Effects of Bilateral Posteroventral Pallidotomy on Gait of Subjects With Parkinson Disease

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Background: Most studies documenting the effect of pallidotomy on parkinsonian gait have reported unilateral surgery and used qualitative scales or timed tests that only provide measures of walking speed.

Objective: To document the effect of bilateral posteroventral pallidotomy on the walking patterns of patients with Parkinson disease (PD).

Design: Case series of gait evaluations performed 1 month before and 1 month after surgery, with antiparkinson medication withheld for 8 hours overnight.

Setting: Movement analysis laboratory of a clinical research center.

Patients: Consecutive sample of 8 men and 3 women with a diagnosis of PD scheduled for bilateral pallidotomy.

Intervention: Bilateral posteroventral pallidotomy.

Main Outcome Measures: A 3-dimensional motion-capture system allowed calculation of temporal and spatial measurements and joint angular displacements of the lower extremities and trunk during gait.

Results: Pallidotomy significantly increased average walking speed from 0.214 stature/s preoperatively to 0.440 stature/s postoperatively (where stature indicates body height) ($P = .03$). A faster postoperative walking speed was achieved almost exclusively by increasing average stride length from 0.24 to 0.47 stature ($P = .03$) rather than changing average gait cycle time (1.32 to 1.37 seconds; $P = .08$). A forward stepwise multiple regression analysis ($P < .001$) revealed that 96% of the change in stride length postoperatively could be explained by the combination of changes in foot-floor angle, knee, and hip excursion during gait.

Conclusions: Bilateral posteroventral pallidotomy was associated with a 2-fold increase in walking speed. Previous studies have demonstrated that walking speed is an important indicator of locomotor performance and level of disability in patients with PD, so the increase in postoperative walking speed likely provided a functional benefit.

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Parkinson disease (PD) is a chronic neurologic disorder resulting in the impairments of tremor, rigidity, bradykinesia, and postural instability. Other functional limitations associated with PD include difficulty with speech, swallowing, self-care, and walking. The primary gait disturbances in PD are reduced walking speed,11 and increased variability.1,12 Overall, component movements of gait are preserved in PD, but the amplitude of movement is diminished.2,4,6

Many investigators have documented that antiparkinsonian medications, in particular levodopa therapy combinations, improve gait function.2,4,7 Motor complications associated with long-term levodopa therapy, eg, progressive deterioration despite continued therapy, large fluctuations in symptoms between doses of medication, and involuntary movement (dyskinesia), have renewed interest in the surgical treatment of PD. In addition, advances in imaging and stereotactic techniques have significantly decreased the adverse effects associated with pallidotomy in the 1950s. In the past decade, Laitinen et al13 reported the first of a series of studies on the effect of pallidotomy.

Studies in the literature report a variable response to pallidotomy, but it appears to be especially beneficial in improving drug-induced dyskinesia and less effective in improving gait. Postoperative motor function while not receiving medication has shown improvement in rigidity,14-19 tremor,14-20 akinesia,14,16-18
SUBJECTS AND METHODS

The study sample included 8 men and 3 women, all with a diagnosis of PD according to the criteria of Hughes et al.24 They were selected consecutively from those scheduled for bilateral contemporary pallidotomies at another institution. Unless otherwise indicated, data are given as mean (SD). Mean age was 59.5 years (9.8 years); height, 1.71 m (0.11 m); and weight, 73.1 kg (14.3 kg). Average disease duration was 18.2 years (7.6 years). Clinical severity as determined by Hoehn and Yahr stage was 4.4 (0.6) while not receiving medication and 3.2 (0.6) while receiving medication. All subjects had a clear response to levodopa and experienced motor fluctuations and dyskinesias. Other clinical assessments performed while patients were and were not receiving medication included the Unified Parkinson’s Disease Rating Scale (UPDRS) with subscores for each of the cardinal signs of PD. Every subject underwent a bilateral pallidotomy during a single surgery performed elsewhere.21 Coronal- and transverse-plane magnetic resonance imaging was performed 1 month postoperatively to document the size and location of the surgical lesion. All lesions involved a large portion of the posteroventral globus pallidus internus; however, postoperative complications included a visual field deficit in 1 subject. No other significant adverse effects occurred. In particular, no upper motor neuron signs (eg, drift, hyperreflexia, up-going toes) were present on results of a detailed neurologic examination.

Subjects underwent evaluation at our institution 1 month before and 1 month after pallidotomy. On average, postoperative assessment occurred 38.3 days after surgery (range, 28-53 days). All subjects were participating in a protocol assessing parkinsonian function that had been reviewed and approved by an institutional review board, and all subjects provided their informed consent. Antiparkinsonian medication was withheld overnight for 8 hours before testing.

Gait patterns were evaluated using previously described procedures.25 Subjects were barefoot and wore shorts and shirts. Reflective targets were applied to the feet, lower legs, thighs, pelvis, and posterior trunk. Subjects were instructed to walk along a 10-m walkway at a self-selected pace, and physical assistance was provided to 5 subjects to ensure safety and prevent falls. A 6-camera motion-capture system (Vicon VX; Oxford Metrics, Oxford, England) sampled 3-dimensional target locations at 50 Hz that were low-pass filtered at 6 Hz. A minimum of 3 repeated walking trials (no longer than 30 seconds) were collected to assess gait variability, except in 2 subjects limited by fatigue to only 2 trials. Additional trials were collected from the faster subjects to increase the number of steps available for analysis. Single static standing trials also were collected from each subject.

Computer software determined 3-dimensional target trajectories (AMASS; Adtech, Gaithersburg, Md), temporal and spatial gait measurements, and joint excursions (in-house software). Previous testing has determined system accuracy to be 3 mm for linear measurements and 1° for angular measurements. Temporal gait variables included gait cycle time, double limb support duration, and bilateral step times, stance durations, and swing durations. Spatial gait variables included stride length and bilateral step lengths. All available steps were used to calculate intra-subject variability of step length and step time using a coefficient of variation (100 × SD/mean).22 Symmetry of step length and step time was computed as the ratio of the shorter step to the longer step.5,6

Joint and segment angles were computed for the standing and the gait trials. From 3 of the repeated gait trials, 1 right and 1 left gait cycle that were closest to the average temporal and spatial measures were selected for additional kinematic analysis. (Two cycles were selected from a single trial if only 2 repeated trials were available for analysis.) Bilateral joint angles in the sagittal plane included foot-floor angle (toe or heel rise), ankle dorsiflexion and planter flexion, knee flexion and extension, and hip flexion and extension. Angular position of the pelvis and trunk in global space and relative to each other were computed in the sagittal and transverse planes. These angles were generated for the entire gait cycle, and discrete values selected for statistical analysis included the peak angle achieved in each direction of movement (such as peak flexion and peak extension angles) and the total range of motion.

For all gait measurements, mean values were generated for each subject, and then subject means were used to generate group means. Group means before and after pallidotomy were compared statistically using paired t tests or repeated-measures analyses of variance (ANOVAs) (SYSTAT 7.0; SPSS Inc, Chicago, Ill). One ANOVA was performed for each joint or segment with repeated factors that included operative status, angle, and side. Operative status included preoperative or postoperative. Angle included static standing angle, peak angle in each direction of movement during gait, and total range of movement during gait. Side included left and right when applicable. When no significant differences existed between sides, data from the left side were reported. The ANOVA post-hoc testing consisted of additional paired t tests with a Bonferroni correction to protect an α level of .05 for the entire experiment. Only 2 variables produced cells that deviated substantially from a normal distribution (peak toe-elevation angle of the foot to the floor and peak ankle-dorsiflexion angle). The probability associated with the ANOVA F statistic was adjusted using the Huynh-Feldt technique26 to correct for possible violations of variance and covariance assumptions. Finally, a forward stepwise multiple regression analysis was used to predict postoperative results from preoperative data.

dyskinesia,14,15,17-22 and other motor signs, including gait,14,15,17-19,21,22 although not always.23 The improvement in walking speed15,17,19 is similar to the initial benefit of pharmacotherapy.2,5 Most of these studies documenting the effect of pallidotomy on gait have reported unilateral surgery14,18,19,21,22 and used qualitative scales14,16,18,21,22 or timed tests15,17,19,20,21 that only provide measures of walking speed. Our purpose was to comprehensively quantify changes in the gait pattern of subjects with PD after undergoing bilateral posteroventral pallidotomy.©2000 American Medical Association. All rights reserved.
RESULTS

Average walking speed after pallidotomy was approximately twice as fast as preoperative walking speed (Table 1), but individual subject response was highly variable (Figure 1). Most subjects achieved at least 80% of their faster postoperative walking speed by increasing step length (Figure 2) and stride length (right plus left step lengths). Step times (Figure 2) and gait cycle times (right plus left step times) were not significantly different postoperatively. Average step time was more symmetrical than step length, but pallidotomy did not change step symmetry significantly. Intrasubject step-to-step variability was greater for step length than step time. Although decreases in variability were noted postoperatively in step length for 9 subjects and in step time for 10 subjects, the magnitude of these changes was not significant. Paired t tests revealed that all other temporal and spatial measures did not change significantly after pallidotomy (Table 1).

Joint excursions of the lower extremities, pelvis, and trunk showed significant change postoperatively. Results of ANOVA revealed a significant operative effect for motion of the knee joint ($P = .002$) and trunk segment ($P = .04$). In addition, the interaction of angle and operative status was significant for many of the movements evaluated (Table 2). The knee and trunk were more extended when standing (Figure 3). Postoperative total joint excursion during gait was significantly greater for foot-floor angle; ankle, knee, and hip motion; and trunk-pelvis counterrotation (Figure 4). Most of the increased range of motion during gait appeared to come from increased peak extension angles throughout (Figure 4), but only peak heel rise and knee extension angles during gait were significantly different postoperatively (Table 2).

The postoperative change in range of motion during gait for the 5 significant movements (Table 2) was used to explain the change in stride length postoperatively using a forward stepwise multiple regression analysis. Knee range of motion, foot-floor angle excursion, and hip range of motion were added to the model on successive steps. The combination of changes in these 3 excursions explained 96% ($R = 0.98$; $P < .001$) of the postoperative change in stride length compared with preoperative values.

Despite the significant differences between average preoperative and postoperative gait measures in the study

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**Table 1. Summary of Preoperative and Postoperative Temporal and Spatial Gait Variables**

<table>
<thead>
<tr>
<th>Temporal and Spatial Variables</th>
<th>Status</th>
<th>Preoperative</th>
<th>Postoperative</th>
<th>$P$†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed, statures/s‡</td>
<td>0.214</td>
<td>0.440</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Stride length, statures§</td>
<td>0.241</td>
<td>0.474</td>
<td>.03</td>
<td></td>
</tr>
<tr>
<td>Step length symmetry</td>
<td>0.72</td>
<td>0.78</td>
<td>.39</td>
<td></td>
</tr>
<tr>
<td>Step length variability</td>
<td>34.0</td>
<td>15.4</td>
<td>.18</td>
<td></td>
</tr>
<tr>
<td>Gait cycle time, s</td>
<td>1.32</td>
<td>1.37</td>
<td>.80</td>
<td></td>
</tr>
<tr>
<td>Step time symmetry</td>
<td>0.92</td>
<td>0.85</td>
<td>.14</td>
<td></td>
</tr>
<tr>
<td>Step time variability</td>
<td>24.2</td>
<td>17.1</td>
<td>.23</td>
<td></td>
</tr>
<tr>
<td>Double limb support duration, % gait cycle</td>
<td>44</td>
<td>32</td>
<td>.09</td>
<td></td>
</tr>
<tr>
<td>Stance duration, % gait cycle</td>
<td>72</td>
<td>66</td>
<td>.07</td>
<td></td>
</tr>
<tr>
<td>Swing duration, % gait cycle</td>
<td>28</td>
<td>34</td>
<td>.07</td>
<td></td>
</tr>
</tbody>
</table>

* Includes 11 subjects.
† Determined using t test.
‡ Expressed as a proportion of body height per second.
§ Expressed as a proportion of body height.

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Figure 1. Preoperative and postoperative walking speed for each of the 11 subjects, expressed in a proportion of stature (ie, body height) per second.

Figure 2. Preoperative and postoperative stepping patterns from 1 subject. Left, Footprints indicate spacing of step lengths and step widths. Lower horizontal bars indicate 500 mm. Right, Horizontal lines indicate timing of the same steps (lines branching to the left, time of left steps; and lines branching to the right, time of right steps). Preoperatively, 12 steps covered approximately 2.5 m in slightly longer than 8 seconds. Postoperatively, only 7 steps were needed to travel the same distance in slightly longer than 3 seconds.
sample, individual subject response to pallidotomy varied greatly. A second forward regression analysis was performed to identify any preoperative measures that might be useful predictors of postoperative outcome. Variables available to predict the increase in postoperative walking speed included subject age, weight, height, symptom duration, size of the surgical lesions, preoperative walking speed, and several preoperative UPDRS scores while not receiving medication and the improvement in scores while receiving medication. The UPDRS scores entered into the analysis included the total score plus 6 subset scores for tremor, freezing, akinesia, rigidity, dyskinesia, and a combined score for postural instability and gait (a total of 14 scores; for the total score and each of the subset scores, both the score in the nonmedicated state and the score in the nonmedicated state minus the score in the medicated state). Subset scores were considered to determine whether any particular PD symptom better predicted postoperative outcome than any other symptom. The final regression model (Table 3) included total UPDRS score while not receiving medication, total UPDRS score response to levodopa, UPDRS tremor score while not receiving medication, and subject age. The com-

<table>
<thead>
<tr>
<th>Joint or Segment</th>
<th>Movement</th>
<th>Angle</th>
<th>Postoperative Change, Degrees</th>
<th>$P$†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot</td>
<td>Foot-floor angle</td>
<td>Peak heel-rise</td>
<td>+27.3</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total range</td>
<td>+30.1</td>
<td>.002</td>
</tr>
<tr>
<td>Ankle</td>
<td>Dorsiplantar flexion</td>
<td>Total range</td>
<td>+9.8</td>
<td>.01</td>
</tr>
<tr>
<td>Knee</td>
<td>Flexion and extension</td>
<td>Peak extension</td>
<td>+7.7</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total range</td>
<td>+17.3</td>
<td>.01</td>
</tr>
<tr>
<td>Hip</td>
<td>Flexion and extension</td>
<td>Total range</td>
<td>+14.1</td>
<td>.007</td>
</tr>
<tr>
<td>Trunk</td>
<td>Flexion and extension</td>
<td>Flexion angle in standing calibration</td>
<td>−6.5</td>
<td>.006</td>
</tr>
<tr>
<td>Trunk and pelvis</td>
<td>Counter-rotation</td>
<td>Peak trunk to right and pelvis to left</td>
<td>+3.0</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total range</td>
<td>−7.0</td>
<td>.004</td>
</tr>
</tbody>
</table>

* Determined using analysis of variance.
† Critical $P = .013$ for each comparison to protect the experimental $\alpha$ level of .05.

Table 2. Highlights of Significant Findings From Post Hoc Tests of Angle and Operative Status Interaction

Figure 3. Geometric model of one subject during the standing calibration trial showing feet, shanks, thighs, pelvis, and trunk segments. Postoperatively, knee flexion angle decreased 17° and trunk flexion angle decreased 8°.

Figure 4. Average joint movements during the left gait cycle that significantly increased postoperatively. For foot-floor movement, lower measure indicates heel rise; for ankle movement, higher measure indicates dorsiflexion; for knee and hip movements, higher measures indicate flexion; and for pelvis-trunk movement, higher measures indicate movement of trunk to left and pelvis to right.

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bination of these 4 variables predicted 99% of the variability in the change in walking speed following surgery (R = 1.00; P<.001).

Preoperatively, study subjects demonstrated severe limitations in gait compared with values reported in the literature. In particular, average preoperative walking speed of subjects in our study was 70% slower than literature values for similarly aged healthy subjects and 30% slower than literature values for other subjects with PD when not receiving medication. Typically, a slow walking speed is associated with increased gait cycle time and decreased stride length, and this relationship has been confirmed in PD by some investigators. Other studies of PD gait have found that the slow walking speed of subjects with PD was almost exclusively due to short stride lengths rather than prolonged gait cycle times. The results of our study appear to support the latter observation. The tremor subset score while on medication and the stage1 and level of disability. In the elderly population in general, customary walking speed predicts the need for long-term care, the use of assistive gait devices, and the incidence of falls. Specifically in PD, walking speed has been proposed as a useful indicator of locomotor performance. Therefore, the increase in walking speed observed in our study likely provided a functional benefit.

Studies documenting the effect of unilateral pallidotomy on gait have been limited to qualitative scales or timed tests of walking speed. Many timed studies of gait following unilateral pallidotomy include a turn, and some also include rising from a chair. One study did measure walking speed around a 50-m circular path and found that walking speed increased 29% following unilateral pallidotomy. Reports of improvement as high as 45% for a sit-stand-walk test have been noted following unilateral pallidotomy. Subjects in our study underwent evaluation after their antiparkinsonian medications were withheld for 8 hours overnight before testing. This condition was selected because pilot testing revealed that preoperative gait patterns were highly variable within and between test sessions while subjects were receiving medication, and much less variable after medication was withheld. However, not all variability was eliminated (Table 1), so multiple steps from multiple trials were analyzed. Another reason subjects underwent evaluation while not receiving medication was that optimum medication level was expected to change postoperatively. Other investigators evaluating the effects of unilateral pallidotomy have attempted to control medication dosage postoperatively, but have acknowledged that optimal dosage may change.

Another methodological difference between our study and other studies of unilateral surgery is a shorter follow-up time for the postoperative evaluation. Allowing at least 4 weeks after surgery should minimize the

<table>
<thead>
<tr>
<th>Variable entered into regression model</th>
<th>UPDRS total score while not receiving medication</th>
<th>Tremor subset score while not receiving medication</th>
<th>UPDRS total score while not receiving medication</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple correlation of entered variable with walking speed response</td>
<td>0.76</td>
<td>0.69</td>
<td>0.22</td>
<td>−0.70</td>
</tr>
<tr>
<td>Partial correlation of entered variable with model on previous step</td>
<td>0.89</td>
<td>−0.83</td>
<td>−0.79</td>
<td></td>
</tr>
<tr>
<td>Multiple R of current model</td>
<td>0.76</td>
<td>0.95</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>P value of current model</td>
<td>.007</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Percentage of explained variability in walking speed response</td>
<td>57.3</td>
<td>90.9</td>
<td>97.2</td>
<td>98.9</td>
</tr>
<tr>
<td>Increase in percentage of explained variability over model on previous step</td>
<td>33.7</td>
<td>6.3</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>Residual (root mean square) of predicted vs observed walking speed response</td>
<td>0.18</td>
<td>0.08</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Residual (root mean square) as a percentage of average increase in walking speed</td>
<td>79.0</td>
<td>36.4</td>
<td>20.2</td>
<td>12.4</td>
</tr>
</tbody>
</table>

*UPDRS indicates Unified Parkinson’s Disease Rating Scale.
effects of edema that may occur within the first or second week after surgery. However, if overall mobility level increases after surgery, gait measurements that may not have changed soon after surgery may change with longer follow-up. A few unilateral studies with longer follow-up times have suggested that postoperative improvements may regress toward preoperative levels at 1 year, but other investigators have reported that a 45% improvement in gait was maintained for at least 1 year. Additional research is needed to determine if the 100% improvement noted at 4 weeks following bilateral surgery in our study will be maintained longer.

The bilateral nature of the surgical procedure may provide additional benefit compared with unilateral surgery. Midline functions such as posture and gait are thought to be influenced by pathways in the brainstem. It is possible that pallidotomy exerts effects on midline functions by diminishing γ-aminobutyric acid–activated descending outflow to the brainstem. This mechanism allows unilateral surgery to affect these midline functions, but bilateral lesions may have an even greater effect on midline motor behaviors such as gait.

Subject response to surgery was highly variable. A few subjects demonstrated dramatic improvement from severely limited preoperative function to nearly normal postoperative function, whereas other subjects demonstrated only minimal change or deterioration (ie, they walked slower). The regression analysis selected the combination of larger changes in total UPDRS score with medication, more tremor while not receiving medication, higher UPDRS score (worse function) while not receiving medication, and a younger age as the best combination of measures to predict greater increases in walking speed postoperatively. Additional study with greater numbers of subjects is needed to determine how successfully this model can predict postoperative outcome on a case-by-case basis.

Somewhat surprisingly, the effect of medication on total UPDRS score, and not the subset of items associated with postural instability and gait, was selected as a better predictor of postoperative outcome. Another variable not selected in the regression analysis was size of the surgical lesion. However, the subject who walked the slowest preoperatively and even slower postoperatively had a visual field deficit postoperatively, consistent with a lesion that extended beyond the posteroventral globus pallidus. However, magnetic resonance imaging could not clearly demarcate the edges of the surgical lesion in this subject nor suggest any reason why 2 other subjects walked slower postoperatively. A review of other clinical data revealed that these 3 subjects were among 4 with no significant resting tremor and among 5 with the smallest (but still significant) motor response to levodopa preoperatively. However, they still had motor fluctuations and drug-induced dyskinesias consistent with the diagnosis of idiopathic PD.

Walking patterns of subjects with advanced PD improved significantly after bilateral posteroventral pal-lidotomy. Sagittal plane excursion of the lower extremity joints and transverse plane rotation of the trunk relative to the pelvis during gait increased postoperatively. Increased peak extension angles contributed more to the increase in range of motion than peak flexion angles, but only total range was significantly greater postoperatively for most joints. Larger postoperative joint excursions were responsible for nearly doubling stride length, and longer stride lengths were predominantly responsible for a faster postoperative walking speed. Measurements associated with the timing of gait, including gait cycle time, step time, and duration of the subphases of gait, did not change significantly postoperatively. Although several clinical measures were identified as predictors of a better postoperative outcome, the small number of subjects in this study may limit the use of these results to predict surgical outcome on an individual basis.

CONCLUSIONS

Walking patterns of subjects with advanced PD improved significantly after bilateral posteroventral pal-lidotomy. Sagittal plane excursion of the lower extremity joints and transverse plane rotation of the trunk relative to the pelvis during gait increased postoperatively. Increased peak extension angles contributed more to the increase in range of motion than peak flexion angles, but only total range was significantly greater postoperatively for most joints. Larger postoperative joint excursions were responsible for nearly doubling stride length, and longer stride lengths were predominantly responsible for a faster postoperative walking speed. Measurements associated with the timing of gait, including gait cycle time, step time, and duration of the subphases of gait, did not change significantly postoperatively. Although several clinical measures were identified as predictors of a better postoperative outcome, the small number of subjects in this study may limit the use of these results to predict surgical outcome on an individual basis.

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REFERENCES


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