Short-Term Recovery of Limb Muscle Strength After Acute Stroke

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Objectives: To document, by using norm-referenced strength measures, the recovery of limb muscle strength of patients undergoing stroke rehabilitation and to examine the relation between comorbidities and the recovery of strength after stroke.

Design: Retrospective analysis of data from a consecutive convenience sample of patients examined clinically between 1994 and 1997.

Setting: Acute inpatient rehabilitation unit.

Participants: Fifty patients with stroke who were able to follow commands and were examined during acute rehabilitation by a single examiner (AWA).

Interventions: Stroke rehabilitation emphasizing early movement, exercise with resistance, and daily functional activities.

Main Outcome Measure: The strength at discharge of 7 muscle actions (shoulder abduction, elbow flexion, elbow extension, wrist extension, hip flexion, knee extension, ankle dorsiflexion) measured bilaterally with a hand-held dynamometer and compared with norm-referenced values.

Results: Differences in strength between admission and discharge were significant for all muscle actions on the weaker side and for 4 of the 7 muscle actions on the stronger side. At discharge, the bilateral strength of all muscle actions was weaker than predicted by data from healthy individuals of comparable age, sex, and weight ($F>17.000$, $P<.001$). Strength did not differ between subjects who did and did not have a previous stroke or comorbidities.

Conclusions: Subjects undergoing inpatient rehabilitation soon after stroke experienced an increase in limb muscle strength bilaterally. This increase was not influenced by previous stroke or comorbidities.

Key Words: Compressive strength; Recovery of function; Rehabilitation; Stroke.

IN THE 1970s, CERTAIN AUTHORS[1,2] contended that testing the strength of patients with stroke was unreliable and inappropriate. Since then, researchers have documented the utility of measuring strength in patients with stroke. The reliability of strength measures obtained from this population has been shown between trials with the same tester,[3,4] between different testers,[5] and across days.[6] Several aspects of the validity of strength testing are supported by studies of patients with stroke. Strength after stroke correlates with independence in functional activities such as transfers,[7] gait,[8,9] and stair climbing.[10] Strength measurements taken from patients with stroke also have predictive capabilities. Strength poststroke has been shown to predict the future status of motor function,[11] functional status at discharge from inpatient rehabilitation,[12,13] length of stay in inpatient rehabilitation,[12] discharge destination after inpatient rehabilitation,[14] and mortality.[15,16] Together these findings have contributed to the movement of strength testing from the status of a taboo to that of an important component of the physical examination of patients with stroke.

Investigators have addressed the recovery of strength in patients with acute stroke. Some have used manual muscle testing to document that strength improves in the first few weeks after stroke.[17-19] Jorgensen et al,[19] who used manual muscle testing to measure strength, judged that neurologic recovery reaches its peak for most patients by week 12 or 13 poststroke. Strength scores obtained via manual muscle testing, however, use an ordinal scale that is not norm-referenced. The force transducers used in instrumented methods of strength testing provide force measurements expressed in real numbers. Researchers[20,21] have used instruments to measure the poststroke recovery of muscle strength, but most have limited their instrumented measurements to a single joint or action. Heller et al,[20] for example, tested only grip strength dynamometrically. Zelaschi et al,[21] who used an isokinetic dynamometer to test strength during a 4-week period in patients with acute stroke, tested the strength of knee flexion and extension to the exclusion of other muscle actions. Bohannon and Smith[22-25] measured the short-term recovery of strength after stroke by using a hand-held dynamometer. They noted improvement in limb muscle strength on the side contralateral to the cerebral lesion[22,23]; however, strength changes were noted in relation to the same muscle actions on the other side of the body. Strength changes were not compared with normative reference values for strength. Bohannon has also reported improvements in strength in muscle actions ipsilateral to the cerebral lesion[24] and in the trunk musculature,[25] but these strength measurements were not compared with norm-referenced values either.

Many comorbid diseases occur more frequently among stroke survivors than among matched controls.[26] Researchers have addressed the relation of comorbidities with functional outcomes[27] and mortality.[28] Despite the demonstrated value of strength testing and the prevalence of medical comorbidities after stroke, no studies have been published that address the influence of comorbidities on the recovery of strength in patients with stroke.

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Table 1: Subject Characteristics

Variable	n	Mean ± SD	Range
Gender (men/women)	26/24		
Side of hemiparesis (left/right)	28/22		
Age (y)		61.6±12.7	35–82
Body weight (kg)		77.8±18.6	45.4–117.3
Time from stroke to admission (d)		12.4±11.6	3–60
Time from stroke to discharge (d)		29.4±15.4	11–69
Presence of previous stroke (yes/no)	12/38		
Presence of comorbidities (yes/no)	22/28		

Abbreviation: SD, standard deviation.

Because of the limitations of previous research, we sought to address 2 main issues in the present study. First, we wanted to use norm-referenced, objective measurements[29] to describe the recovery of limb muscle strength early after stroke. These measurements would allow us to look at the degree of strength impairment (relative to reference norms) at admission and discharge and the degree of strength recovery in subjects with and without comorbidities. Second, we wanted to examine the relation between comorbidities and the recovery of strength after stroke.

METHODS

We conducted a retrospective analysis of data obtained from a consecutive convenience sample of patients examined between 1994 and 1997. This study was approved by the Committee on the Protection of the Rights of Human Subjects at the University of North Carolina School of Medicine. Subjects were consecutively admitted to inpatient rehabilitation; met all of the inclusion criteria; and were examined by a single, unblinded examiner (AWA). Subjects were tested on admission and at discharge with the same testing device and protocol by the examiner in accordance with institutional guidelines.

All subjects were inpatients on the 16-bed, interdisciplinary rehabilitation unit at the University of North Carolina Hospitals between 1994 and 1997. The most common diagnosis seen on this rehabilitation unit is stroke; however, this unit serves patients with other neurologic or orthopedic diagnoses. Stroke rehabilitation emphasizing early movement, exercise with resistance, balance retraining in sitting and standing, and daily functional activities was instituted for all subjects. Subjects were engaged in at least 3 hours of physical, occupational, and recreational therapy on each weekday and at least 1 hour of therapy on each weekend day. Speech-language pathology was provided as needed for 1 hour daily.

Fifty patients admitted for inpatient rehabilitation and examined by a single examiner served as subjects. All subjects had a clinical diagnosis of an acute stroke; that is, "a sudden loss of neurological function, caused by vascular injury to the brain."[30] More than 90% of these patients had neuroimaging evidence of acute stroke. Subjects were excluded if they were unable to follow directions (eg, global aphasia) or if strength testing was contraindicated (eg, recent cardiac surgery). Table 1 presents descriptive information about the subjects. Twenty-six men and 24 women participated. The subjects' mean age was 61.6±12.7 years. Twenty-eight were hemiparetic on the left side, and 22 were hemiparetic on the right. Subjects were tested on admission (12.4±11.6d poststroke) and on discharge from rehabilitation (29.4±15.4d poststroke).

Age, sex, dates (stroke onset, admission, discharge), weight, history of previous stroke, and comorbidities were recorded from the subjects' medical records. Only comorbidities known to affect strength or mobility were recorded (ie, arthritis, hip fracture, peripheral arterial disease, traumatic brain injury, chronic obstructive pulmonary disease, alcohol abuse, joint replacement, congestive heart failure, diabetes). The dominant upper and lower extremity were determined by asking the subject his/her preferred limb for throwing and kicking a ball, respectively.

Limb muscle strength was assessed bilaterally with a digital hand-held dynamometer.[a] Static strength was examined on admission to inpatient rehabilitation and again on discharge by an examiner (AWA) whose intrarater reliability with hand-held dynamometry has been established previously.[29] The selection of actions was based on the examiner's ability to hold the dynamometer against patient effort (thus the exclusion of hip extension and ankle plantarflexion) and the availability of reference values for comparison. Shoulder abduction, elbow flexion, elbow extension, and wrist extension were tested in each upper limb. Hip flexion, knee extension, and ankle dorsiflexion were tested in each lower limb. Specific procedures for testing strength are listed elsewhere.[29] Briefly, the limb segment was placed in a gravity-neutral position. The limb segment was moved passively through the desired motion by the examiner. The subject then was asked to perform the desired movement actively until the examiner was confident of the subject's understanding. The examiner then placed the dynamometer perpendicular to the limb segment and as distal as possible without crossing another joint. The subject was asked to build force gradually to a maximum while the examiner held the dynamometer stable. Peak forces obtained during efforts of 3 to 4 seconds were recorded in pounds and converted to Newtons. Strength values obtained at admission and discharge were compared with predicted values based on normative values established in our earlier work.[29] The strength norms published previously were obtained from 156 apparently healthy adults between the ages of 50 and 79 years.[29] We compared the normative values with those from our stroke subjects grouping them by age, gender, and body weight, factors known to influence strength.

Systat, version 10.0,[b] was used for all statistical analysis. After the calculation of conventional descriptive statistics, a mixed model 2 (previous stroke: yes vs no) ×2 (comorbidities: yes vs no) ×7 (muscle action) ×2 (side: stronger vs weaker) ×3 (measurement: admission vs discharge vs predicted) analysis of variance (ANOVA) was performed. When significant interactions were found, follow-up ANOVAs or *t* tests were conducted.

RESULTS

Table 2 reports the muscle strength measurements obtained from the subjects. Table 3 presents the results of the 2×2×7×2×3 ANOVA. The strength of the 7 actions differed significantly ($F=124.632$, $P<.0001$). As expected, the strength of the weaker and stronger sides also differed significantly ($F=38.661$, $P<.0001$). A significant difference between measurements (admission, discharge, predicted) was found ($F=77.219$, $P<.0001$). There was a significant interaction between action and measurement ($F=23.951$, $P<.0001$), meaning that differences between measurements depended on the action. We also found a significant interaction between side and measurement ($F=30.039$, $P<.0001$), which means that differences between measurements were dependent on side. Finally, a significant interaction existed among action, side, and measurement ($F=2.741$, $P=.014$). Consequently, differences between measurements were influenced simultaneously

Table 2: Summary of Muscle Strength Measurements Obtained from Subjects With Stroke

Action	Side	Measurement	Muscle Strength (N) Mean ± SD	CI (95%)
Shoulder abduction	Weaker	Admission	52.3±51.4	37.6–66.7
		Discharge	67.2±54.5	51.7–82.7
		Predicted*	176.7±56.7	160.6–192.8
	Stronger	Admission	119.1±50.8	104.7–133.6
		Discharge	127.1±49.3	113.1–141.1
		Predicted	180.2±57.5	163.8–196.5
Elbow flexion	Weaker	Admission	61.0±60.0	43.9–78.0
		Discharge	85.8±64.6	67.4–104.2
		Predicted	219.6±66.1	200.8–238.4
	Stronger	Admission	154.2±57.0	138.0–170.4
		Discharge	159.9±57.8	143.4–176.3
		Predicted	221.9±67.0	202.8–240.9
Elbow extension	Weaker	Admission	52.7±52.0	37.9–67.5
		Discharge	66.6±51.7	51.9–81.3
		Predicted	146.1±48.3	132.3–159.8
	Stronger	Admission	120.2±43.6	107.9–132.6
		Discharge	123.9±44.8	111.2–136.6
		Predicted	146.7±47.8	133.1–160.3
Wrist extension	Weaker	Admission	26.3±35.7	16.2–36.5
		Discharge	40.2±40.6	28.7–51.8
		Predicted	117.9±39.2	106.7–129.0
	Stronger	Admission	86.5±37.8	75.8–97.2
		Discharge	95.1±37.1	84.5–105.6
		Predicted	119.2±40.0	107.8–130.6
Hip flexion	Weaker	Admission	47.0±44.1	34.5–59.5
		Discharge	65.1±44.1	52.5–77.6
		Predicted	163.6±46.0	150.5–176.6
	Stronger	Admission	94.1±43.3	81.8–106.4
		Discharge	105.4±46.4	92.2–118.6
		Predicted	164.6±47.0	151.2–177.9
Knee extension	Weaker	Admission	129.0±89.9	103.4–154.5
		Discharge	191.5±91.3	139.3–191.5
		Predicted	373.4±126.6	337.4–409.4
	Stronger	Admission	219.8±101.5	190.9–248.6
		Discharge	247.4±93.1	220.9–273.8
		Predicted	374.0±125.7	338.3–409.7
Ankle dorsiflexion	Weaker	Admission	75.6±72.3	55.1–96.2
		Discharge	102.4±86.3	77.9–127.0
		Predicted	249.2±80.3	226.4–272.0
	Stronger	Admission	164.7±68.1	145.3–184.0
		Discharge	185.5±65.6	166.9–204.2
		Predicted	250.6±83.3	226.9–274.3

Abbreviation: CI, confidence interval.
* Predicted on the basis of age, gender, and weight for each muscle action.[29]

by both action and side. Statistical follow-up tests revealed that strength differed between measurements (admission, discharge, predicted) for every individual muscle action on both sides ($F>17.000$, $P<.001$). More specific comparisons showed that increases in strength between admission and discharge were significant for all 7 weaker side actions and for 4 stronger side actions (wrist extension, hip flexion, knee extension, ankle dorsiflexion). Measures of strength on admission were significantly less than predicted (normal)[29] for every muscle action of both the weaker and the stronger sides. Measures of strength on discharge also were significantly less than predicted for every muscle action of both the weaker and stronger sides.[29]

Of the 50 patients who were subjects in this investigation, 12 (24%) had experienced a previous stroke and 22 (44%) had comorbidities of consequence. Strength did not differ significantly between subjects who did and subjects who did not have a history of previous stroke ($F=1.973$ $P=.167$) or notable comorbidities ($F=.292$ $P=.592$).

DISCUSSION

Of the 7 muscle actions on the weaker side, all 7 showed an increase in strength from admission to discharge, whereas only 4 of 7 actions on the stronger side showed an increase during the same time period. Furthermore, the mean percentage increase in strength from admission to discharge was greater for each muscle action on the weaker side. Greater strength recovery on the weaker side than the stronger side is not surprising given the greater potential for progress on the weaker side and

Table 3: Results of Mixed-Model ANOVA

Source	*df*	Mean Square	F	*P*
Previous stroke (PS)	1	152519.821	1.973	.167
Comorbidities (C)	1	22549.240	.292	.592
PS×C	1	73859.451	.955	.333
Error	46	77309.235		
Action (A)	6	468107.942	124.632	.000
A×PS	6	5492.662	1.462	.191
A×C	6	1777.290	.473	.828
A×PS×C	6	2204.524	.587	.741
Error	276	3755.916		
Side (S)	1	517812.676	38.661	.000
S×PS	1	554.177	.041	.840
S×C	1	26272.380	1.962	.168
S×PS×C	1	1492.567	.111	.740
Error	46	13393.515		
Measurement (M)	2	1056413.402	77.219	.000
M×PS	2	5102.892	.373	.690
M×C	2	1780.487	.130	.878
M×PS×C	2	4186.496	.306	.737
Error	92	13680.684		
A×S	6	3623.767	4.533	.000
A×S×PS	6	134.252	.168	.928
A×S×C	6	337.602	.422	.864
A×S×PS×C	6	645.937	.808	.564
Error	276	799.484		
A×M	12	30297.394	23.951	.000
A×M×PS	12	1447.123	1.144	.321
A×M×C	12	843.243	.667	.784
A×M×PS×C	12	1443.315	1.141	.324
Error	552	1264.97		
S×M	2	114274.873	30.039	.000
S×M×PS	2	3017.897	.793	.455
S×M×C	2	5779.853	1.519	.224
S×M×PS×C	2	1529.518	.402	.670
Error	92	3804.258		
A×S×M	12	1082.297	2.741	.001
A×S×M×PS	12	358.050	.907	.540
A×S×M×C	12	189.928	.481	.926
A×S×M×PS×C	12	295.971	.749	.703
Error	552	394.922		

the thrust of rehabilitation intervention. Therapists emphasized strength gains on the weaker side in their interventions. Nevertheless, improvements in strength cannot solely be attributed to rehabilitation. Improvements in strength also may have been influenced by other factors not addressed in the present study (eg, natural neurologic recovery, fatigue, depression, lethargy).

In the stronger upper limb, only 1 of the 4 muscle actions (ie, wrist extension) showed a significant increase in strength ($t=-3.616$, $P=.002$) from admission to discharge. In the stronger lower limb, however, all 3 muscle actions included in the analysis showed a significant increase in strength from admission to discharge. This increase may have occurred because rehabilitation sessions emphasized early standing and gait activities. Because of their hemiparesis, our subjects may have been forced to support most of their weight in standing through the stronger lower limb to enhance stability. Early standing and gait may have forced the stronger lower limb to work more, with a consequent strength increase in both the weaker and the stronger lower limb.

In comparing strength measurements taken at admission to predicted measurements, all muscle actions on both sides were weaker than predicted. Weakness on the side contralateral to the brain lesion would be expected. Although previously published research[8,31,32] would suggest that apraxia or weakness ipsilateral to the lesion also might be present, one would certainly expect it to be less. One or more of the 3 following possibilities may explain weakness on the side ipsilateral to the lesion. First, not all corticospinal axons cross to the contralateral side at the pyramidal decussation. Ten percent or less of the corticospinal axons remain ipsilateral.[33] Second, the subjects were 12.4 ± 11.6 days poststroke by the time their admission measurements were taken. Most subjects were admitted from a tertiary care hospital. Although the subjects were receiving rehabilitation services in the hospital, they were inactive for most of the day. Disuse atrophy may have limited strength on both sides during the first few days poststroke. Harris et al[31] found a decrease in strength on the side ipsilateral to the lesion within the first week poststroke. They found an average 30% decrease in knee extensor strength on the stronger side at the end of the first week poststroke. These researchers attributed this acquired weakness to a lack of exercise and a lack of nutritional support soon after the stroke. Last, subjects in our study may have led a sedentary lifestyle compared with the healthy, elderly subjects used to obtain the predicted strength values. Thus, the subjects with stroke may have been weaker premorbidly in comparison to the control subjects.

When we compared strength measurements taken at discharge to reference measurements obtained from healthy individuals and controlled for age, gender, and weight, we found that all muscle actions on both sides remained weaker than predicted at discharge from the rehabilitation unit. This finding is consistent with previous studies[8,32] that have detected weakness on the side ipsilateral to an acute cerebral lesion.

The presence of comorbidities appears to negatively affect the functional outcomes[27] and mortality[28] of persons who have a stroke. In the present study, however, the presence of comorbidities and previous stroke(s) did not adversely affect our subjects' strength. Evidently, the acute cerebral lesion is the primary factor responsible for determining the degree of strength impairment. The recovery of muscle strength from admission to discharge also was not affected by whether the subject had confounding comorbidities or previous stroke(s). Muscle strength impairments in our 50 subjects with stroke improved in the short term irrespective of comorbidities. An actual difference in strength between patients with and without comorbidities or previous stroke may be found in a larger sample of subjects with stroke.

Another limitation of the present study is that the final strength measurements were taken 29.4 ± 15.4 days poststroke. Because our subjects were followed for a shorter time than subjects in other studies,[19] our findings may not be applicable to subjects who are more than 1 month poststroke. Notably, evidence[34,35] suggests that in subjects with chronic stroke, strength on the side ipsilateral to the lesion is within the range of predicted values. We did not detect such a normality in strength on the stronger side because we did not follow our subjects for a long period of time.

The short time frame between measurements in the present study also may belie the influence of comorbidities and previous stroke on muscle strength. We might have found an influence of comorbidities and previous stroke on the recovery of strength had we followed our subjects throughout the entire course of their recovery. In addition, we could have formatted our data in a more formal comorbidity index, such as that proposed by Liu et al.[27] Use of a comorbidity index might have led to a different conclusion about the influence of comorbidities on muscle strength.

A single, unblinded examiner, who has demonstrated high reliability with hand-held dynamometry,[29] tested all subjects in the present study. However, unconscious biasing of the strength scores was possible because that the examiner also was the individual providing rehabilitation interventions to the subjects.

CONCLUSION

Hand-held dynamometry measurements showed that subjects with acute stroke undergoing inpatient rehabilitation increased their limb muscle strength. Although strength increased more on the weaker side, it also increased for some muscle actions on the stronger side. However, an average of 2 weeks of inpatient rehabilitation emphasizing early movement, exercise with resistance, and function was insufficient to increase strength to levels equal to predicted values. Strength at discharge from inpatient rehabilitation was less than predicted by data from apparently healthy subjects of comparable age, gender, and weight,[29] even on the stronger side. Thus, the need for strengthening activities along with functional retraining, even in the acute setting, is supported.

Although previous stroke(s) or other comorbidities might be expected to affect strength and the short-term recovery of strength after stroke, they did not at this early time poststroke. The extent of the acute cerebral lesion may be a much greater influence on a person's strength after stroke.

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Suppliers

a. Model CSD100; Ametek-Chatillon, 8600 Somerset Dr, Largo, FL 33773.
b. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.