Chapter 3

Functional recovery of the paretic upper limb after stroke: Who regains upper limb capacity?

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Accepted for publication in
Arch Phys Med Rehabil

ABSTRACT

Objective: To describe recovery of dexterity after stroke during inpatient rehabilitation based on the Stroke Upper Limb Capacity Scale (SULCS).

Design: Prospective observational study.

Setting: Inpatient department of a rehabilitation center.

Participants: Patients with stroke (N=299) admitted to a specialized stroke rehabilitation center.

Main outcome measure: Upper-limb capacity was assessed at the start and end of the rehabilitation phase with the SULCS (range 0–10). The following demographic and clinical characteristics were registered: age, sex, side of stroke, stroke type, time since stroke, and length of stay in the rehabilitation center.

Results: On admission, 125 patients had no hand capacity (SULCS score 0–3), 58 had basic hand capacity (SULCS score 4–7) and 116 had advanced hand capacity (SULCS score 8–10). Of the patients without initial hand capacity, 41% regained some dexterity (SULCS≥4) at discharge. Of these, patients with SULCS scores 2 and 3 had 29 and 97 times greater odds of regaining some dexterity compared to patients with an initial SULCS score 0, respectively. Of the patients with initial basic hand capacity, 78% regained advanced hand capacity at discharge. The SULCS score on admission explained 51% of the SULCS score variance at discharge, while time since stroke was negatively associated with upper-limb recovery, explaining an additional 7% of the SULCS score variance at discharge.

Conclusion: Even patients with minimal proximal shoulder and elbow control of the upper paretic limb on admission in a rehabilitation center have a fair chance of regaining some dexterity in the long term after stroke, whereas patients without such proximal arm control have a much poorer prognosis for regaining dexterity.

INTRODUCTION

Upper-limb recovery after stroke is crucial for performing activities of daily living (ADL). According to the International Classification of Functioning, Disability and Health (ICF), the domain "activity" is divided in two qualifiers, "capacity" (i.e., the maximal level of execution of an activity in a standardized environment) and "performance" (i.e., the actual performance of an activity in daily life).[1] In rehabilitation medicine, optimizing upper-limb capacity is essential for improving performance. However, in studies on patients with severe to complete upper-limb paresis, it has been shown that about 60% fails to achieve some dexterity at 6 months after stroke, indicating that the prognosis for functional recovery of the paretic upper limb in severely affected patients is poor.[2, 3] In contrast, patients with mild to moderate upper-limb paresis have a much better prognosis for recovery, as 71% of these patients achieve at least some dexterity at 6 months after stroke.[4] Other studies have shown that distal motor function,[5] more specifically the presence of residual active finger extension,[4, 6, 7] is predictive for regaining some dexterity at 6 months post stroke.

Predicting functional recovery after stroke is essential not only to provide patients with an accurate and realistic prognosis, but also for selecting the most appropriate rehabilitation intervention. For example, the ability to stratify patients into groups with a poor vs. more favorable prognosis after stroke[8, 9] allows clinicians to select patients who will benefit most from intensive training interventions and prevent disappointment in others. Ultimately, adequate selection of stroke patients increases the efficiency of applied rehabilitation services for the paretic upper limb. There are, however, only a few prospective cohort studies on upper-limb recovery after stroke.[4, 10-14] Because the main goal of upper-limb rehabilitation is to optimize dexterity to be able to execute meaningful tasks in daily life, it is necessary to predict recovery of upper-limb *capacity*. Yet, several studies merely assessed upper-limb *function* (i.e., neuromusculoskeletal and movement-related functions such as synergism, muscle strength and joint mobility) as an indication of upper-limb recovery.[10-12] Other studies did use *capacity* measures to assess upper-limb recovery, such as the Action Research Arm Test (ARAT)[4, 13] and the Nine Hole Peg Test.[14] These measures are, however, relatively insensitive for restoration of proximal arm capacity in patients without hand capacity.[15] Against this background, a new scale has recently been developed, the Stroke Upper Limb Capacity Scale (SULCS), that is particularly sensitive to (changes in) proximal arm capacity in patients with little or no hand-related capacity.[16] It has been shown that the SULCS is a unidimensional and hierarchical scale with excellent psychometric properties.[15, 16] Because of its sensitivity to differences in both proximal arm and distal hand capacity, the SULCS may be used to discriminate between patients with a good chance to regain some upper limb capacity and those with a poor chance of recovery.

The aim of the present prospective study was therefore to investigate recovery of upper-limb capacity in a large sample of patients admitted to a rehabilitation center after stroke by recording the SULCS on admission and at discharge. The primary goal of this study was to investigate the recovery of (some) hand capacity in patients without any hand capacity at the start of the rehabilitation phase. We therefore categorized patients at admission based on the presence or absence of initial hand capacity. In the subgroup without any hand capacity at admission, we investigated the differences in the initial SULCS score and in demographic and clinical characteristics such as age, sex, type of stroke, time since stroke, and length of stay in the rehabilitation center between patients who showed (some) recovery of hand capacity (i.e., "responders"), and those who did not ("non-responders") at discharge. We then investigated the predictive value of these characteristics for recovery of hand capacity by means of logistic regression analysis.

METHODS

Participants

Patients were eligible when they were admitted to a specialized rehabilitation center in The Netherlands between August 2001 and October 2008, and when they had a definite diagnosis of stroke as determined by an MRI or CT scan. Typically, patients selected for inpatient rehabilitation in The Netherlands have limited disabling co-morbidity (such as other neurological disorders or severe osteoarthritis) and are considered to have a fair chance to fully regain functional independence in basic ADL within 4 months after admission. All patients were admitted to the rehabilitation center directly from a stroke unit or neurological department of a hospital or, in some cases, after a temporary stay in a nursing home. Inclusion criteria were admission within 10 weeks after stroke and a minimum stay in the rehabilitation center of 3 weeks. Patients were excluded when there were: 1) no limitations in upper-limb capacity; or 2) severe cognitive or communicative impairments limiting their understanding of the measurements. All participants were classified into 3 groups based on their admission SULCS score: patients without any hand capacity (SULCS score 0–3), patients with basic hand capacity (SULCS score 4–7), and those with advanced hand capacity (SULCS scores 8–10). Patients in the subgroup without hand capacity were classified as "responders" when they regained some hand capacity at discharge from the rehabilitation center (SULCS score ≥4). Patients who did not regain any hand capacity were classified as "non-responders".

Procedure and measurements

Participants received individual occupational (3 times 30 minutes per week) and physical therapy (5 times 30 minutes per week) and additional daily group therapy sessions (1–2 times 60 minutes) depending on their functional level. The therapy was generally based on the evidence-based guidelines[17] and aimed at improving independent functioning in daily life, guided by individual goal setting. Since the assessments were part of standard care in the rehabilitation center of the Sint Maartenskliniek, they were performed by approximately 15 occupational therapists over the 7-year inclusion period. The inter-rater reliability of the SULCS was excellent (ICC=0.94).[16] For each patient, upper limb capacity was assessed within 1 week after admission and again, by the same occupational therapist, during the week before discharge. Upper-limb capacity was assessed with the SULCS, which consists of 10 items representing meaningful tasks that relate to daily activities in the home environment.[15] The first 3 items assess proximal arm capacity without the need for active wrist or finger movements, items 4 through 7 assess arm capacity combined with basic hand capacity (grasp tasks without manipulation), and items 8 through 10 assess advanced hand capacity (manipulation tasks). This unidimensional and hierarchical scale has been shown to have excellent psychometric properties and to be suitable for application in patients with mild to severe upper-limb paresis.[15, 16] All occupational therapists received instructions and training on how to administer the SULCS, so that the test items were performed and scored uniformly. Clinical characteristics were obtained from the medical records. The study was approved by the local ethics committee and conducted in accordance with the ethical standards laid down in the 1975 Declaration of Helsinki. Since the SULCS assessment was part of the standard medical practice in the rehabilitation center of the Sint Maartenskliniek, according to Dutch legislation, no written informed consent was required from the participants.

Data analysis

After the participants were categorized in the 3 subgroups (i.e. no hand capacity, basic hand capacity and advanced hand capacity), the percentages of the patients who remained in the same subgroup or changed subgroup were calculated. Clinical characteristics of the patients without any hand capacity on admission (SULCS score 0–3) but who had regained some dexterity at discharge (SULCS score ≥4) ("responders") were compared to those who did not regain any dexterity ("non-responders"). Differences between these subgroups were tested using independent samples t-tests (for age, time between stroke and admission, time between admission and discharge) or Mann-Whitney tests (for sex, side of stroke, cause of stroke,

initial SULCS score). To investigate the predictive value of the most important determinants for regaining some dexterity, a multivariate logistic regression analysis (forward stepwise approach) was performed with "dexterity" as dependent variable (discharge SULCS score 0–3 vs. score 4–10) and the characteristics that were significantly different between responders and non-responders as independent variables. Using this multivariate approach, the logistic regression analysis was adjusted for significant covariates. The initial SULCS score was added as a categorical variable, so that the chance of regaining some dexterity was calculated for SULCS scores 1, 2 and 3 relative to SULCS score 0. The characteristics that were found to be predictive for regaining some dexterity were further tested for their individual predictive values. All analyses were conducted two-sided with a level of significance of 0.05.

RESULTS

Table 3.1 shows the demographic and clinical characteristics of the 299 patients that were included. Table 3.2 shows (the changes in) the number of participants in each SULCS subgroup from admission to discharge. Of the patients who had no hand capacity on admission (N=125), 59% remained in this subgroup ("non-responders"), whereas 30% regained basic hand capacity

Table 3.1 Characteristics of all participants at admission in the rehabilitation centre

	Participants (N=299)
Age, mean (SD)	60.0 (11.1)
Time between stroke and admission, days (SD)	32.4 (12.2)
Time between admission and discharge, days (SD)	77.0 (47.9)
Gender, N (%)	
Male	174 (58.2)
Female	125 (41.8)
Side of stroke, N (%)	
Left hemisphere	136 (45.5)
Right hemisphere	132 (44.1)
Other	31 (10.4)
Cause of stroke, N (%)	
Infarct	228 (76.3)
Haemorrhage	71 (23.7)
SULCS score admission, median (IQR)	6.0 (1.0–9.0)
SULCS score discharge, median (IQR)	8.0 (4.0–10.0)

SD, standard deviation; IQR, interquartile range.

and 10% advanced hand capacity ("responders"). The demographic and clinical characteristics of the responders (N=51) and non-responders (N=74) are presented in Table 3.3. Responders had significantly higher initial SULCS scores than non-responders (median SULCS score 2 vs. 0, respectively; P<0.001). Furthermore, they were admitted on average 5.4 days earlier after stroke

Table 3.2 Recovery of hand capacity from admission to discharge

	Discharge N (%)			
Admission	No	Basic	Advanced	Total
No	74 (59.2%)	38 (30.4%)	13 (10.4%)	125 (100%)
Basic	0	13 (22.4%)	45 (77.6%)	58 (100%)
Advanced	0	1 (0.9%)	115 (99.1%)	116 (100%)

Table 3.3 Clinical characteristics of patients without hand capacity at admission (initial SULCS score 0–3). Patients who recovered basic or advanced hand capacity at discharge are presented as 'responders' while patients without any hand recovery are presented as 'non-responders'.

	Responders (N=51)	Non-responders (N=74)	P-value
Age, mean (SD)	58.4 (9.8)	57.8 (9.5)	P=.71
Time between stroke and admission, days (SD)	29.2 (9.9)	34.6 (13.0)	P<.05
Time between admission and discharge, days (SD)	89.4 (43.0)	115.8 (54.6)	P<.01
Gender, N (%)			P=.36
Male	24 (47.1)	41 (55.4)	
Female	27 (52.9)	33 (44.6)	
Side of stroke, N (%)			P=.78
Left hemisphere	22 (43.1)	33 (44.6)	
Right hemisphere	26 (51.0)	36 (48.6)	
Other	3 (5.9)	5 (6.8)	
Cause of stroke, N (%)			P=.99
Infarct	40 (78.4)	58 (78.4)	
Haemorrhage	11 (21.6)	16 (21.6)	
SULCS score admission, median (IQR)	2.0 (2.0–3.0)	0.0 (0.0–1.0)	P<.001
SULCS score admission, N (%)			
0	6 (11.8)	38 (51.4)	
1	6 (11.8)	27 (36.5)	
2	20 (39.2)	7 (9.5)	
3	19 (37.3)	2 (2.7)	

SD, standard deviation; SULCS, Stroke Upper Limb Capacity Scale; IQR, interquartile range.

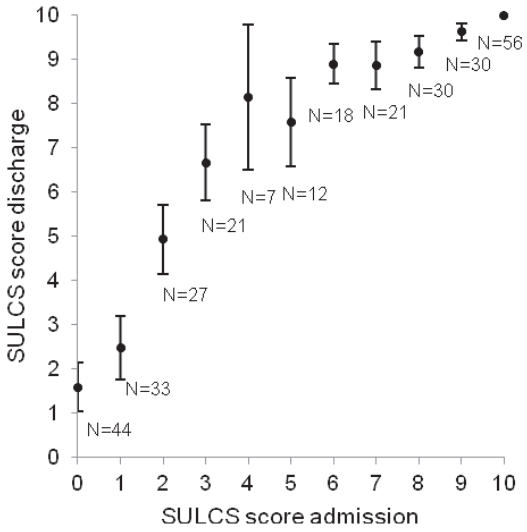

Figure 3.1 Mean discharge SULCS scores with corresponding 95% confidence intervals categorized by SULCS score on admission (N=299).

(P<0.05) and remained in the rehabilitation center on average 26.4 days shorter (P<0.01). No group differences were found for age, sex, stroke location, or cause of stroke. In Figure 3.1, the mean SULCS scores at discharge with their corresponding 95% CIs are categorized according to the initial SULCS score for all patients. It shows that most patients (84%) with the lowest initial SULCS scores (0 or 1) did not regain any hand capacity, whereas those with an initial SULCS score 2 or 3 did develop at least some dexterity at discharge (81%).

The results of the logistic regression analysis are presented in Table 3.4. Only the initial SULCS score and the time between stroke and admission were significantly and independently predictive of regaining hand capacity at discharge. Specifically, of the patients without initial hand capacity, those with SULCS scores 2 and 3 had 29 and 97 times greater chance of recovery than those with a SULCS score 0, respectively. The chances for recovery of patients with an initial SULCS score 1 were not significantly different from those with an initial SULCS score 0 (Table 3.4). This means that patients with a higher SULCS score at the start of the rehabilitation phase had a greater chance of recovering hand capacity than patients with a lower SULCS score. Furthermore, patients who were admitted earlier after stroke had a greater chance of recovery than patients who were admitted later after stroke. However, even in the group with the lowest initial SULCS scores (0 or 1) there were positive exceptions, as 12% regained basic

Table 3.4 Odds ratio of the determinants that predict recovery of hand capacity for patients without hand capacity (subgroup 1: SULCS 0–3) to regain any hand capacity (subgroup 2 or 3: SULCS 4–10)

	N=125	
Determinant	OR (95% CI)	R^2 (Nagelkerke)
SULCS score admission (total)		0.505
SULCS score 1 vs 0	1.82 (0.50–6.72)	
SULCS score 2 vs 0	29.2 (7.30–117)*	
SULCS score 3 vs 0	97.5 (14.6–651)*	
Time between stroke and admission	0.94 (0.90–0.98)**	0.065

Note: model R^2 (Nagelkerke) = 0.566.
OR, odds ratio; CI, confidence interval; SULCS, Stroke Upper Limb Capacity Scale; * P-value <.001; ** P-value <.01.

hand capacity (SULCS 4–7) and 4% even regained advanced hand capacity (SULCS 8–10). The variance in recovery explained by the initial SULCS score and by the time between stroke and admission was 51% and 7%, respectively.

Of the patients with basic hand capacity on admission (N=58), 78% had developed advanced hand capacity at discharge. There were no differences in clinical characteristics between the patients who recovered advanced hand capacity at discharge (N=45) and those who remained in the basic subgroup (N=13), therefore no further analyses were performed in this group.

DISCUSSION

The aim of this prospective study was to investigate recovery of upper-limb capacity in patients admitted to a rehabilitation center after stroke using the Stroke Upper Limb Capacity Scale (SULCS). There are only a few prospective studies on functional recovery of the upper limb after stroke using outcome measures directed at the capacity level of the ICF.[4, 13] None of these studies have used capacity measures that are sensitive for proximal arm capacity, independent of hand capacity. The SULCS has been developed to be able to score (differences in) both proximal arm and distal hand capacity. Better proximal arm capacity in the acute phase of stroke might be related to a greater chance of regaining some degree of dexterity.[4] The results of this study appear to confirm this hypothesis.

Of the 299 patients who participated in this study, 125 (42%) had an initial SULCS score 0–3, indicating that they only had proximal arm capacity on admission in the rehabilitation center. Of these, 74 (59%) had not regained dexterity at discharge. Of the patients who were able to

use their hand in basic activities on admission (SULCS score 4–7), 78% regained advanced hand capacity at discharge (SULCS score 8–10). These results are comparable to findings 6 months after stroke which demonstrated that about 60% of severely affected patients did not regain any dexterity,[2, 3] whereas about 70% of the mildly to moderately affected patients did.[4]

Of the 125 participants without any hand capacity on admission, the 51 patients that regained some degree of dexterity at discharge ("responders") differed from those that did not regain dexterity ("non-responders") by a higher initial SULCS score, a shorter time between stroke and admission, and a shorter length of stay in the rehabilitation center. Logistic regression analysis indicated that only the initial SULCS score and the time between stroke and admission were significantly and independently related to recovery of dexterity. Patients with the same initial level of upper-limb capacity who had had their stroke a shorter time ago had a better chance of regaining dexterity. This finding is in line with the study by Kwakkel et al.[18] who found that time alone accounted for 19% of upper-limb functional recovery (as assessed with the ARAT) during the first 8 weeks after stroke. In the present study, however, time explained only 7% of the SULCS variance at discharge, which is most likely due to the fact that we included patients on average 32 days (range 3–68 days) after stroke. When comparing the impact of time observed in the study by Kwakkel et al.[18] during the same time period (i.e., from 4 weeks post stroke onwards) time alone explained about 9% of the later change in ARAT score, a result comparable to the 7% observed in the present study.

The initial SULCS score explained 51% of the SULCS variance at discharge. Previous studies have emphasized that the presence of residual active extension of the fingers is an important determinant of regaining dexterity.[4, 6, 7] The results of this study indicate that early differences in proximal arm capacity may have an important prognostic value as well. In the present study, patients with a SULCS score 2 or 3 (reflecting the ability to clamp an object between the trunk and upper arm, and the ability to slide an object across a table, respectively) had 29 and 97 times greater chance of regaining some dexterity than patients with a SULCS score 0 (being unable to take support on the forearm on a table). These results appear to be in line with other reports indicating that the early presence of active shoulder abduction is also a determinant of upper-limb functional recovery.[4] These data raise the question how proximal control of the shoulder and elbow is related to the intactness of the crossed corticospinal tracts,[3, 19] which are considered to be the critical neural pathways for controlling the hand.[20] It may be that particularly the selective activity of the extensor muscles relies on intact corticospinal drive, both proximally and distally. Indeed, when the damage to the corticospinal tract is irreversible, there is evidence from a study in macaque monkeys that medial brainstem pathways undergo functional changes that selectively strengthen connections to forearm flexor and intrinsic hand motor neurons, but

not to forearm extensor motor neurons.[21] This would explain the dominant flexion pattern of the upper extremity after stroke, and the difficulty of recovery of the extensor muscles.

The present results can be used to improve rehabilitation services after stroke. Evidence-based medicine includes a cyclical process in which appropriate goal setting is a key aspect of making clinical decisions.[22] This cyclical process involves 1) assessment; 2) goal setting; 3) intervention; and 4) monitoring change in terms of the ICF.[23] For goal setting, knowledge about predictive determinants is highly relevant in order to stratify patients into individuals with potential for upper-limb functional recovery after stroke, and those without such potential.[8, 9] This study showed that the presence (or absence) of proximal arm capacity early in the rehabilitation process may be used to discriminate between these groups. In particular, careful assessment whether patients have active control of both the affected shoulder and elbow, such that patients are able to slide an object with their affected hand across a table, appears to be discriminatory. Patients who are able to perform this task should be offered intensive training to optimize the chance that they will regain at least some degree of dexterity.[24] Interestingly, even some individual patients without any proximal arm capacity on admission still showed substantial functional recovery despite a poor prognosis. In future studies, these patients need to be characterized based on other relevant determinants that may influence upper-limb capacity, such as for instance dyspraxia or neglect.

A strength of this study is that the SULCS is a hierarchical and unidimensional scale with excellent psychometric properties that is sensitive to (changes in) both proximal arm and distal hand capacity and, thus, applicable in patients with mild to severe stroke. In addition, recovery of upper-limb capacity was investigated in a relatively large number of patients, including many individuals with severe upper-limb paresis.

Study limitations

A limitation of this study is that only inpatients of a rehabilitation center were included. As a consequence, not all participants were tested in the first week (but within a range of 3–68 days) after stroke and the follow-up period differed substantially between patients. Therefore, future studies should assess upper-limb capacity within the first week after stroke and use fixed follow-up measurements. Furthermore, we included a limited number of clinical characteristics in the regression model and used only a single outcome measure of upper-limb capacity. Future studies need to interrelate various outcome measures at both the "function" and "capacity" level of the ICF, including neurophysiological, kinematic and kinetic assessments, to obtain more insight in the mechanisms underlying upper-limb functional recovery after stroke.

CONCLUSIONS

In conclusion, the results of this study indicate that the presence of proximal arm capacity early in the rehabilitation process, particularly the capacity to slide an object with the affected hand across a table, is predictive of a fair chance to regain some degree of dexterity at discharge from a rehabilitation center after stroke. These patients should be offered intensive training aimed to optimize functional recovery of the affected upper limb.

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