Quantitative Measurement of Physical Activity in Acute Ischemic Stroke and Transient Ischemic Attack

Anna Maria Strømmen, MD; Thomas Christensen, MD, DMSc; Kai Jensen, MD, DMSc

Background and Purpose—The purpose of this study was to quantitatively measure and describe the amount and pattern of physical activity in patients within the first week after acute ischemic stroke and transient ischemic attack using accelerometers.

Methods—A total of 100 patients with acute ischemic stroke or transient ischemic attack admitted to our acute stroke unit wore Actical accelerometers attached to both wrists and ankles and the hip for ≤7 days. Patients were included within 72 hours of symptom onset. Accelerometer output was measured in activity counts (AC). Patients were tested daily with Scandinavian Stroke Scale.

Results—Physical activity peaked in the morning and declined during the rest of the day. In patients with stroke, total AC were 71% lower than in patients with transient ischemic attack. AC were 80% lower in the paretic compared with those in the nonparetic arm in patients with ischemic stroke. For the legs AC were 44% lower on the paretic side and an overall increase in AC with time was found. There was a significant increase in AC with increasing Scandinavian Stroke Scale and a decrease in AC with increasing age.

Conclusions—This study demonstrates the feasibility of using accelerometers to quantitatively and continuously measure physical activity simultaneously from all 4 extremities and the hip in patients with acute ischemic stroke and transient ischemic attack. Our study provides quantitative evidence of physical inactivity in patients with acute ischemic stroke. The method offers a low cost and noninvasive tool for future clinical interventional physiotherapeutic and early mobilization studies.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT01560520. (Stroke. 2014;45:00-00.)

Key Words: accelerometer ■ ischemic attack, transient ■ motor activity
Study Population
Patients with suspected acute ischemic stroke or TIA and aged >18 years were included consecutively in the study at the acute stroke unit at Copenhagen University Hospital–Nordsjællands Hospital, Hillerød, Denmark. Patients with hemorrhagic stroke were excluded to achieve a more homogenous population sample and to get around the problem of a possible detrimental effect of a rise in blood pressure because of physical activity in patients with hemorrhagic stroke. The stroke unit is an acute comprehensive stroke unit with 21 beds in a catchment area of 310,000 inhabitants. The study period was December 2011 to September 2012. Patients were included on days when the investigators were present at the stroke unit. Exclusion criteria were (1) symptoms attributable to other diseases than ischemic stroke or TIA; (2) isolation regime because of infection; (3) onset of symptoms >48 hours before admission; (4) informed consent not given within 24 hours of admission; (5) ulcers or other skin diseases in the area of accelerometer placement; and (6) allergic skin reactions to the accelerometers.

Patients were admitted to the acute stroke unit either directly or via the 2 regional thrombolysis centers. Patients received routine diagnostic investigations and medical treatment including rehabilitation in accordance with Danish National Guidelines. The definitive diagnosis of stroke or TIA was made by an experienced stroke neurologist based on clinical characteristics and neuroimaging. In a few cases, the initial suspicion of TIA or ischemic stroke could not be upheld after a thorough clinical and neuroradiological workup resulting in exclusion of a proportion of the included patients (Figure 1).

Accelerometer
Physical activity was measured with Actical accelerometers (Philips Respironics), which are small (29×37×11 mm and 16 g) omnidirectional, piezoelectric accelerometers. Actical accelerometers register vibrations during acceleration, which produce a proportional variable electric voltage. The output is expressed as activity counts (AC) in epochs of 15 seconds. Details about Actical accelerometers are described elsewhere.

In a previous study, which tested Actical accelerometers under 6 different hydraulic shaker table conditions, intrument reliability was estimated as a mean coefficient of variation of 0.4% to 0.5% with an interinstrument reliability of mean coefficient of variation 5.4% to 15.5%. Because each patient wore 5 accelerometers, data from each patient were collected in 5 files, 1 for each accelerometer. Total AC indicated AC summed for all 5 accelerometers. Simultaneous inactivity was registered as AC=0 in all 5 accelerometers during 5-minute periods.

Procedure
Within 2 hours of inclusion, patients were equipped with 5 Actical accelerometers, which were worn continuously until discharge or a maximum of 7 days. The accelerometers were attached to both wrists and both ankles using Velcro bands or plastic straps. In addition, 1 accelerometer was placed over the right anterior superior iliac spine by means of an elastic belt. Patients were instructed to move about without consideration to the equipment. Accelerometer recording started at the coming first full hour (eg, 10:00 AM) and ended at the end of the last recorded full hour.

Stroke severity was assessed daily with Scandinavian Stroke Scale (SSS) and National Institutes of Health Stroke Scale by 1 of 2 investigators. SSS was the primary stroke scale used to score severity of stroke with National Institutes of Health Stroke Scale used as a secondary scale. Supplementary testing with Glasgow Coma Scale, modified Rankin Scale, Barthels Index and a 10-m walk test at comfortable pace was performed both on the day of inclusion and on the patient's last trial day.

Admission data were retrieved from Danish Stroke Registry (DSR), which is a mandatory national registry with the purpose to document, monitor, and improve the quality of treatment and care for stroke. DSR data were, when possible, also retrieved for eligible patients who were not included in the study. These DSR data were compared with DSR data from the patients with ischemic stroke included in the study. To ensure accuracy, DSR data for included patients were checked for consistency by comparison with the patients’ medical history obtained from both the patients themselves and from their medical records.

Statistical Analysis
A priori calculation of the statistical power of the study was based on the information concerning the variability of accelerometer measurements in patients with stroke given by Rand et al and the assumptions that we wished to be able to detect a 30% increase in AC for 7 days and that 30% of the patients were expected to be discharged before 7 full days of measurement. In addition, it was assumed that AC transformed with natural logarithm (ln) are normally distributed. Based on this, a sample size of 80 patients was calculated using a mixed linear model and a 90% power. A larger sample size comprising 100 patients was chosen, because only scarce previous knowledge existed on the variation of AC.

The level of significance was set at P<0.05 for all analyses. A mixed linear model was used to test the relationship between ln AC and the baseline variables age and SSS, as well as the relationship...
Table 1. Demographic Data for Included (n=100) and Not Included Patients (n=378)

<table>
<thead>
<tr>
<th></th>
<th>Included Patients*</th>
<th>Not Included Patients</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>TIA† n</td>
<td>Ischemic Stroke n</td>
</tr>
<tr>
<td>Age (mean±SD), y</td>
<td>68.9±10.7</td>
<td>67.0±19.9§</td>
</tr>
<tr>
<td>Sex, % male/female</td>
<td>44/56</td>
<td>58/42§</td>
</tr>
<tr>
<td>Body mass index (mean±SD), kg/m²</td>
<td>25.9±4.3</td>
<td>25.6±5.5</td>
</tr>
<tr>
<td>Symptoms to hospitalization</td>
<td>4.8 (3.0–13.7)</td>
<td>16.7 (5.8–33.0)</td>
</tr>
<tr>
<td>Symptoms to inclusion</td>
<td>23.5 (19.3–28.7)</td>
<td>35.5 (25.2–46.8)</td>
</tr>
<tr>
<td>Symptoms to accelerometer wear</td>
<td>23.5 (18.9–29.4)</td>
<td>36.3 (26.0–46.8)</td>
</tr>
</tbody>
</table>

Table 2. Scores at Inclusion and Last Trial Day for Included Patients

<table>
<thead>
<tr>
<th></th>
<th>Median (IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All n TIA n Ischemic Stroke n</td>
</tr>
<tr>
<td>SSS Inclusion</td>
<td>56 (53–58) 99 58 (57–58) 43 54 (44–58) 56</td>
</tr>
<tr>
<td>Last</td>
<td>58 (55–58) 100 58 (57–58) 43 56 (49–58) 57</td>
</tr>
<tr>
<td>NIHSS Inclusion</td>
<td>1 (0–4) 99 0 (0–1) 43 3 (1–7) 56</td>
</tr>
<tr>
<td>Last</td>
<td>1 (0–3) 100 0 (0–1) 43 2 (1–5) 57</td>
</tr>
<tr>
<td>mRS† Prior</td>
<td>0 (0–0) 99 0 (0–0) 43 0 (0–0) 56</td>
</tr>
<tr>
<td>Inclusion</td>
<td>1 (0–2) 98 0 (0–1) 42 2 (1–3) 56</td>
</tr>
<tr>
<td>Last</td>
<td>1 (0–2) 99 0 (0–0) 43 1 (0–3) 56</td>
</tr>
<tr>
<td>BI Inclusion</td>
<td>100 (90–100) 99 100 (100–100) 43 100 (64–100) 56</td>
</tr>
<tr>
<td>Last</td>
<td>100 (99–100) 100 100 (100–100) 43 100 (90–100) 57</td>
</tr>
<tr>
<td>10MWT, s‡</td>
<td>9 (8–13) 79 9 (8–11) 41 10 (8–15) 38</td>
</tr>
<tr>
<td>Last</td>
<td>10 (8–15) 89 9 (8–13) 42 10 (9–16) 47</td>
</tr>
</tbody>
</table>

Results

Study Population

Of 500 patients who were assigned an initial working diagnosis of acute ischemic stroke or TIA, 156 patients were asked to participate in the study during the 10-month enrollment period. A total of 126 patients were eventually included in the study; however, 26 patients subsequently had to be excluded because of one of the reasons shown in Figure 1. Consequently, 100 patients completed the study. Fifty-seven patients had ischemic stroke and 43 had TIA. Demographic data are presented in Table 1 and stroke severity scores are presented in Table 2.

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between hourly ln total AC and time during the first 24 hours of inclusion. The mixed linear model was also used to test the difference in ln total AC between the paretic and nonparetic extremities and variation in ln total AC of the extremities with time. Total AC were transformed using ln because of the assumption of normality of residuals to get the best model fit.

Mixed linear analysis accommodates dependence because of the fact that the same patient was measured repeatedly and the model also accommodates the fact that not all patients stayed in the study for the full 7 days.

The Wilcoxon–Mann–Whitney test was used to test for differences between the total AC as well as AC of arms/legs in patients with TIA and ischemic stroke on day 1 after inclusion. The Wilcoxon–Mann–Whitney test was chosen rather than a t test of ln AC, because ln AC still showed skewness before testing. Two-sample independent t test was used to test for differences between study population and not included patients with TIA and ischemic stroke for age, sex, and body mass index.

No significant difference was found between included patients with TIA and included patients with ischemic stroke for age, sex, and body mass index. No significant difference was found between included patients with TIA in included and not included patients: 43% and 37%, respectively, P>0.05. Only data from patients with acute ischemic stroke are registered in DSR.

Missing data (MD) were defined as (1) clearly erroneous recording or erroneously missing recording, that is, incorrect zero output, on 1 or several accelerometers, (2) nonwear time registered by the investigator, or (3) a recording error for other reasons. Accelerometer outputs with MD were excluded from the analysis only when relevant (eg, only MD from paretic arms was removed in an analysis on AC of paretic arms). Furthermore, in all analyses AC from full 24-hour periods were used, resulting in removal of incomplete 24-hour periods (eg, because of discharge or MRI). The use of only full 24-hour intervals as well as the discard of MD contributed to a different number of patients for the various tests as reported for each analysis.

10MWT indicates 10-m walk test; BI, Barthel Index 100; IQR, interquartile range; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; SSS, Scandinavian Stroke Scale; and TIA, transient ischemic attack.

†Scores before present symptoms are also shown.
‡Scores from patients with only 1 test day because of short duration of hospitalization figure with the same scores under both inclusion and last subheadings.
§At comfortable pace, only a proportion of patients were able to perform a 10MWT because of severity of symptoms.

DSR indicates Danish Stroke Registry; IQR, interquartile range; SSS, Scandinavian Stroke Scale; and TIA, transient ischemic attack.

†Proportion of patients with TIA in included and not included patients: 43% and 37%, respectively, P>0.05.
‡At comfortable pace, only a proportion of patients were able to perform a 10MWT because of severity of symptoms.
Accelerometer Data
Median accelerometer recording time for all patients was 47.0 hours (range, 2.0–167.0 hours). Patients with ischemic stroke had median accelerometer recording time of 71.0 hours (range, 20.0–166.0 hours), whereas patients with TIA had recordings for a median of 27.0 hours (range, 2.0–167.0 hours).

MD constituted 2.85% of the total file time for all patients, for detailed information, see Figure I in the online-only Data Supplement. Total file time refers to the sum of all accelerometers’ recording time (5 files for each patient). Calculation of the total file time is based on the difference between start and end time points registered by the accelerometer.

Hourly and Total AC, First 24 Hours After Inclusion
There was a significant variation of hourly total AC during the first 24 hours after inclusion ($P<0.0001$; n=77 of 100 patients; 15 patients excluded because of incomplete 24-hour period, 8 patients excluded because of MD) for patients with ischemic stroke or TIA. Figure 2 shows the pattern of hourly total AC during the first 24 hours after inclusion. Table 3 shows AC in patients with both TIA and ischemic stroke on day 1 after inclusion. Additional visualization of accelerometer contribution from each accelerometer in patients with hemiparetic stroke and TIA on day 1 after inclusion can be found in Figure II in the online-only Data Supplement.

Figure 2. The distribution of raw hourly total activity counts (AC) during the first 24 hours after inclusion (n=77) shown as a box and whiskers plot. The length of the box represents the interquartile range with the group median shown as an interior horizontal line. The whiskers represent values from the upper or lower boundary of the box plus or minus 1.5x the interquartile range, with outliers outside this range represented by circles. Two far outliers outside the y axis are represented with their respective values in the upper part of the plot.
In patients with ischemic stroke, a significant difference between the paretic and nonparetic arm was found. The median AC of the paretic arm was 80% (95% confidence interval, 67–88%) lower than that of the nonparetic arm (P<0.0001, n=22 patients with ischemic stroke with arm paresis on day 1; 2 patients excluded because of incomplete 24-hour periods, and 1 patient excluded because of MD). No significant time effect in AC of neither the paretic nor the nonparetic arm was found (P=0.3442; Figure 3A).

There was also a significant difference between the paretic and nonparetic leg (P=0.0056, n=17 of 20 patients with ischemic stroke with leg paresis on day 1; 2 patients excluded because of incomplete 24-hour periods, and 1 patient excluded because of MD) with the median AC of the paretic leg being 44% (95% confidence interval, 18%–62%) lower than that of the nonparetic leg. A significant time effect was found for both the paretic and the nonparetic leg (P=0.0415; Figure 3B). No interaction was found between the paretic and nonparetic legs and time (P=0.0715), meaning that the change in AC with time was similar in both legs.

Discussion
This study shows the 24-hour pattern of physical activity in hospitalized patients with acute ischemic stroke or TIA. Physical activity was higher in younger patients with ischemic stroke and in patients with less severe stroke. There was a significant difference between the paretic and nonparetic extremities but a time effect in the course of the first 6 days was demonstrated only for the legs.

Currently, our study is the first to record physical activity objectively and continuously in a largely unselected group of patients during the initial few days after admission for acute ischemic stroke or TIA to an acute comprehensive stroke unit by accelerometry. Investigation of physical activity with accelerometers on all 4 extremities and over the hip simultaneously has, to our knowledge, not been conducted in this patient group previously. Furthermore, a systematic account of MD and the analysis of data with mixed linear model is novel in this type of study in patients with stroke.

Behavioral mapping studies have shown that patients with stroke generally have a low level of physical activity within the first few weeks with 44% to 98% of daytime observations spent inactive in bed. In comprehensive acute stroke units patients are inactive for 30% to 46% of the daytime observations. In contrast to these behavioral mapping studies, we measured physical activity continuously for 24-hour periods. Studies combining accelerometry and tilt switches have shown that patients are sitting for 51% and lying for 36% of the day. Our data do not discriminate between physical activity in different positions. Our patients with ischemic stroke were inactive 16% of the time between 7:00 AM and 11:00 AM during the first 24 hours after inclusion. Inactivity periods based on accelerometer recordings cannot be directly compared with the findings of the behavioral mapping studies or studies using tilt switches because of significant differences in the methodology. We chose to use 5-minute periods of zero AC as a measure of complete physical inactivity assuming a 5-minute period to be more than just a short break in any on-going activity. Others have chosen ways of defining periods of activity or inactivity based on AC from the upper extremities that differ too much to justify comparison with our observations. The pattern of physical activity during a 24-hour period measured in our study follows the general daily routines of most hospital wards. It also illustrates that afternoons and early evenings may offer better possibilities for increasing the physical activity of patients with stroke than the morning peak hours.

AC in patients with TIA were higher than those obtained from the patients with stroke for each of the 5 accelerometers. This is
not surprising because patients with TIA had only negligible neurological deficits on admission. Patients with TIA may hence serve as a clinically relevant control group to the patients with stroke.

Total AC increased significantly with increasing SSS score. In contrast, a decline in physical activity was found with increasing age. Others have found activity recorded over the paretic arm to correlate with National Institutes of Health Stroke Scale scores. Interpretation of studies of physical activity measured with accelerometers must therefore take into account the influence of stroke severity as well as age.

Previous studies have to some extent investigated the difference in activity between paretic and nonparetic arms and the change in activity with time, whereas no previous studies comparing the activity in the legs seem to exist. Our study showed 80% lower AC in the paretic arm compared with that in the nonparetic arm. Others have reported a similar finding in a sample of patients with stroke at a rehabilitation center 1 month after stroke. We found AC from the paretic leg were 44% lower than from the nonparetic side. This difference may be attributed to movements of the nonparetic leg while lying in bed or sitting in a chair, because the difference should be minimal during walking.

One previous study showed an increase in the activity of both the paretic and nonparetic arm in a subgroup of patients with acute stroke during daytime in the course of 4 days. No increase in arm activity with time was found at a later stage in patients with stroke in a rehabilitation center although the study found a significant increase in the number of steps with time, despite low physical activity in the legs. Although our results did show a significant time effect for both the paretic and the nonparetic leg, the relatively few observations calls for caution before concluding that AC from the legs increase with time in the first week after ischemic stroke. One might expect a time effect to be apparent in the acute phase after stroke, where the recovery rate is relatively fast. Neurological recovery is, however, obtained faster than functional recovery and

Figure 3. The distribution of raw activity counts (AC; 24-hour periods) of the paretic and nonparetic extremities during the 6 days of hospitalization for the (A) arms (n=19) and (B) legs (n=17) shown as a box and whiskers plot. Note that patients have different lengths of hospitalization and data from 1 patient was excluded on day 1 because of missing data (therefore n=18 on day 1). The length of the box represents the interquartile range with the group median shown as an interior horizontal line. The whiskers represent values from the upper or lower boundary of the box plus or minus 1.5× the interquartile range, with outliers outside this range represented by circles.
this may in part explain why a time effect on physical activity measured by accelerometers has not been reported consistently in the acute stage after stroke.

No bias in the sampling of our patients was detected, because the demographics between included and not included eligible patients were similar. However, our patient population may well differ from patient populations in stroke units elsewhere. Because conditions and clinical routines including physical and occupational therapy differ between stroke units, the pattern of physical activity during a 24-hour period observed in our study cannot be generalized to all stroke units.

In our study, median total AC from patients with acute ischemic stroke were 71% lower than in the patients with TIA (Table 3). This shows that in the acute phase, patients with stroke are indeed relatively physically inactive, even in a comprehensive stroke unit, and that this inactivity was particularly pronounced for the older patients and for those with the most severe strokes. Mobilization and physical activity may contribute to prevention of complications and deterioration of comorbidities in the acute phase of stroke although there is at present no scientific evidence to support this hypothesis. Our study shows that an objective and simple parameter such as AC per unit of time is easily obtained in the clinical setting during periods lasting several days. Accelerometers may therefore be the low cost and noninvasive tool of choice in future studies aiming to provide such evidence. Thus, accelerometers offer stroke units the opportunity to document changes in physical activity of their inpatients as a result of changes in the mobilization and rehabilitation routines at the unit. Likewise, AC obtained from accelerometers may be valuable parameters in future clinical studies of clinical outcome and the effect of, for example, specific physiotherapeutic interventions.

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Disclosures

None.

References

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Copenhagen University Hospital – Nordsjællands Hospital, Hillerød, Denmark

Online supplement

- **Figure I.** Causes of accelerometer missing data.
- **Figure II.** The distribution of the total AC in TIA and in hemiparetic patients on day 1 after inclusion.
Figure I. Causes of accelerometer missing data (n=500 files) shown as percentages of the total file time (left pie chart). Causes of technical error are specified in the right pie chart. Left pie chart: patient related: accelerometers detached by the patient due to confusion; investigator related: e.g. file overwrite or recording set too late.

Right pie chart: recording error, low: clearly erroneously accelerometer output values of zero despite full recording; recording error, high: clearly erroneously high accelerometer output values; device recording too early: device started recording too early, despite correctly set up recording date and time, with resulting loss of data in the end of a recording; device recording too late: device started recording too late, despite a correctly set up recording date and time, with resulting loss of data in the beginning of a recording. Abbreviations: MRI, magnetic resonance imaging.
**Figure II.** The distribution of the total activity counts in A) TIA (n=21) and in B) hemiparetic patients (n=14) on the first day after inclusion. Only TIA patients with maximal SSS score of 58 on the first day after inclusion were included (n=29 of which 5 patients had incomplete 24 hour periods and 3 had MD and were therefore excluded), and only ischemic stroke patients with a hemiparesis were included (n=18 of which 2 patients had incomplete 24 hour periods and 2 had MD and were therefore excluded).