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ORIGINAL REPORT

LIMITED FINE HAND USE AFTER STROKE AND ITS ASSOCIATION WITH OTHER DISABILITIES

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Objective: **To describe the recovery of fine hand use and the associations between fine hand use and, respectively, somatosensory functions, grip strength, upper extremity movements and self-care, in the first week and at 3 and 18 months after stroke, and to describe whether these associations change over time.**

Design: **Prospective observational study.**

Patients: **Sixty-six consecutive patients with stroke.**

Methods: **The following parameters were assessed in the first week, and at 3 and 18 months after stroke: fine hand use, grip strength (not assessed in the first week), touch, proprioceptive and upper extremity movement functions; and self-care.**

Results: **Seventy percent of all patients had limited fine hand use in the first week, 41% at 3 months and 45% at 18 months after stroke. The associations between fine hand use and the other functionings were moderate to high, but decreased over time for fine hand use and, respectively, somatosensory functions, upper extremity movements and self-care.**

Conclusion: **Limited fine hand use is common after acute stroke. Our results suggest that, with time after stroke, upper extremity movements and self-care become less dependent on fine hand use and fine hand use becomes less dependent on touch function, although no ultimate conclusions can be drawn on causality.**

Key words: cerebrovascular accident, hand function, upper extremity, self-care.

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INTRODUCTION

Recovery from upper extremity impairments and activity limitations occurs mainly in the first 2–3 months after stroke (1, 2), although a study in a rehabilitation setting has shown that, in some patients, recovery continues long after the onset of stroke (2). A study of severely disabled patients with stroke shows that 38% had regained some fine hand use and 12% had regained complete fine hand use 6 months after onset (3). Data concerning the percentage of all patients with stroke who recover from limited fine hand use or the degree of recovery that occurs are, however, scarce (4). Furthermore, little is known about the long-term outcome of fine hand use in these patients. The present study describes fine hand use and its associations with other functioning in patients with stroke.

Somatosensory impairments and impaired grip strength have been shown to be related to impaired movements of the upper extremity in patients with stroke (5, 6). It has been suggested that movements of the affected upper extremity in patients with stroke explain up to 40% of the variance in abilities to perform the normal activities of daily living (7). Furthermore, it has been shown that active finger extension is associated with recovery from arm disabilities (8). Fine hand use requires finger extension and good proximal control to place and hold the hand in the correct position. In addition, fine hand use consists of more complex tasks, and might, therefore, be influenced by the patient's cognitive functions, including perception and control of action (9). The associations between fine hand use and, respectively, somatosensory functions, grip strength, upper extremity movements and self-care have, however, not been clearly described. Nor has it been elucidated whether these associations change with time after stroke. Knowledge concerning this might help prioritize rehabilitation methods at different time-points after stroke onset.

It has been suggested that the passing of time accounts for more of the recovery of upper extremity movements and self-care than it does for the recovery of fine hand use (10). In contrast, it has been suggested that the improvements regarding activity limitations, such as limited fine hand use and self-care limitations (11), are greater and occur faster compared with those regarding impairments (11), such as impaired upper extremity movements (12). As a difference in recovery between 2 variables may change their association over time, data describing differences in recovery may add valuable information in explaining changes of associations.

The aim of the present study was to describe and analyse the recovery of fine hand use and the associations between fine hand use and, respectively, somatosensory functions, grip

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strength, upper extremity movements and self-care, in the first week and at 3 and 18 months after stroke, and to describe whether these associations change over time.

METHODS

Patients were recruited consecutively (unless presenting on weekends or public holidays) from the stroke unit of Danderyd Hospital in Stockholm, Sweden, between June 2001 and March 2002. Patients ultimately enrolled in the study were those residing in Stockholm who had an acute, first-ever stroke (unless characterized by subarachnoid haemorrhage or a cerebellar lesion), in the absence of other diagnoses affecting muscle tone, who were conscious and agreed to participate in the study. During the study period, 583 patients with stroke were admitted to the unit; 56 patients were excluded on account of admission and discharge during the same weekend or public holiday, and 418 on account of failing to fulfil the inclusion criteria (20 patients were not residing in Stockholm, 256 patients had earlier strokes, 6 subarachnoid haemorrhages, 32 cerebellar lesions, 64 other diagnoses affecting muscle tone and 40 patients died before inclusion).

Patients were assessed in the acute phase (mean: 4.8 days (standard deviation (SD) 1.8)), 3 months (mean: 98 days (SD 13.3)) and 18 months (mean: 559 days (SD 49)) after acute stroke, with regard to the parameters described below. All assessments were performed either in the hospital or in the patient's residence by 4 specifically-trained physiotherapists.

Fine hand use was assessed by the Nine-Hole Peg Test (NHPT) (13). The task involves putting 9 pegs in holes on a wooden board as quickly as possible and within 60 sec. A patient's fine hand use was considered limited if the time to complete the test exceeded the normal value plus 2 SD, adjusted for age, gender and affected side (14). The cut-off for limited fine hand use was based on the ability to perform the test within normal values because 95% of all healthy individuals perform the test within 2 SD of the mean value (14). Patients who were unable to pick up a peg or unable to participate in the test; or who could place some pegs but were unable to place all the pegs within 60 sec were also considered to have limited fine hand use. The NHPT is considered valid and reliable for evaluating fine hand use (13) and has been suggested to be one of the best clinical measures of fine hand use after stroke (15).

Grip strength was assessed by the Vigorimeter (Martin, Germany), which measures air pressure in a rubber bulb. The pressure in the bulb is registered on a manometer via a rubber junction tube and expressed in kiloPascals (kPa). A medium-sized bulb was used for women and a large bulb for men. Grip strength was only assessed at 3 and 18 month after stroke. The Vigorimeter is considered valid and reliable (16).

Touch function was determined by testing the ability to perceive light touch (cotton wool) on the upper arm, forearm and hand with the patient's eyes closed (possible range: normal/impaired). If the patient was unable to perceive light touch in one or more location on the affected side, the test was defined as indicating impaired touch function. The test is frequently used and is considered to show satisfactory reliability with a rough grading into normal or impaired touch function (17).

Proprioceptive function of the affected upper limb was tested by the Thumb Localising Test (possible range: normal/impaired) (18). The upper limb of the affected side is positioned passively and the patient is asked to pinch the thumb of that limb with the opposite thumb and index finger, repeated 4 times. Proprioceptive function is considered normal if the patient is able to locate the thumb on the affected side in 3 of the 4 tests with his/her eyes closed. The test is considered valid (18) but has not been tested for reliability.

Control of voluntary movement functions was assessed using part 1 of the 7-part Lindmark Motor Assessment Scale (LMAS), which assesses voluntary movements of both the affected and non-affected upper extremity (19). Scores for the affected side were used in the analyses. The total score for each side ranges from 0 to 57 for the upper extremity and from 0 to 36 for the lower extremity. The LMAS assesses active movements of the whole upper extremity, for example, arm flexion; putting the hand to the neck; forearm supination; wrist dorsiflexion; and grasping a glass. The LMAS is considered valid and reliable (19, 20).

Self-care was assessed by the Barthel Index (BI) (possible range: 0–100 points) (21). Although the BI is quite a rough measure of self-care, it was chosen because it is widely used and results can be compared with other studies. Furthermore, the BI was chosen since it is designed to assess improvement, is sensitive to change (22), can be used in all patients and can be used to predict outcome after stroke (23).The BI is considered valid and reliable (24).

The patients' age and gender were also registered. The study was approved by the regional ethics review board in Stockholm. Informed consent was obtained from all participants.

Statistics

Descriptive statistics were used to describe the numbers of patients who recovered from limited fine hand use. The Mann-Whitney *U* test was used to compare movement function and self-care scores for patients who were able to complete the NHPT with those who were not, and to compare NHPT scores of the patients who completed the study with those who did not. Spearman rank-order correlations and 95% confidence intervals (CIs) were used to establish the correlations between fine hand use and somatosensory functions, grip strength, upper extremity movements and self-care, respectively, the first week as well as at 3 and 18 months after stroke. In the correlation analyses, fine hand use was used as continuous data for the patients' who could place all the pegs within 60 sec. Patients who were unable to pick up a peg or unable to participate in the test were given the lowest possible rank in the correlation analyses. Furthermore, patients who could place some pegs but were unable to place all the pegs within 60 sec were given the second lowest rank. Correlation coefficients with absolute values less than 0.5 are referred to as low; between 0.5 and 0.75, as moderate to good; and coefficients with values greater than 0.75, as high (25). The differences in the number of patients who improved from limited fine hand use compared with the number of patients, who improved from somatosensory impairments, impaired grip strength, upper extremity movement impairments and self-care limitations, respectively, were calculated using the χ^2 test and Fisher's exact test. Positive and negative predictive values for improvements in impaired grip strength and somatosensory impairment to parallel improvements of fine hand use as well as 95% CIs were calculated according to Clopper-Pearson. Positive and negative predictive values for improvements in fine hand use to parallel improvements in movement function and self-care scores were also calculated. The significance level was set at $p < 0.05$. Data were analysed using Statistica 7.0 and StatXact 4 for Windows.

RESULTS

Initially, 109 patients were enrolled in the study, although one patient had a second stroke before he was fully assessed in the first week. During the 3-month follow-up, 3 patients suffered a second stroke; 4 died; 5 claimed to be fully recovered and declined further participation and one could no longer be located. At the 18-month follow-up, an additional 29 patients had been excluded: 9 had had a second stroke; 15 had died; 4 declined further participation (including one who claimed to be fully recovered); and one could no longer be located. Thus, 66 patients (44 women and 22 men) with a mean age at recruitment of 76 years (SD 10, range 44–93 years) were still enrolled in the study at the end of the 18-month follow-up period. Hence, 42 of all 108 patients were not followed up at 18 months. There was no statistically significant difference in NHPT scores, for the first week after stroke, between these 42 patients and the 66 patients who completed the study ($p = 0.557$).

Table I shows the numbers of patients who were unable to pick up a peg or unable to participate in the NHPT; who could

Table I. *Investigation of the patients' fine hand use ability by the NHPT*

Time of assessment	Patients unable to pick up a peg or unable to participate (*n*)	Patients unable to place all the pegs within 60 sec (*n*)	Patients able to place all the pegs within 60 sec although the time exceeded 2 SD (*n*)	Patients with normal fine hand use (*n*)
First week	25	15	6	20
3 months	11	6	10	39
18 months	10	8	12	36

SD: standard deviation.

place some pegs but were unable to place all the pegs within 60 sec; who could place all the pegs within 60 sec although the time exceeded the normal value plus 2 SD. In total, 46 (70%) of the 66 patients had limited fine hand use the first week, 27 (41%) at 3 months and 30 (45%) at 18 months after stroke.

Between the first week and 3 months after stroke, 43 of all 66 patients improved their fine hand use and 6 deteriorated. Between 3 and 18 months after stroke, 25 patients improved their fine hand use (median 4 sec improvement, inter quartile range (IQR): 3–6 sec) and 22 deteriorated (median 6 sec deterioration, IQR: 3–16 sec).

The patients who were non-assessable according to the NHPT showed significantly poorer upper extremity movement function and self-care scores than the patients in whom the assessment of fine hand use was possible ($p < 0.001$). This was true for all 3 time points.

Table II shows the number of patients with normal vs impaired somatosensory functions, as well as medians, IQRs and ranges for grip strength, upper extremity movement function and self-care, in the first week and at 3 and 18 months after stroke onset. Significant correlations ($p < 0.05$) and 95% CIs between fine hand use and somatosensory functions, grip strength, upper extremity movements and self-care, in the first week as well as at 3 and 18 months after stroke, for the 66 patients are shown in Table III. Moderate to good correlations were observed between fine hand use and grip strength at 3 and 18 months. Moderate to good correlations were observed between fine hand use and the somatosensory tests in the first week and at 3 months, and low correlations at 18 months after stroke. High correlations were observed between fine hand use and upper extremity movement function in the first week and at 3 months, and moderate to good correlations at 18 months after stroke. Moderate to good correlations were observed at all time points between fine hand use and self-care, although the strength of the correlations decreased from 0.69 to 0.54 from the first week until 18 months after stroke. The strength of the correlations between fine hand use and somatosensory functions, movement function and self-care, respectively, decreased over time.

Significantly fewer ($p < 0.05$) patients improved from limited fine hand use compared with impaired movement function of the upper extremity and self-care limitations between the first week and 3 months. No significant difference in improvement was seen between fine hand use and somatosensory functions or grip strength, respectively; or between fine hand use and movement function or self-care, respectively, between 3 and 18 months after stroke. The difference in improvement between fine hand use and movement function of the upper extremity between 3 and 18 months, however, tended to reach statistical significance ($p = 0.059$).

Table IV shows the positive and negative predictive values and 95% CIs for improvements in impaired grip strength and somatosensory impairment to parallel improvements of fine hand use, as well as for improvements in fine hand use to parallel improvements in movement function and self-care scores, between the first week and 18 months after stroke.

DISCUSSION

The present study describes the recovery of limited fine hand use between the first week and 3 months and between 3 and 18 months after stroke onset. Seventy percent of the 66 patients followed up at 18 months had limited fine hand use in the first week, 41% at 3 months and 45% at 18 months after stroke. An earlier population-based study has shown that 79% of the patients with stroke attain full ability to perform upper extremity self-care activities (1). However, in that study, patients were allowed to compensate with their unaffected extremity

Table II. *Number of patients with normal vs impaired somatosensory functions, as well as medians, interquartile ranges (IQRs)and ranges for grip strength, upper extremity movement function and self-care, in the first week and at 3 and 18 months after stroke onset*

	First week after stroke		3 months after stroke		18 months after stroke	
Functioning	Normal	Impaired	Normal	Impaired	Normal	Impaired
Somatosensory functions, *n*						
Touch function (Light touch)	43	20	53	11	51	12
Proprioceptive function (Thumb Localising test)	35	24	53	10	51	10
Grip strength, movement function and self-care, medians, (range), [OQRs]						
Grip strength (Vigorimeter)	NA		46 (17–60) [0–99]		48 (30–58) [0–105]	
Upper extremity movement function (Lindmark Motor Assessment Scale)	51 (8–57) [0–57]		57 (52–57) [0–57]		57 (51–57) [0–57]	
Self-care (Barthel Index)	65 (15–95) [0–100]		100 (80–100) [0–100]		100 (85–100) [5–100]	

NA: not assessed.

Table III. *Significant ($p < 0.05$) correlations and 95% confidence intervals (CIs) between fine hand use, assessed with the 9-hole peg test (NHPT), and grip strength, touch function, proprioceptive function, upper extremity movement function and self-care, respectively, in the first week as well as at 3 and 18 months after stroke onset*

Body functions/activities (clinical scales) correlated to fine hand use	First week after stroke, *r* (95% CI)	3 months after stroke, *r* (95% CI)	18 months after stroke, *r* (95% CI)
Grip strength (Vigorimeter)	NA	0.60 (0.42–0.74)	0.58 (0.39–0.72)
Touch function (Light touch)	0.59 (0.40–0.73)	0.56 (0.36–0.71)	0.46 (0.24–0.64)
Proprioceptive function (Thumb Localising test)	0.56 (0.36–0.71)	0.50 (0.29–0.67)	0.46 (0.24–0.64)
Upper extremity movement function (Lindmark Motor Assessment Scale)	0.86 (0.78–0.91)	0.76 (0.64–0.85)	0.74 (0.61–0.83)
Self-care (Barthel Index)	0.69 (0.54–0.80)	0.62 (0.44–0.75)	0.54 (0.34–0.69)

NA: not assessed.

when performing the activities. We found that only 59% of the patients attained full fine hand use 3 months after stroke onset. Between 3 and 18 months after stroke, a few more patients improved ($n = 25$) than deteriorated ($n = 22$). However, according to our definition, slightly more patients had limited fine hand use at 18 than at 3 months, which may be explained by the median deterioration score, which was slightly higher than the median improvement score (6 vs 4 sec). Our results indicate that rehabilitation of fine hand use is warranted, especially active training of fine hand use in self-care activities at an early stage after stroke.

We found moderate to good correlations between fine hand use and grip strength and somatosensory functions, respectively, in the first week, but the correlation between fine hand use and somatosensory functions tended to decrease with time after stroke. A plausible explanation for the decreased correlation is that some patients learn to compensate for their impaired somatosensory function, for example by using their vision (26). This hypothesis is further supported by the high positive and low negative predictive values for touch function, in predicting the recovery of fine hand use. This further indicates that most patients who recover from impaired touch function also recover from impaired fine hand use, although many patients recover from limited fine hand use without recovering from impaired touch function. The high negative predictive value for the Thumb Localising Test may reflect that proprioceptive impairment is more difficult to compensate for than impaired touch function when performing hand activities, perhaps because the Thumb Localising Test may give information also about perceptual function (27). The high negative predictive value for the Vigorimeter suggests that grip strength is important for fine hand use, since few patients who did not improve their grip strength improved their fine hand use.

Table IV. *The positive (PPV) and negative (NPV) predictive values and 95% confidence intervals (CIs) for improvements in grip strength and somatosensory function to parallel improvements in fine hand use and for improvements in fine hand use to parallel improvements in upper extremity movement function and self-care, between the first week and 18 months after stroke*

	Fine hand use	
Body functions/activities	PPV, % (95% CI)	NPV, % (95% CI)
Grip strength	53.6 (33.9–72.5)	73.7 (56.9–86.6)
Touch function	70.0 (34.8–93.3)	44.4 (13.7–78.8)
Proprioceptive function	80.0 (51.9–95.7)	75.0 (34.9–96.8)
Upper extremity movement function	100.0 (88.8–100)	50.0 (23.0–77.0)
Self-care	100.0 (90.0–100)	18.8 (4.1–45.7)

We found high correlations between fine hand use and upper extremity movement functions and moderate to good correlations between fine hand use and self-care activities, in the first week after stroke. These correlations all decreased with time after stroke onset; perhaps because patients develop more compensatory strategies for upper extremity movement impairments and self-care limitations, since these tasks consist of more gross motor tasks than fine hand use does, thus requiring less precise movements. Self-care activities can also be performed by involving the non-paretic hand (28). The use of the affected upper extremity may be negatively reinforced by its ineffectiveness in carrying out activities (29). Indeed, we found that more improvements seem to occur in upper extremity movements and self-care activities than in fine hand use with the passage of time after stroke. Furthermore, the predictive values for fine hand use, in predicting the recovery of movement impairments and self-care limitations, indicate that all patients who recover from limited fine hand use also recover from movement impairments and self-care limitations, although many patients recover from movement impairments and self-care activities without recovering from limited fine hand use.

According to the International Classification of Functioning, Disability and Health (ICF), fine hand use is an activity (11). The components described in the ICF, however, work in 2 directions; just as the body function impairments may modify the activities, activity limitations may also modify the body functions (11). Since distal movements of the hand, as required for fine hand use, has been shown to be associated with recovery from arm disabilities after stroke (8), we have assumed that patients with stroke depend on fine hand use when performing upper extremity movements and self-care activities. It is, however, reasonable to assume that the causality may be reversed, so that just as the patients may depend on fine hand use when performing upper extremity movements and self-care activities, the recovery of fine hand use may

also depend on the extent to which the patient perform upper extremity movements and self-care activities requiring fine hand use. Furthermore, it is reasonable to assume that just as the patients may depend on somatosensory function and grip strength when performing activities requiring fine hand use, the recovery of somatosensory function and grip strength may also depend on the extent of fine hand use.

The moderate to good correlation between fine hand use and self-care may suggest that the NHPT partly reflects the general neurological status of the patient, perhaps because the NHPT assesses an activity requiring movements of the whole upper extremity. In addition, the test consists of complex movements, for example fast eye-hand coordination, and might, therefore, be influenced by the patient's cognitive functions (9). Fine hand use may not be the most important contributor to upper extremity functioning in patients with stroke. Our results, however, suggest that the NHPT provides clinically valuable information about fine hand use and upper extremity functioning in patients with stroke.

Although the associations between fine hand use and, respectively, upper extremity movements and self-care decreased, with time after stroke onset, limited fine hand use might still cause great inconvenience to the patients affected and should, therefore, be treated adequately, for example by Constraint Induced Movement Therapy (CIT) (29). CIT includes intensive repetitive training of "real world tasks" with shaping, e.g. constantly increasing the challenge of the task, and a constraint on the non-affected upper extremity. This therapy has been shown to be effective even months and years after stroke onset (29).

Patients, who were non-assessable according to the NHPT, because they were unable to pick up a peg due to some impairment, were all given the lowest NHPT score in the correlation analyses. This is a potential limitation of the study. These patients, however, form a homogenous group, where the inability to be assessed acts as a common indicator of low self-care scores. Another limitation of the study includes the relatively small sample size as well as the decreased sample size at each measurement time, which leads to a less representative sample of the initial population. We chose to exclude the patients who suffered a second stroke from the follow-ups; our results can, therefore, only be generalized to patients with first-ever stroke. All correlations are cross-sectional. Therefore, no ultimate conclusions can be drawn on causality. Also, the 95% CIs were generally wide, thus presenting an element of uncertainty in the estimates. Therefore no ultimate conclusions can be drawn on the extent of change in associations between fine hand use and the other functioning. However, between fine hand use and, respectively, upper extremity movements and self-care, the upper limit of the CIs show with 95% certainty that the associations at 18 months after stroke were lower, respectively equal to the association at the first week after stroke, indicating real decreases in associations. Further limitations of the study include the various sensitivities of the scales as well as ceiling effects, which may have affected the comparisons and the associations between scales. The tests administered are, however, currently used in clinical and research settings as outcome measures for stroke rehabilitation, which makes our results comparable to other study results and also clinically useful.

In conclusion, limited fine hand use is common after acute stroke. Although many patients recover from limited fine hand use, approximately 40% of the patients have remaining limitations in fine hand use at 3 months and slightly more patients at 18 months after stroke. The strength of the associations between fine hand use and touch function, upper extremity movements and self-care tended to decrease over time. Our results suggest that, with time after stroke, upper extremity movements and self-care activities become less dependent on fine hand use and fine hand use becomes less dependent on touch function, although no ultimate conclusions can be drawn on causality.

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REFERENCES

1. Nakayama H, Jørgensen HS, Raaschou HO, Olsen TS. Recovery of upper extremity function in stroke patients: the Copenhagen Stroke Study. Arch Phys Med Rehabil 1994; 75: 394–398.
2. Broeks JG, Lankhorst GJ, Rumping K, Prevo AJ. The long-term outcome of arm function after stroke: results of a follow-up study. Disabil Rehabil 1999; 21: 357–364.
3. Kwakkel G, Kollen BJ, van der Grond J, Prevo AJ. Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. Stroke 2003; 34: 2181–2186.
4. Hendricks HT, van Limbeek J, Geurts AC, Zwarts MJ. Motor recovery after stroke: a systematic review of the literature. Arch Phys Med Rehabil 2002; 83: 1629–1637.
5. Hendricks HT, Hageman G, van Limbeek J. Prediction of recovery from upper extremity paralysis after stroke by measuring evoked potentials. Scand J Rehabil Med 1997; 29: 155–159.
6. Kamper DG, Fischer HC, Cruz EG, Rymer WZ. Weakness is the primary contributor to finger impairment in chronic stroke. Arch Phys Med Rehabil 2006; 87: 1262–1269.
7. Mercier L, Audet T, Hebert R, Rochette A, Dubois MF. Impact of motor, cognitive, and perceptual disorders on ability to perform activities of daily living after stroke. Stroke 2001; 32: 2602–2608.
8. Smania N, Paolucci S, Tinazzi M, Borghero A, Manganotti P, Fiaschi A, et al. Active finger extension: a simple movement predicting recovery of arm function in patients with acute stroke. Stroke 2007; 38: 1088–1090.
9. Sunderland A, Bowers MP, Sluman SM, Wilcock DJ, Ardron ME. Impaired dexterity of the ipsilateral hand after stroke and the relationship to cognitive deficit. Stroke 1999; 30: 949–955.
10. Kwakkel G, Kollen B, Twisk J. Impact of time on improvement of outcome after stroke. Stroke 2006; 37: 2348–2353.
11. WHO. Word Health Organization. International classification of functioning disability and health. Geneva: WHO; 2001. Available from: www.who.int.classification/icf
12. Desrosiers J, Malouin F, Richards C, Bourbonnais D, Rochette A,

Bravo G. Comparison of changes in upper and lower extremity impairments and disabilities after stroke. Int J Rehabil Res 2003; 26: 109–116.
13. Heller A, Wade DT, Wood VA, Sunderland A, Hewer RL, Ward E. Arm function after stroke: measurement and recovery over the first three months. J Neurol Neurosurg Psychiatry 1987; 50: 714–719.
14. Mathiowetz V, Weber K, Kashman N, Volland G. Adult norms for the nine hole peg test of finger dexterity. Occup Ther J Res 1985; 5: 24–37.
15. Wade DT. Measuring arm impairment and disability after stroke. Int Disabil Stud 1989; 11: 89–92.
16. Merkies IS, Schmitz PI, Samijn JP, Meché FG, Toyka KV, van Doorn PA. Assessing grip strength in healthy individuals and patients with immune-mediated polyneuropathies. Muscle Nerve 2000; 23: 1393–1401.
17. Wade DT, editor. Measurement in neurological rehabilitation. Oxford: Oxford Medical Publications; 1992.
18. Hirayama K, Fukutake T, Kawamura M. "Thumb localizing test" for detecting a lesion in the posterior column-medial lemniscal system. J Neurol Sci 1999; 167: 45–49.
19. Lindmark B. Evaluation of functional capacity after stroke with special emphasis on motor function and activities of daily living. Scand J Rehabil Med 1988; 20 Suppl 21: 1–40.
20. Lindmark B, Hamrin E. Evaluation of functional capacity after stroke as basis for active intervention: validation of a modified chart for motor capacity assessment. Scand J Rehabil Med 1988; 20: 111–115.
21. Mahoney FI, Barthel DW. Functional evaluation: Barthel Index. Md State Med J 1965; 14: 61–65.
22. Dromerick AW, Edwards DF, Diringer MN. Sensitivity to changes in disability after stroke: a comparison of four scales useful in clinical trials. J Rehabil Res Dev 2003; 40: 1–8.
23. Kasner SE. Clinical interpretation and use of stroke scales. Lancet Neurol 2006; 5: 603–612.
24. Collin C, Wade DT, Davies S, Horne V. The Barthel ADL index: a reliability study. Int Disabil Stud 1988; 10: 61–63.
25. Colton T, editor. Statistics in medicine. Boston: Little, Brown and Company; 1974.
26. Pause M, Kunesch E, Binkofski F, Freund HJ. Sensorimotor disturbances in patients with lesions of the parietal cortex. Brain 1989; 112: 1599–1625.
27. Welmer AK, von Arbin M, Murray V, Holmqvist LW, Sommerfeld DK. Determinants of mobility and self-care in older people with stroke: importance of somatosensory and perceptual functions. Phys Ther 2007; 87: 1633–1641.
28. Nakayama H, Jorgensen HS, Raaschou HO, Olsen TS. Compensation in recovery of upper extremity function after stroke: the Copenhagen Stroke Study. Arch Phys Med Rehabil 1994; 75: 852–857.
29. Wolf SL, Winstein CJ, Miller JP, Taub E, Uswatte G, Morris D, Giuliani C, Light KE, Nichols-Larsen D, EXCITE Investigators. Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. JAMA 2006; 296: 2095–2104.