), which reflected the period that a subject could exhibit more than 80% of the peak force during a six seconds trial. The criterion of "more than 80% of the peak force" was determined for the following reasons. A typical strength-time curve of the healthy subjects during the six seconds trial consisted of an initial rapid rise of force, followed by a gradual decrease in height[16,18]. Furthermore, the momentary force after five seconds was kept at 82 ± 10% (female's non-dominant hand)–87 ± 7% (male's dominant hand) of the peak force[18].

The isometric grip strength (F_g) of the paretic hands was measured with a Jamar dynamometer, which is a standard mechanical hydraulic device with a pressure sensor. The output signal of the pressure sensor was fed to a conventional personal computer via an A/D converter (12 bits; sampling time 100 times per second). This measuring system is lighter (9 kg) than the Dexter system (115

kg Cedaron Medical Inc.), which was used in our previous studies[16-18]. The load characteristics of the measuring system was calibrated by using five standardized precise weights of 5, 12.5, 20, 30 and 40 kgf at each measurement of F_g. The accuracy of the measurement was less than ± 2 % at 5 and 12.5 kgf, and less than ± 3% at 20, 30 and 40 kgf. Because this dynamometer cannot measure strength above 40 kgf, the maximal grip strength over 40 kgf was measured by the Dexter system including a digital Jamar dynamometer.

The measuring posture and the handle position of the dynamometer, standardized by the American Society of Hand Therapists[12] and Mathiowetz[20,21], was adopted. A subject sat on a chair with the shoulder adducted, the elbow flexed to 90°, the forearm neutralized, and the wrist between 0° and 30° of extension. The Jamar dynamometer was set at the second handle position from the inside. This measuring posture was chosen because keeping this posture while squeezing the dynamometer requires a voluntary stabilization of the wrist. This position is essential for effective hand use in ADL, but it is usually difficult for a stroke patient[8,31]. Whenever a subject inadvertently changed the measuring posture during a measurement, the trial was stopped and tried again.

The examiner instructed each subject as follows, "Squeeze the dynamometer for 6 seconds as hard as you can," and "Go." Six and a half seconds later, the examiner said, "Stop." If a subject moved the dynamometer and/or did not keep the above posture during a measurement, the trial was done once again. The grip strength of both the paretic and non-paretic hands of the stroke patients was alternately measured twice during a test, the non-paretic hands first. A rest of at least one minute was allowed between trials. No feedback regarding the performance was given at the measurement.

Strength data were analyzed for 6 sec from the time the dynamometer detected more than 1 kgf. The set of data representing the highest peak force in the two trials was analyzed, except in the following case: if the sustained period of either one or two trials was under four seconds, the set of data representing the longest sustained period was chosen for analysis.

The reliability of the SGST was examined for the first consecutive 13 stroke patients among all the participants. According to an assessment by criteria described by Meyers[22], the test-retest reliability of the maximal grip strength of the paretic hands of the stroke patients was high (the interclass correlation coefficient = 0.95).

The ability to squeeze an object during ADL

The degree of disability is usually inferred from a patient's perceived difficulty in performing activities and/or a rater's assessment of observed activities[13,27]. Therefore, both methods were used here. The examiner (the first author) asked each subject about his/her hand disturbances. The questions addressed difficulties in carrying out four ADL tasks which demanded forceful grip strength of the paretic hands. These were activities which stroke patients with mild pareses often complain about, with the exception of activities demanding a great deal of complicated and dynamic arm movements and manual dexterity. The tasks comprised two bilateral and two unilateral activities. The former consisted of (1) wringing a wet wash cloth when taking a bath, and (2) opening a jar and a bottle (i.e. the lid of an unsealed jar of boiled seaweed in soy sauce, and the cap of a stainless steel bottle). The latter consisted of (3) lifting and moving a container filled with one liter of liquid (i.e. a carton of milk or juice, and a plastic bottle of soy sauce), and (4) washing the outside of the arm on the non-paretic side with a wash cloth when taking a bath. A subject was asked to choose one of the following three responses for each task: "can do it without difficulty," "can do it with some difficulty," or "cannot do it".

To substantiate the subjective assessment, each occupational therapist providing therapy individually evaluated the above functions according to the same criteria through objective observation. They did not know the results of the subjective assessment before performing their evaluations. The administrator of the subjective assessment did not know the results of the clinical observations of the occupational therapists before the assessments. All the subjective assessments were consistent with the clinical evaluations by the therapists.

Data analysis

The maximal grip strength and the sustained period of the paretic hands of the stroke patients were compared with those of the control healthy hands and those of the non-paretic hands of the stroke patients. The association between the demographics of the stroke patients (the intervals after stroke and BRS (arm)) and the results of the SGST of the paretic hands was investigated. The relationship of these results with the ability to squeeze an object was examined. In comparing three samples, following the Kruskal-Wallis test, multiple comparisons between the conditions was made. Unless otherwise stated, the Mann-Whitney test was used in comparing two samples. P values under 0.05 were considered as statistically significant.

RESULTS

Comparison of the results of the SGST

Both the maximal grip strength (10.9 ± 4.1 kgf) and the sustained period (3.8 ± 1.4 sec) of the paretic hands of the stroke patients were inferior to those of the non-dominant hands of the control

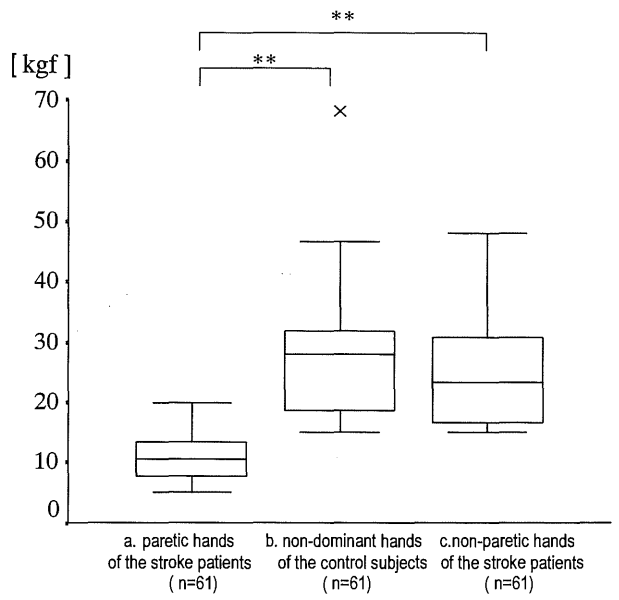

Fig. 1. Maximal grip strength results
The maximal grip strength of the paretic hands (a) was inferior to that of the other hands (b & c) (Mann-Whitney test following the Kruskal Wallis test, $p < 0.01$).
** $p < 0.01$
×: outlier of the value > (75th percentile) + 1.5 × (the interquartile range)

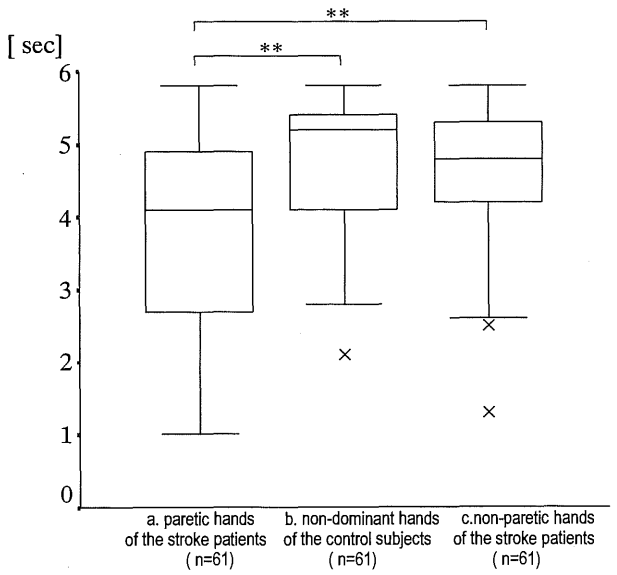

Fig. 2. Sustained period results
The sustained period of the paretic hands (a) was inferior to that of the other hands (b & c) (Mann-Whiteney test following the Kruskal Wallis test, $p < 0.01$).
** $p < 0.01$
×: outlier of the value < (25th percentile) – 1.5 × (the interquartile range)

subjects, and those of the non-paretic hands ($p < 0.01$, see Figures 1 and 2). But there was no significant difference between the control hands and the non-paretic hands.

In the latter analyses, the consequences of the sustained period were divided into two categories: over 3 sec or under 3 sec. Less than 3 sec as the sustained period was adopted as the yardstick to detect the inferior ability of sustained grip strength, because the lower edge of the whisker of the sustained period of the healthy control hand group was 2.8 sec in the box-whisker plot (see Figure 2). The paretic hand group included 19 hands (31.1%) of which the sustained period was under 3 sec. In contrast, there were three control hands (4.9%) and four non-paretic hands (6.6%) of which the sustained period was under 3 sec.

Effects of the demographics on the results of the SGST

There was no significant difference in the maximal grip strength between the paretic hands where the sustained period was over 3 sec (11.4 ± 4.3 kgf, n = 42) and where it was under 3 sec (9.8 ± 3.4 kgf, n = 19) ($p = 0.183$).

The associations between the sustained period of the paretic hands and either the intervals after stroke or the BRS (arm) are shown in Table 3. Fisher's exact probability test of these data revealed significantly that patients who had suffered a stroke within one month had a sustained period of under 3 sec in the paretic hands more often than the other patients ($p = 0.007$). There was no significant effect of the BRS (arm) (VI or V) on whether the sustained period was over 3 sec or not ($p = 0.069$). However, the lack of a significant difference was a marginal one.

In the analysis of the association between the maximal grip strength of the paretic hands and the intervals after stroke, no significant difference in the maximal grip strength was found between patients whose interval after stroke was over one month (11.2 ± 4.0 kgf, n = 51) and that of the other patients (9.5 ± 4.2 kgf, n = 10) ($p = 0.176$). There was also no significant difference in the maximal grip strength between the paretic hands with BRS (arm) VI (11.1 ± 3.9 kgf, n = 55) and those with

Table 3. Association between sustained period and demographics

Sustained period	over 3sec (n=42)	under 3sec (n=19)	p-value
Interval after stroke			
over 1month (n=51)	39	12	0.007**
within 1month (n=10)	3	7	
Brunnstrom Stage			
arm VI (n=55)	40	15	0.069
arm V (n=6)	2	4	

** $p<0.01$
According to Fisher's exact probability test, patients suffering a stroke within one month had a sustained period of under 3 sec more often than other patients.

BRS (arm) V (9.3 ± 5.4 kgf, n = 6) (p = 0.184).

Relationship between the ability to squeeze an object and the results of the SGST

Respective tasks:

The distributions of the results of the assessments of the ability to squeeze an object are shown in Table 4. Chi-square analysis of these data revealed that there is a significant effect of the sustained period (whether over 3 sec or not) on the distribution of the degree of the difficulty in each task.

All 42 patients whose sustained period of the paretic hands was over 3 sec could open a jar and bottle and wash the non-paretic arm. Five patients among them could not wring a wet wash cloth, and the same number could not lift a container with the paretic hands. In spite of the sustained period of the paretic hands being under 3 sec, there were five patients who could open a jar and bottle, seven patients who could wash the non-paretic arms, two patients who could wring a wet wash cloth, and four patients who could lift a container with the paretic hands.

With regard to the paretic hands with a sustained period over 3 sec, there was a significant relationship between the degree of difficulty in doing each task and the maximal grip strength

Table 4. Distribution of the results of the assessments of the ability to squeeze an object (n=61)

Task /Degree of difficulty	cannot do	can do with some difficulty	can do without difficulty
Bilateral tasks			
Wring a wet wash cloth	14 (5)	23 (15)	24 (22)
Open a jar & a bottle	9 (0)	19 (14)	33 (28)
Unilateral tasks			
Lift a container	16 (5)	18 (14)	27 (23)
Wash the non-paretic arm	8 (0)	15 (11)	38 (31)

( ) Number of subjects whose sustained period was over 3 sec.
All patients whose sustained period of the paretic hands was over 3 sec could open a jar & a bottle and wash the non-paretic arms.

Table 5. Association between maximal grip strength of the paretic hands and the degree of difficulty in each task, in the cases of subjects whose sustained period was over 3 sec

Task / Degree of difficulty	cannot do	can do with some difficulty	can do without difficulty
Bilateral tasks			
Wring a wet wash cloth	6.2 ± 1.0 (n=5)	9.3 ± 3.4 (n=15)	14.1 ± 3.3 (n=22)
Open a jar & a bottle	—	9.0 ± 2.9 (n=14)	12.6 ± 4.4 (n=28)
Unilateral tasks			
Lift a container	7.7 ± 3.0 (n=5)	9.0 ± 2.8 (n=14)	13.7 ± 4.0 (n=23)
Wash the non-paretic arm	—	8.7 ± 2.7 (n=11)	12.4 ± 4.3 (n=31)

Aver ± SD [kgf] (n=42)
Mann -Whitney test following Kruskal-Wallis test * $p < 0.05$ ** $p < 0.01$
The maximal grip strength of patients who could do the task without difficulty was significantly greater than that of patients who could do it with some difficulty ($p < 0.05$).

Table 6. Association between maximal grip strength of the paretic hands and ability to squeeze an object

Sustained Period	over 3 sec	under 3 sec
can do 4 tasks without difficulty (n=18)		
Aver ± SD	14.8 ± 3.4 (n=16)	14.3 ± 0.8 (n=2)
Range	8.5–19.8	13.7–14.9
cannot do 2 tasks or more and had difficulty in doing the other tasks (n=12)		
Aver ± SD	5.7† (n=1)	8.8 ± 2.9 (n=11)
Range	—	5.0–14.1

† the value of the maximal grip strength [kgf]

($p < 0.05$). The maximal grip strength of the patients who could do the task without difficulty was significantly higher than that of the patients who could do it with some difficulty, in all four assessments ($p < 0.05$, see Table 5). However, for the paretic hand subgroup with under a 3 sec sustained period, there was no significant relationship between the degree of the difficulty in doing each task and the maximal grip strength.

Overall tasks:

There were 18 patients who could do all four tasks without difficulty. Their intervals after stroke, except in one case, was over one month. And the BRS (arm) was VI in all cases. However, 12 patients could not do two tasks or more and had difficulty in doing the other tasks. They included seven patients who had suffered a stroke within one month, and four patients whose paretic arms were at BRS V. The results of the grip strength test are shown in Table 6. Sixteen patients whose sustained period of the paretic hands was over 3 sec (38.1%) could do all the tasks without difficulty. Their maximal grip strength was 14.8 ± 3.4 kgf (range 8.5–19.8 kgf). Two patients whose sustained period of the paretic hands was under 3 sec also could do them without difficulty. Their maximal grip strength was 13.7 kgf and 14.9 kgf. On the other hand, eleven stroke patients whose sustained period of the paretic hands was under 3 sec (57.9%) could not do two tasks or more and had difficulty in doing the other tasks. One stroke patient whose sustained period of the paretic hands was over 3 sec had the same results.

DISCUSSION

The relationship between the sustained grip strength of paretic hands of stroke patients with mild pareses and the ability to squeeze an object during ADL (wringing a wet wash cloth, opening a jar & a bottle, lifting a container, washing the non-paretic arm) was investigated. Our results showed a significant relationship of the sustained period (whether over 3 sec or not) with these abilities. Only in the cases whose sustained period of the paretic hands was over 3 sec was the maximal grip strength of the patients who could do the task without difficulty significantly higher than that of patients who could do it with some difficulty, in all four assessments ($p < 0.05$). Therefore, when the sustained period was over 3 sec, the larger maximal grip strength (range form 5 kgf to 20 kgf) seems to correlate with less of a difficulty in squeezing an object. Twenty-six patients in this study, who met this condition (over 3 sec sustained period), had some difficulty in squeezing an object. The SGST can be utilized as a quantification of the difficulty in squeezing an object for such stroke patients.

Our results showed that the smallest maximal grip strength of paretic hands of the stroke patients who could do all four squeezing tasks without difficulty was 8.5 kgf. Philips[28] examined the relationship between the maximal grip strength of patients with rheumatoid arthritis and a disturbed functional grip in ADL. She stated that, "A grip strength of at least 20 lbs. (9.1 kgf) is necessary for most ADL. Below this level, patients begin to have difficulty in lifting objects and may be unable to lift a pot or a pan from the stove." Consequently, if each specific property of a disease is taken into account and a standardized method is used, the maximal grip strength range of 8 to 9 kgf may be the critical line between showing a difficulty in squeezing an object during ADL or the lack of it. For mild paretic hands caused by stroke, not only the maximal grip strength but also the ability to sustain grip strength should be taken into account.

Considering the tasks of washing the non-paretic arm and opening a jar and bottle, there were no patients whose sustained period of the paretic hands was over 3 sec, but some of these patients could not wring a wet wash cloth and/or lift a container with the paretic hands. If it can be assumed that the ability to squeeze an object involves grip strength plus being able to sustain the grip strength, then the first two tasks require at least a maximal grip strength of 5 kgf and a sustained period of more than 3 sec. The last two tasks most likely require a higher maximal grip strength, even though the sustained period may remain the same.

There were 19 patients whose sustained period of the paretic hands was under 3 sec, and eleven (57.9%) could not do two tasks or more and had difficulty in doing the other tasks. In contrast, there was one patient whose ability was similar and whose sustained period was over 3 sec. These results suggest that an under 3 sec sustained period of the paretic hands due to stroke is accompanied by an inability to squeeze an object. In other words, the ability to sustain grip strength is essential in squeezing an object. On the contrary, two patients whose sustained period of the paretic hands was under 3 sec could do all the squeezing tasks without difficulty. The maximal grip strength of their paretic hands was 13.7 kgf and 14.9 kgf. Therefore, we must be cautious in simply using an under 3 sec sustained period as the index of an inability to squeeze an object, and take into account other factors, including a low maximal grip strength.

Patients who suffered a stroke within one month more frequently had a significant under 3 sec sustained period in the paretic hands ($p = 0.007$). This was also true for patients whose BRS (arm) was V, but with no significant difference noted ($p = 0.069$). These results suggest that a

convalescent stage of one month or less, and/or poor control of the paretic arm are associated with a short sustained period.

One limitation of this study is that whether an increase in the maximal grip strength and sustained period of a paretic hand would be accompanied by the recovery of the ability to squeeze an object could not be validated. According to previous studies[6,15,19,33,44], it has been suggested that the maximal grip strength of paretic hands provides a link to spontaneous and/or treatment-induced recovery. There are no previous studies on the sustained period, but an improvement may well occur over time. In our study, more than half of the patients who had suffered a stroke within one month had a sustained period of less than 3 sec. It is possible that this result may be an indication of further recovery. As a result, the use of the SGST as a disability evaluation will have to be validated by a longitudinal study which examines the above assumption about stroke patients with mild pareses.

Another limitation is the lack of an adequate explanation of the mechanism of the short sustained period. Because proximal postural stabilization is necessary for a distal focal movement[43], the level of wrist control and hand/arm muscle strength of the paretic side may affect the ability to sustain grip strength. However, these factors were not examined in this study. Thus, to resolve the above problem, further research is needed which will take into account these elements, as well as the intervals after stroke and the ability to control the paretic arm, which may have a relationship to the sustained period.

In this study, the ability to squeeze an object was surveyed by interviewing the patients directly and their occupational therapists. The results from both interviews were consistent, and the reliability of the results was confirmed. However, in future studies, the rater should not only interview but actually test the squeezing abilities of the patients to obtain good reliability.

Bütefisch et al[6] showed that the repeated practice of extension and flexion of the wrists and fingers of paretic hands due to stroke caused an increase in the maximal grip strength, the peak acceleration of isotonic wrist extension, and recovery of hand/arm functional movements. The SGST may be used to evaluate a muscle reeducation program, as recommended by Bütefisch. Therefore, this test may be of benefit in the rehabilitation of stroke patients with mild pareses.

In conclusion, for stroke patients with mild pareses, the maximal grip strength of the paretic hands may be one useful index for determining the difficulty in squeezing an object during ADL, when the range is from 5 kgf to 20 kgf and with an over 3 sec sustained period. The importance of the ability to sustain grip strength has been reported in previous studies[25], but this study is the first to use the quantification of the ability to evaluate disability. Because stroke patients with mild pareses sometimes cannot squeeze an object with the paretic hands due to the reduced ability to sustain a grip strength, the SGST may be helpful as one focal disability evaluation tool.

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