Background and Purpose Although gait training is prominent in the rehabilitation of hemiparetic stroke patients, little is known about its outcome and prognostic factors in mildly affected patients. We therefore intended to assess gait in ambulatory stroke patients before and after a 4-week inpatient rehabilitation program based on the neurodevelopmental technique.

Methods We measured vertical ground reaction forces by force plates in 148 stroke patients. Variables were stance durations, peak vertical ground reaction forces at heel strike (Fz1) and toe-off (Fz2), loading and deloading rates, time to Fz1, and time to Fz2. The absolute changes for both legs and symmetry outcome were calculated. In addition, we assessed maximal walking speed, walking endurance, stair climbing ability, and the Motricity Index.

Results Stance duration, weight acceptance, push-off of both legs, and the stance duration symmetry improved independently of changes of gait velocity. The symmetry of the ground reaction forces did not improve. Results were even worse for Fz1 and the loading rate at the end of treatment. Sex, age, side of hemiparesis, motor strength, stroke interval, and sensory impairment had no influence on the outcome of symmetry. Functional performance did not improve considerably.

Conclusions The absolute changes of the ground reaction forces indicated better weight acceptance and push-off of both legs and thus confirmed the efficacy of the neurodevelopmental technique. The symmetry outcome and the functional performance at the end of treatment, however, challenge the efficacy of intensive rehabilitation therapy for 4 weeks in its attempts to restore physiological gait in these mildly affected patients. (Stroke. 1994;25:1999-2004.)

Key Words • gait • prognosis • rehabilitation

Cerebral vascular disease is a leading cause of gait impairment resulting in long-term disability and handicap. In a study of 60 patients admitted to a general hospital, the authors reported that 25% of all stroke survivors would never be able to ambulate independently, and in 50%, walking speed was still more or less reduced after 3 months.1

To rehabilitate stroke patients and to improve their gait, physiotherapists apply different treatment techniques, including a functionally oriented traditional approach and other techniques based on neurophysiological models, such as the Bobath neurodevelopmental technique (NDT) and the Brunnstrom, Rood, and proprioceptive neuromuscular facilitation (PNF) concepts.2 The superiority of a particular treatment approach has not yet been proven in terms of activities of daily living, including general mobility.3,4,5

Gait outcome studies thus far have focused on the walking ability of acute stroke patients admitted to a general hospital and its predictors.1,6,7 Little has been done to evaluate the gait outcome and prognostic factors of a comprehensive stroke rehabilitation of ambulatory patients in a later stage of recovery.

The purpose of this investigation was to study gait outcome in a large group of mildly affected stroke patients, defined as those who were ambulatory and competent for the most part in the basic activities of daily living. These patients are frequently admitted for a 4-week comprehensive stroke rehabilitation program based on NDT. In a preliminary investigation we studied gait symmetry and functional walking performance, showing no relevant improvement of either variable at the end of treatment for this group of patients.10

In continuation of this report we decided to investigate a larger number of patients to further elucidate gait outcome after a 4-week rehabilitation program. In addition to assessing gait symmetry, we assessed absolute changes of vertical ground reaction forces, another process-oriented variable of the Bobath technique in which physiotherapists who are trained in NDT strictly control weight acceptance and push-off of both lower limbs.11 Predicting factors were analyzed to assess which patients were more likely to benefit from the NDT program. We further assessed functional walking abilities relevant to daily living (eg, endurance, stair climbing).

Subjects and Methods

Subjects

The study, which was approved by the local ethical committee, included all hemiparetic patients treated in our department in 1992. A total of 156 patients entered the study; 8 patients dropped out, and 148 completed the study. Only the latter were considered for statistical analysis (91 men and 57 women; mean age, 57.1 years [range, 15 to 84 years]). Seventy-
Assessment of Functional Status

The following tasks were performed by the subjects: (1) 10-m walk on level ground at maximum gait velocity; (2) walking endurance (self-adopted speed; limit, 600 m); and (3) stair climbing (self-adopted speed with or without handrail; limit, 90 stairs of 16 cm each).

Patients wore their preferred shoes and used no aids or orthoses. They were instructed to walk or climb at their preferred speed (except in the 10-m walking test) until they felt unable to continue. Required time, uninterrupted walking distance, and number of steps were recorded. In addition, scores of the Motricity Index of the paretic lower and upper extremities (0 to 100 points) were documented.

Statistical Analysis

Confidence intervals were calculated for the mean change in each individual functional parameter. Changes were regarded as significant when the corresponding confidence interval did not include zero.

Absolute changes (ABS) of each ground reaction force variable were calculated for the affected (aff) and nonaffected (naf) legs before (pre) and after (post) therapy:

\[ X_{-\text{ABSaff}} = X_{-\text{affpost}} - X_{-\text{affpre}} \]

and

\[ X_{-\text{ABSnaf}} = X_{-\text{nafpost}} - X_{-\text{nafpre}} \]

where \( X \) denotes the variable number.

Differences (D) of each ground reaction force variable between the affected and nonaffected sides were calculated before and after therapy:

\[ X_{-\text{Dpre}} = X_{-\text{affpre}} - X_{-\text{nafpre}} \]

and

\[ X_{-\text{Dpost}} = X_{-\text{affpost}} - X_{-\text{nafpost}} \]

To document a change in symmetry (S) regardless of sign, the following parameters were used:

\[ X_{-S^2} = X_{-\text{Dpre}^2} - X_{-\text{Dpost}^2} \]

A positive sign always indicated an improvement. The \( X_{-S^2} \) values were then retransformed according to the following equation:

\[ X_{-S} = X_{-S^2}/(X_{-S^2})^{1/2} \]

For the statistical analysis three Hotelling’s \( T^2 \) tests were calculated for the sets of \( X_{-\text{ABSaff}}, X_{-\text{ABSnaf}}, \) and \( X_{-S} \) (\( \alpha = .01 \)), and a univariate F test was also performed within these groups of variables (\( \alpha = .0014 \)). The statistical software SYSTAT was applied.

Results

Functional Parameters Before and After Therapy

As shown in Table 1, the functional status of the patients only partially improved. They walked and climbed more quickly, but their endurance (ground level walking and stair climbing) remained virtually un-

Data Acquisition

Assessment of Vertical Ground Reaction Forces

Vertical ground reaction forces were measured for each leg by means of a gait symmetry system (Kistler AG), which consists of a walkway (8x1.2 m) with two embedded force plates (60x40 cm). When possible, double-step measurements were made. If the stride was not long enough to hit both plates, single-step measurements were performed instead. Patients walked barefoot at their preferred speed. Five single- or double-step measurements were recorded. Measurements were repeated when the step was not representative. Mean curves were then plotted together with seven measured parameters for each leg (Fig 1): foot-floor contact stance time, peak vertical ground reaction forces at heel strike (Fz1) and toe-off (Fz2), and loading and unloading rates (LR and DLR, respectively) in the time from 0% to 80% of Fz1 and 0% to 80% of Fz2. The peak forces Fz1 and Fz2 were normalized by the body weight (Fz1% and Fz2%, respectively). The temporal occurrence of peak forces, t1 and t2, was estimated in terms of percentage of the stance duration.

Advantages of the vertical ground reaction forces are minimal intrasubject variability,\(^\text{12}\) high accuracy of measurement, simple applicability,\(^\text{13}\) and the fact that the peaks and slopes are indicators for weight acceptance and push-off.\(^\text{12,14}\)

Assessment of Vertical Ground Reaction Forces

peak vertical ground reaction force at heel strike (Fz1) and curves were then plotted together with seven measured parameters for each leg (Fig 1): foot-floor contact stance time, peak vertical ground reaction force at toe-off (Fz2), and loading and unloading rates (LR and DLR, respectively) in the time from 0% to 80% of Fz1 and 0% to 80% of Fz2. The peak forces Fz1 and Fz2 were normalized by the body weight (Fz1% and Fz2%, respectively). The temporal occurrence of peak forces, t1 and t2, was estimated in terms of percentage of the stance duration.

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Table 1. Functional Gait Parameters Before and After Therapy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before Therapy</th>
<th>After Therapy</th>
<th>99% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time for 10-m distance at maximum speed, s</td>
<td>11.9±6.6</td>
<td>11.0±6.5</td>
<td>−1.75 to −0.21*</td>
</tr>
<tr>
<td>Max walking distance (limit, 600 m), m</td>
<td>465.5±192.4</td>
<td>480.1±175.3</td>
<td>−7.03 to 31.44</td>
</tr>
<tr>
<td>Velocity during endurance walking, m/min</td>
<td>53.0±18.1</td>
<td>61.0±20.5</td>
<td>4.88 to 11.03*</td>
</tr>
<tr>
<td>Max number of climbed steps (limit, 90)</td>
<td>70.7±126.6</td>
<td>74.4±22.4</td>
<td>−0.30 to 5.75</td>
</tr>
<tr>
<td>Velocity during step climbing, No. per min</td>
<td>47.8±20.2</td>
<td>56.2±22.2</td>
<td>3.73 to 10.91*</td>
</tr>
<tr>
<td>Motricity Index in affected leg</td>
<td>82.2±17.7</td>
<td>86.4±16.3</td>
<td>4.4 to 8.76*</td>
</tr>
<tr>
<td>Motricity Index in affected arm</td>
<td>69.9±27.9</td>
<td>77.0±25.7</td>
<td>2.07 to 5.59*</td>
</tr>
</tbody>
</table>

CI indicates confidence interval; max, maximum. Values are mean±SD.
*CI does not include zero (ie, significant change after therapy).

Vertical Ground Reaction Forces

As shown in Table 2, for the affected and nonaffected legs, absolute changes could be demonstrated with Hotelling’s T² tests (P<.01=α). Univariate F tests revealed significant changes for stance durations, LR, and DLR for both sides. There was a significant change in t1 and t2 only for the affected leg. All these significant changes have to be interpreted as an improvement, ie, the stance duration was reduced, Fz1 occurred earlier, LR and DLR increased, and Fz2 occurred later on the affected side. Fig 2 shows the vertical force profile of patient 69 (male; age, 67 years; left hemiparesis; time after stroke, 75 days at study admission) before and after therapy.

These changes were independent of the improvements in gait velocity, as could be shown by plotting the individual changes in any of the gait variables against the corresponding changes in gait velocity. The R² values ranged between 0.4% and 5.0%. Fig 3 displays the dependence of the absolute change of the stance duration of the affected leg on the change of the gait velocity.

Gait Symmetry

As shown in Table 3, the symmetry parameters changed significantly (P=.002<α) according to the multivariate statistics. Univariate F tests, however, only showed significant improvement for the stance duration, and Fz1% and LR significantly deteriorated.

Probability of the improvement of at least four of the seven variables was estimated as 37.8% (95% confidence interval, 28.8% to 47.2%).

Plots of X-S² against X-Dpre revealed a dependence of both improvement and deterioration of the initial asymmetry, ie, the larger the initial imbalance, the greater the possible change in both directions. Fig 4 shows the dependence of the squared symmetry value (X-S²) of the LR on the absolute difference between the affected and nonaffected legs before therapy.

In addition, X-S was plotted against age, initial Motricity Index (weighted average of upper and lower extremities), and stroke interval. No apparent dependencies could be detected, with coefficients of determination (R²) ranging between 0.9% and 6.1%.

Furthermore, quantile-quantile plots of X-S (male) versus X-S (female) were made. Similar plots were calculated for the side of hemiparesis (left or right) and

Table 2. Vertical Ground Reaction Force Parameters of Affected and Nonaffected Legs Before Therapy and Absolute Change After Therapy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Absolute Value of Affected Leg Before Therapy</th>
<th>Absolute Change of Affected Leg After Therapy</th>
<th>Absolute Value of Nonaffected Leg Before Therapy</th>
<th>Absolute Change of Nonaffected Leg After Therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stance duration, s</td>
<td>0.91±0.23</td>
<td>−0.05±0.15*</td>
<td>0.99±0.30</td>
<td>−0.07±0.15*</td>
</tr>
<tr>
<td>Fz1%, % BW</td>
<td>103.0±7.6</td>
<td>2.1±9.6</td>
<td>101.0±5.3</td>
<td>1.3±6.7</td>
</tr>
<tr>
<td>Relative occurrence of Fz1%, % stance</td>
<td>31.7±8.4</td>
<td>−2.6±5.4*</td>
<td>28.0±7.4</td>
<td>−1.2±6.1</td>
</tr>
<tr>
<td>Loading rate, kN/s</td>
<td>3.64±1.65</td>
<td>0.7±1.1*</td>
<td>3.83±1.54</td>
<td>0.5±0.9*</td>
</tr>
<tr>
<td>Fz2%, % BW</td>
<td>102.6±7.4</td>
<td>−0.04±7.1</td>
<td>105.2±6.7</td>
<td>0.68±4.9</td>
</tr>
<tr>
<td>Relative occurrence of Fz2%, % stance</td>
<td>67.0±9.8</td>
<td>1.6±7.6*</td>
<td>72.8±5.9</td>
<td>−0.7±7.1</td>
</tr>
<tr>
<td>Deloading rate, kN/s</td>
<td>3.58±1.52</td>
<td>0.5±0.8*</td>
<td>3.93±1.42</td>
<td>0.4±0.8*</td>
</tr>
</tbody>
</table>

Fz1% indicates peak vertical ground reaction force at heel strike normalized by body weight (BW); Fz2%, peak vertical ground reaction force at toe-off normalized by BW. Values are mean±SD.

*Significant change after therapy according to univariate F test with corrected α=.0014.
sensory impairment (present or absent). No marked differences could be seen.

Discussion

This study intended to investigate the gait outcome of mildly affected hemiparetic patients who were able to walk independently at least 20 m and were competent for the most part in the activities of daily living. The duration of their comprehensive stroke rehabilitation program is normally restricted to 4 weeks, and the rather low frequency of therapies reflects the realistic situation.

Functional Walking Performance

Although some functional parameters improved significantly (gait and stair climbing velocities, Motricity Index–Foot, Motricity Index–Hand), confidence intervals (particularly for time for 10-m distance at maximum speed) revealed that these changes were not very marked (Table 1), and walking and stair climbing endurance did not improve at all. The minimal changes can probably be explained by the fact that during a Bobath session static exercises (sitting, standing) prevail while the patient is requested to walk slowly and in a controlled manner. Therapists also do not encourage patients to walk by themselves for fear of stereotyped mass synergies.11

Vertical Force Parameters

Absolute values of the seven ground reaction force parameters before therapy corresponded with those in previous reports: The stance duration of the affected leg was shorter,16 and the push-off was less pronounced on the paretic side.10,14 Fz1% and LR were larger on the affected side.10,12

Global changes of the vertical ground reaction forces revealed significant improvements in five variables on the affected side and three on the nonaffected side. Changes in gait velocity did not predict these parameter changes. Thus, gait kinetics serve as an independent measure of therapeutic effects in this group of patients. This does not exclude the existence of a relation between force parameters and gait velocity for each individual subject, as in the case of healthy subjects.17

The reduced stance duration for both lower limbs is therefore not exclusively explained by an increase of walking speed, and it does not change in direct proportion to the cycle duration. The double support times tend to increase with the impairment in hemiplegic gait.16 It may therefore be assumed that the double support times were reduced more than the cycle times with the improvement of gait disability. The fact that gait improved is further supported by a significant increase of the variables, indicating weight acceptance and push-off of both lower limbs. Therefore, patients showed changes that are in accordance with the intentions of the NDT, ie, an improved weight acceptance and push-off.11 Comparable data are not available, and control studies had different scopes.3–8

Symmetry of Ground Reaction Force Parameters

Stance symmetry improved, which, together with a reduction of stance durations, confirmed the objectives of NDT. Symmetry of the ground reaction forces, however, did not improve. On the contrary, Fz1% and LR both deteriorated significantly for this group of patients. These findings refer to mean values and do not exclude improvements in individual patients. If it is assumed that a clinically relevant change requires improvement of at least four of seven symmetry parameters, then the probability of improvement is less than 50%. These findings question the achievement of a main
TABLE 3. Differences Between Affected and Nonaffected Legs Before Therapy and Change of Symmetry After Therapy

<table>
<thead>
<tr>
<th></th>
<th>Difference Between Affected and Nonaffected Legs Before Therapy</th>
<th>Change of Symmetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symmetry of stance durations</td>
<td>-0.09±0.15</td>
<td>0.04±0.13*</td>
</tr>
<tr>
<td>Symmetry of Fz1%</td>
<td>1.96±7.62</td>
<td>-0.65±8.64*</td>
</tr>
<tr>
<td>Symmetry of relative occurrences of Fz1%</td>
<td>3.71±9.41</td>
<td>0.40±8.33</td>
</tr>
<tr>
<td>Symmetry of loading rates</td>
<td>-0.19±1.07</td>
<td>-0.18±0.96*</td>
</tr>
<tr>
<td>Symmetry of Fz2%</td>
<td>-2.54±8.37</td>
<td>-0.06±9.2</td>
</tr>
<tr>
<td>Symmetry of relative occurrences of Fz2%</td>
<td>-5.83±9.87</td>
<td>0.46±10.24</td>
</tr>
<tr>
<td>Symmetry of deloading rates</td>
<td>-0.34±0.75</td>
<td>-0.003±0.79</td>
</tr>
<tr>
<td>Multivariate probability</td>
<td>P=.000</td>
<td>P=.000</td>
</tr>
</tbody>
</table>

Fz1% indicates peak vertical ground reaction force at heel strike normalized by body weight; Fz2%, peak vertical ground reaction force at toe-off normalized by body weight. Values are mean±SD.

*Significant change after therapy according to univariate F test with corrected α=.0014.

To channel resources, it is desirable to find predictors that patients are most likely to profit from because therapy is both time- and cost-intensive. In a report on the ability to walk 6 months after a stroke, age, visual neglect, and leg power (Medical Research Council grades) best predicted outcome among 113 subjects.9 We did not find any relevant influence of sex, age, side of hemiparesis, motor strength, stroke interval, or sensory impairment on the outcome of symmetry in these mildly affected patients. The initial state of asymmetry allowed the prediction of the absolute amount of change but not the direction of change (improvement or deterioration). Thus, there were no criteria to predict which of these mildly affected patients might benefit more from the comprehensive stroke rehabilitation program with regard to gait symmetry.

Contrary to the literature on general rehabilitation, elder patients or patients after the period of spontaneous recovery did not profit less from NDT.18 Sensory impairment did not influence the symmetry outcome, which is in agreement with existing reports on its poor predictive value regarding activities of daily living and the weak correlation between sensation and walking performance, upright stability, and other aspects of motor control.19,20

Conclusions

In conclusion, stance duration, weight acceptance, push-off of both legs, and stance-duration symmetry improved significantly during the 4-week NDT rehabilitation program. However, the symmetry of ground reaction forces did not improve, although gait imbalance therapy is a primary component of NDT. The functional performance of the patients did not improve considerably. These results thus challenge the efficacy of intensive rehabilitation therapy in its attempts to restore physiological gait in minimally affected hemiparetic patients. The study does not exclude possible improvements in other aspects of motor behavior, such as reduction of spasticity and retraining of upright posture, that are within the scope of NDT. Further conclusions regarding the rehabilitation of mildly affected hemiparetic patients should be drawn with great caution. On the other hand, the patients might have reached a certain level of functional ability as a result of adaptive mechanisms, so that no substantial further improvements of gait could be expected.

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Gait outcome in ambulatory hemiparetic patients after a 4-week comprehensive rehabilitation program and prognostic factors.
S A Hesse, M T Jahnke, C M Bertelt, C Schreiner, D Lücke and K H Mauritz

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