Active Range of Motion Predicts Upper Extremity Function 3 Months After Stroke

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Background and Purpose—After stroke, 80% of patients experience acute paresis of the upper extremity and only approximately one-third achieve full functional recovery. Predicting functional recovery for these patients is highly important to provide focused, cost-effective rehabilitation. Our purpose was to examine if early measures of upper extremity active range of motion (AROM) could predict recovery of upper extremity function, and to describe the trajectory of upper extremity AROM recovery over time.

Methods—Thirty-three subjects were tested at 1 month and then at 3 months after stroke. Upper extremity function was measured with 6 standardized clinical tests that were synthesized into a single, sensitive score for upper extremity function using principal component analysis. The ability to move each segment (AROM) was measured using a 3-dimensional electromagnetic tracking system.

Results—Stepwise multiple regression revealed that AROM of the shoulder and middle finger segments taken at 1 month could predict 71% of the variance in upper extremity function at 3 months. All segments of the upper extremity recover similarly and no evidence of a proximal to distal gradient in motor deficits appeared over time.

Conclusions—Simple AROM measurements of the upper extremity taken within 1 month after stroke can be used to predict upper extremity function at 3 months. This information is important for determining the prognosis of upper extremity functional recovery. (Stroke. 2009;40:1772-1779.)

Key Words: function ■ prediction ■ recovery ■ stroke

Recovery of upper extremity movement and function is a major concern facing individuals who have upper extremity paresis after stroke. Of the 80% of patients experiencing acute paresis of the upper extremity after stroke, only approximately one-third achieve full functional recovery. Predicting functional recovery for these patients is highly important to provide focused, cost-effective rehabilitation. Although there are several good models for predicting mortality, life satisfaction, discharge destination, or likelihood of independent function, only a few models have tried to predict recovery of upper extremity function specifically. Of those, many of the predictors were complicated or time-consuming or they predicted a small portion of the variance. A quick and simple method to predict upper extremity functional recovery would be of high utility to patients and clinicians.

We have recently found that the simple measure of active range of motion (AROM) can account for 82% of the variance in upper extremity function in people with hemiparesis <1 month after stroke. Conceptually, AROM against gravity in people after stroke can be considered a quick measure of the capacity of the spared motor system to activate the spinal motoneuron pools that move a given segment. Our result opens the possibility that AROM values are predictive of later upper extremity function and, if indeed their predictive value is strong enough, these values may be used to estimate arm function prognosis in individual patients. Thus, the purpose of the present study was to examine if early measures of upper extremity AROM could predict recovery of upper extremity function.

Here, we extend our earlier work by following patients to 3 months after stroke. We evaluated AROM and upper extremity function at both time points and hypothesize that AROM measured within 1 month will be predictive of upper extremity function evaluated at 3 months after stroke. A secondary purpose of this study was to examine how AROM at various upper extremity segments recovered over this same time period. This was important to evaluate because relatively greater recovery in one segment vs another could impact the predictive value of the early AROM measurements.

Materials and Methods

We prospectively studied 33 subjects with hemiparesis attributable to stroke between July 2005 and December 2007. This accounted for ~5% of all subjects screened for inclusion into the study. Subjects were recruited from the Cognitive Rehabilitation Research Group Stroke Registry based on the presence of hemiparesis. The Cognitive
Rehabilitation Research Group Stroke Registry is a tertiary program that includes all patients who are admitted to Barnes-Jewish Hospital and who are seen by the Stroke Management and Rehabilitation Team. Subjects were included if they: (1) had a diagnosis of ischemic or hemorrhagic stroke by a stroke neurologist within 1 month of onset; (2) had CT or MRI imaging data consistent with clinical presentation; (3) had persistent hemiparesis with a score of 1 to 4 on the Motor Arm item of the National Institutes of Health Stroke Scale (NIHSS); (4) had evidence of preserved cognition as indicated by a score of 0 or 1 on the Consciousness and Communication item of the NIHSS; and (5) had the ability to follow 2-step commands. Patients were excluded from the study because of the following reasons: (1) orthopaedic or other medical conditions that limited the affected upper extremity before the stroke; (2) history of hemiparesis or stroke; (3) hemispatial neglect as evidenced by a score of 2 on the Extinction and Inattention item of the NIHSS; (4) severe aphasia as evidenced by a score of 2 or 3 on the Language item of the NIHSS; (5) complete hemianopsia as evidenced by a score of 2 or 3 on the Visual item of the NIHSS; (6) the subject was unable to give informed consent; or (7) the subject chose not to participate. Characteristics of the group are provided in Table 1. This study was approved by the Washington University Human Research Protection Office, and all participants provided informed consent before participation.

By the 3-month follow-up visit, 28 subjects remained. Subject attrition by the 3-month time point was attributed to 1 being deceased, 2 with additional medical complications that prohibited them from continuing, and 2 who could not be reached for follow-up. Comparison of baseline values for those subjects lost between time points indicated no significant differences between those who did not finish and those who completed the study.

Testing Paradigm
Subjects were tested for their ability to use the affected upper extremity for functional activities and for their ability to move 9 segments of that upper extremity against gravity (ie, AROM) at 2 time points: within 1 month and 3 months after stroke. Initial testing was completed, in most cases, during a single testing session lasting ~2 hours. In a few cases, during the 1-month time point only, testing was completed in 2 separate 1-hour sessions within a 24-hour period because of rehabilitation schedules or medical testing. All 3-month testing occurred during a single testing session. All kinematic testing occurred in our laboratory.

Measurement of Upper Extremity Function
All subjects underwent a battery of 6 standardized clinical tests of upper extremity function. A battery was used because a single test...
may not suitably capture and quantify upper extremity function across this patient population. The tests were selected based on published data (at the time of study initiation) regarding reliability, validity, normative values, and appropriateness for use with people with stroke. All clinical tests were performed on both sides such that the unaffected upper extremity served as the matched control for the affected side. The following 6 tests were used: Grip Strength, Pinch Strength, Action Research Arm Test, Jebsen Taylor Test of Hand Function, G-Hole Peg Test, and the Stroke Impact Scale Hand.

The first task of the Jebsen, writing a sentence, was not used because it is dependent on hand dominance and education level.

The results of the test battery were synthesized to yield a single measure of upper extremity function for each subject using principal components analysis. For the principal component analysis, the 6 Jebsen subtest scores were entered separately, such that a total of 11 test scores were used for each individual. The first principal component (Eigen value = 9.37) explained 85.2% of the variance in the test scores, and no other components yielded Eigen values >0.53. The weighted linear coefficients of the first principal component were then used to generate a single upper extremity function score for each subject.

Measurement of AROM

The AROM measurements performed in this study were highly instrumented because our overall testing paradigm at study initiation included the calculation of different variables for separate investigations within the same sample. We note that these same AROM measurements could have been obtained bedside or in the clinic with a standard goniometer. Briefly, kinematic techniques were used to quantify AROM of 9 upper extremity segments on the affected side, contralateral to the lesion. Three-dimensional movements of the upper extremity were captured using an electromagnetic tracking system. Nine sensors were attached to the trunk (1), upper arm (1), forearm (1), hand (1), and fingers (5). Subjects were seated in a straight-backed chair and were able to maintain a seated position for the duration of testing. While seated with the upper extremity hanging down by the side, subjects were instructed to make movements of one segment while keeping the other upper extremity segments still. Care was taken to ensure that the tested upper extremity did not contact or otherwise be obstructed by the side edge of the chair. The 9 instructed movements were shoulder flexion, elbow flexion, forearm supination/protonation, wrist flexion/extension, thumb flexion, index finger flexion, middle finger flexion, ring finger flexion, and little finger flexion. Subjects were allowed to move at a self-selected pace and instructed to move the segment as far as they could then return to the starting position. Because the start position was with the upper extremity hanging down by the side, 2 movements, forearm supination/protonation and thumb flexion, were tested in a gravity eliminated position. In these 2 movements, the moment arms were negligible such that gravity was not likely to have a substantial influence in a subject’s ability to perform the movements. Each movement was first demonstrated by the tester and replicated by the subject before each trial. Two trials of each movement were recorded. The instrumentation and software used permitted accurate measurement of AROM irrespective of movement at noninstructed segments, ie, elbow AROM was the range through which the elbow moved regardless of whether the shoulder and the wrist also moved. Because of upgrades in the data collection system during the study, data were collected at either 60 Hz or 100 Hz and stored offline for subsequent analyses. Kinematic data were low-pass filtered at 6 Hz using a second-order Butterworth filter. Motion Monitor software (Innovative Sports Training Inc) and custom-written software in MATLAB (The Mathworks) were used to extract and calculate position and angle data.

For each trial, the main variable extracted was AROM. AROM is a measure of how far a segment can be moved against gravity. For a given segment, AROM was calculated relative to the adjacent proximal segment as the angular excursion through which the segment moved when it was the instructed one. For finger AROM, finger angular excursions were calculated from finger angle data. A Euler angle calculation that represents the rotation at all 3 joints of each finger. The 9 different segments have different anatomic ranges of motion. To examine how one segment may be affected and recover compared to another, raw AROM values were converted from degrees to percent of normal range of the unaffected side of comparable aged individuals with stroke during the same task. Normalizing to this group eased the testing burden on the subjects in the present study.

Additional Descriptive Measures

Additional tests were conducted to provide a more thorough description of the sample (Table 1). To quantify upper extremity strength, maximal voluntary isometric contractions were measured using a hand-held dynamometer. Both flexion and extension of the shoulder, elbow, wrist, and index finger were measured once in standard manual muscle test positions. Both affected and unaffected sides were tested. If the subject was unable to hold the manual muscle testing position, then a score of zero was given for that muscle group. If the subject could maintain the test position, then the subject was instructed, “hold the position, and don’t let me move you.” All testing for each subject was performed by the same tester. Results were averaged across all joints on each side then expressed as a percentage of unaffected side. (Table 1, composite strength).

Affected side shoulder pain was assessed using a standard 11-point pain scale, in which 0 indicated no pain (Table 1, shoulder pain). Joint position sense was evaluated on both sides at the index finger using standard clinical techniques, for which normal was correct on ≥3 of 5 trials (Table 1, index finger joint position sense). Last, spasticity was evaluated on the affected side using the Modified Ashworth Scale at 4 joints: metacarpophalangeal joints of the hand, the wrist, the elbow, and the shoulder (Table 1, modified Ashworth scale).

Data Analysis

SPSS version 13 was used for all statistical analyses and the criterion for statistical significance was set at P < 0.05. Distributions of variables were examined for normality using the Kolmogorov-Smirnov test. The 6 subtest scores from the Jebsen test were not normally distributed and were transformed for further statistical analyses. Each subtest score was transformed using the In function. All subsequent analyses using these 6 variables were performed with the transformed data. Paired *t* tests were used to evaluate differences between time points for the descriptive measures. A repeated measures within subjects ANOVA with 2 factors, time and segment, was used to determine if normalized AROM at the 9 upper extremity segments were similarly or differentially affected within and between time points. When significant effects were found, Bonferroni corrected post hoc *t* tests were used to detect where differences existed.

Pearson product moment correlations were used to evaluate the relationships between AROM at all 9 segments at 1 month and upper extremity function (score from principal components analysis) at 3 months. Based on our sample size, correlation coefficients with an absolute value ≥0.34 were statistically significant. To determine the most parsimonious set of AROM variables that could explain the variance in upper extremity function scores without an a priori theory, we used stepwise multiple regression analysis. The dependent variable was the upper extremity function score obtained from the principal components analysis at 3 months. The independent variables were the 1-month AROM values of the 9 upper extremity segments.

**Results**

Thirty-three subjects (57 ± 10 years; range, 31–77) with hemiparesis were tested within 1 month (18.6 ± 5.6 days; range, 8–30) and at 3 months (98.3 ± 14.9 days; range, 98–138) after stroke. Subject characteristics and lesion information are included in Table 1. Subjects had varying degrees...
of hemiparesis from nearly complete plegia to just barely detectable paresis, as indicated by the range in composite strength (Table 1). Composite strength improved from 1 to 3 months (P<0.01). Subjects had minimal shoulder pain initially, and showed a trend toward increasing pain by 3 months (P=0.067). Only 6 subjects had impaired joint position sense partially, and showed a trend toward increasing pain by 3 months (P=0.01). Subjects had minimal shoulder pain initially.

Group AROM raw values, in degrees, are presented for each segment in the Figure A. Average normalized AROM for each segment of the upper extremity ranged from 44% to 67% at 1 month, and from 72% to 99% at 3 months (Figure, B). Using a repeated measures ANOVA, we found a significant main effect of time (P=0.001), indicating that AROM increased between 1 and 3 months. We also found a significant main effect of segment (P=0.007), indicating that differences existed between segments within each time point. Post hoc comparisons indicated that forearm AROM was greater than the index finger AROM (P=0.004) at 1 month, and forearm AROM was greater than the shoulder (P=0.006), elbow (P=0.005), middle finger (P=0.006), index (P<0.001) finger, and thumb (P=0.033) AROM at 3 months. We did not find a time by segment interaction (P=0.575), indicating that all segments recovered to a similar degree over time.

Table 2 includes group mean scores for each upper extremity function test, individual subject NIHSS motor arm scores, upper extremity function scores for each test, the composite upper extremity function scores, and group mean change scores between 1 and 3 months for each upper extremity function test. Following principal components analysis, upper extremity function scores were normally distributed with a mean of 0 (SD, 1; range, −1.81–1.23), in which higher functioning was indicated by positive numbers and lower functioning was indicated by negative numbers.

One-month AROM values were strongly correlated with upper extremity function at 3 months (Table 3, correlations), indicating that greater movement ability at 1 month was related to greater upper extremity function at 3 months. All correlations were significant at the P<0.01 level. Overall, the correlation between shoulder AROM and upper extremity function was the largest (r=0.81), and the correlation between forearm AROM and upper extremity function was the smallest (r=0.67). Stepwise multiple regression analysis was used to determine if AROM taken within 1 month could predict upper extremity function at 3 months (Table 3, variance explained). Only the 1-month shoulder (R²=0.65) and middle finger (R²=0.66) AROM values entered the model. Thus, measurement of AROM of the shoulder and middle finger within 1 month after stroke predicted 71% of the variance in upper extremity function at 3 months (F²,25=30.38; P<0.001). No other variables we tested entered the prediction model.

Discussion

In our sample, stroke similarly affected the ability to move in all 9 upper extremity segments at 1 month after injury.22 Here, we found that recovery of volitional movement, as measured by AROM, showed a trend toward being similar across segments. AROM measures at 1 month were strongly correlated with upper extremity function at 3 months. The most parsimonious model for using AROM at 1 month to predict upper extremity function at 3 months included only 2 segments: the shoulder and the middle finger. These 2 segments explained the majority (71%) of the variance in upper extremity function.

Our current findings build on existing literature examining the prediction of upper extremity functional recovery after stroke1,17–19,21,46 by examining how AROM can predict upper extremity function at 3 months after stroke. Our finding that this simple measure was able to predict 71% of the variance in upper extremity function is important. The portion of variance in upper extremity function predicted by our model is much higher than that predicted by Katrak et al.,17 in which their models predicted <25% of the variance on a functional test using different independent variables. Our predicted variance in upper extremity function was more similar to that predicted by the models of Smania et al.,1 in which 3 different
models (3 different functional test scores used as dependent variables) were able to predict 42%, 75%, and 70% of the variance in upper extremity function at 90 days. A major strength of our model was that our dependent variable used to measure upper extremity function was a composite score derived from the principal components analysis on a battery of clinical tests. Using this methodology, we were able to sensitively quantify upper extremity function by avoiding ceiling and floor effects for any 1 test and by assessing a range of behaviors/movements across tests (eg, fine dexterity with the 9-Hole Peg Test, functional capacity at home with the Stroke Impact Scale Hand Function subscale). Thus, we were able to avoid generating and interpreting multiple models in which contributions from independent variables may not have been consistent.1 Another methodological difference is we did not make distinctions of what constituted better or worse AROM; rather, we used the measured value of AROM at each of the segments as our independent variables. We also investigated AROM of the entire upper extremity, not just proximally or distally,1,17 allowing for middle segments to contribute to the prediction of upper extremity function. Nonetheless, it is interesting that our results support

Table 2. Individual Subject Scores for NIHSS, 6 Upper Extremity Function Tests, and Composite Upper Extremity Function Score

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<th>Grip, kg</th>
<th>Pinch, kg</th>
<th>ARAT</th>
<th>Jebsen, Sec</th>
<th>9 HPT, Sec</th>
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Mean±SD 2.06±1.14 14.0±10.3 5.3±3.3 39.5±19.7 200±250 67.8±41.7 48.4±32.7 0.00±1.00

Group mean±SD change 3.9±8.3 1.5±1.9 10.3±14.6 −188±239 −18.3±26.1 26.2±25.8

ARAT indicates Action Research Arm Test; HPT, 9-Hole Peg Test; SIS, Stroke Impact Scale.

NIHSS motor arm: scores are from hospital admission; therefore, scores for all 33 subjects are listed.

All other scores reported are from the 3-month follow-up; therefore, scores for the 28 remaining subjects are presented.

Group mean change: mean change for each functional test between the 1- and 3-month time points. Jebsen and 9HPT are both timed tests; therefore, negative numbers equal a decrease in time, reflecting improved performance.

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All other scores reported are from the 3-month follow-up; therefore, scores for the 28 remaining subjects are presented.

Group mean change: mean change for each functional test between the 1- and 3-month time points. Jebsen and 9HPT are both timed tests; therefore, negative numbers equal a decrease in time, reflecting improved performance.

models (3 different functional test scores used as dependent variables) were able to predict 42%, 75%, and 70% of the variance in upper extremity function at 90 days. A major strength of our model was that our dependent variable used to measure upper extremity function was a composite score derived from the principal components analysis on a battery of clinical tests. Using this methodology, we were able to sensitively quantify upper extremity function by avoiding ceiling and floor effects for any 1 test and by assessing a range of behaviors/movements across tests (eg, fine dexterity with the 9-Hole Peg Test, functional capacity at home with the Stroke Impact Scale Hand Function subscale). Thus, we were able to avoid generating and interpreting multiple models in which contributions from independent variables may not have been consistent.1 Another methodological difference is we did not make distinctions of what constituted better or worse AROM; rather, we used the measured value of AROM at each of the segments as our independent variables. We also investigated AROM of the entire upper extremity, not just proximally or distally,1,17 allowing for middle segments to contribute to the prediction of upper extremity function. Nonetheless, it is interesting that our results support
those found by both Katrak et al.⁷ and Smania et al.,¹ and it is remarkable that AROM measurement, a basic clinical skill taught to many health care professionals, can provide such a large amount of information about future upper extremity function.

AROM of the shoulder and the middle finger were the 2 variables that predicted upper extremity function in our model. Along with their strong correlations with upper extremity function, AROM values at all 9 segments were strongly correlated with each other at the 1-month time point.²² The shoulder and middle finger AROM variables that entered the stepwise model can therefore be interpreted as representative of AROM at the other segments as well. Because of the intercorrelations between shoulder AROM and AROM at other segments, the information contributed by shoulder AROM likely reflects the ability of the proximal arm to translate and orient the hand to functionally interact with objects in the environment. Similarly, information contributed by middle finger AROM likely reflects the ability of the distal segments to manipulate objects. These results suggest that measuring AROM at only 2 segments, shoulder flexion and middle finger flexion early after stroke, is useful for determining prognosis of upper extremity function at 3 months after stroke.

Although the present study does not include data >3 months after stroke, the question does arise as to whether the predictive ability of AROM would change at a more chronic phase after stroke. We found only 1 study¹ in the literature that has attempted to investigate this question. Their data showed mixed results (59%, 72%, 64% of the variance) when predicting function to 6 months after stroke, depending on the dependent variable used to measure upper extremity function.¹ These authors did not make conclusions based on how the variance changed over time; however, by interpreting their results, it would appear that AROM continues to be a good predictor beyond 3 months. Also, we recently reported in a cross-sectional study of individuals with chronic stroke (21 months) that AROM explained 73% of the variance in upper extremity function using very similar methodology to the present study.⁴² Because the similar amount of explained variance in the present study and in both of these referenced articles, it would be reasonable to conclude that AROM would be a good predictor of upper extremity function at a more chronic phase after stroke.

A secondary purpose of our study was to examine how AROM at various upper extremity segments recovered in this time period. Our subjects recovered, on average, between 72% and 99% of normal AROM by 3 months. This amount of recovery may be a function of initial NIHSS, with motor arm scores indicating that the subjects were only moderately affected. We recently and unexpectedly found that the 9 segments of the upper extremity were similarly affected at 1 month after stroke.²² This finding is in conflict with common clinical perceptions⁴⁷ but is consistent with earlier, qualitative work.⁴⁻ Here, our results indicate that the ability to move each segment showed a trend toward recovering to a similar degree as demonstrated by a significant main effect of time and no interactions between time and segment (Figure). Our longitudinal data therefore indicate that upper extremity paresis after stroke is not more severe distally than proximally at 1 month and that a proximal to distal gradient in movement deficits does not manifest over time. One explanation for this may be that the lesions disrupt similar proportions of proximal and distal inputs. A similar proportion of inputs could be disrupted after stroke because motor cortical territory for proximal and distal muscles is strongly overlapping,⁴⁹ and as the axons descend through the subcortical structures, they are densely packed together.⁵⁰ In our sample with heterogeneous lesions, damage to many locations within the motor system may result in a similar disruption to proximal and distal inputs.

Four limitations with this study are important to address when interpreting the results. First, the sample size was small and a portion of subjects was lost to attrition. Statistical analyses indicated that those subjects lost to attrition did not differ from the subjects who remained. Further studies are needed to confirm the predictive value of our model in a larger sample. Second, subjects in this sample had primarily motor deficits. Similar to other studies of motor function after stroke, our inclusion/exclusion restricted our sample by eliminating individuals who had severe aphasia, neglect, or who could not give informed consent. Our results may be less applicable to patients with other substantial deficits beyond the motor domain. Third, it was surprising that normalized forearm AROM values at both time points (Figure, B) were significantly greater than normalized AROM values of other segments. This result may be because the start position for forearm AROM was tested in a gravity-eliminated position. We find this possibility unlikely, however, because of the aforementioned negligible moment arm, and the normal group was tested in the same manner. Another reason that this result might have arisen is that our control sample from which the normalizing values were taken⁴² had smaller-than-expected forearm motion. In looking at the raw values (Figure, A), it appears that the average change (recovery) in forearm AROM values is similar to the change in the other segments. Fourth, we did not collect information on factors such as motivation, depression, participation in rehabilitation,
and so on. It is possible that these data could have predicted additional variance in upper extremity function beyond that which AROM predicted.

In conclusion, we found that AROM measurements taken an average of 3 weeks after stroke can be used to predict upper extremity function at 3 months. AROM can be measured quickly at bedside or in the clinic with a goniometer by a variety of health care practitioners. Taking these inexpensive simple measurements at only 2 segments provides a significant amount of information about eventual upper extremity function. More accurate prognosis about upper extremity function is important for determining appropriate rehabilitation strategies and discussing expectations of functional recovery with patients and their families. Future studies are needed to test the predictive value of our model in larger more heterogeneous samples and at earlier time points than those evaluated here.

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