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Postural control in Parkinson's disease after unilateral posteroventral pallidotomy

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Summary

Postural control changes were studied in 27 patients with Parkinson's disease after unilateral posteroventral pallidotomy (PVP). Patients were evaluated before PVP and at 3, 6 and 12 months post-PVP, both 'off' and 'on' parkinsonian medications, with selected evaluation tools representing functional performance, functional balance and posturographic components of balance. The majority of variables in the 'off' state were significantly improved at 3 months post-PVP. Improvement was maintained at 6 months but had declined for some variables by the 12 month follow-up. Standing up from a chair (P = 0.009), the balance and gait sections of the Performance-Oriented Assessment ($P \leq 0.0004$), and the limits of stability (LOS) posturography variables ($P < 0.0005$) of the average time to reach a target, the number of targets missed and the initial excursion distance to the target (P = 0.029) retained significant improvement at the 12 month follow-up. When the patients were in the 'on' state, LOS posturography variables of average time to target, average path length deviation, and the number of targets missed were the only variables significantly improved at 3 months post-PVP (P = –0.013) and this improvement was maintained at 12 months post-PVP (P = 0.012–0.041). Unilateral PVP improves axial symptoms of Parkinson's disease involved in functional performance such as gait disturbance as well as improving postural stability in the 'off' state. Generally, the maximum improvement is seen at 3 months post-PVP with many variables remaining significantly improved at 12 months post-PVP. Axial dyskinesias in the 'on' state are also significantly reduced with the improvement maintained at 12 months post-PVP. These findings suggest that unilateral pallidotomy is not only effective in abolishing levodopa-induced dyskinesias, but that it also improves the axial signs of Parkinson's disease.

Keywords: postural instability; Parkinson's disease; pallidotomy; balance; postural control

Abbreviations: FR = functional reach; LOS = limits of stability; POAG/POAB = gait and balance sections of the Performance-Oriented Assessment; PVP = posteroventral pallidotomy; UPDRS = Unified Parkinson's Disease Rating Scale

Introduction

Impairment of postural control, one of the cardinal symptoms of Parkinson's disease, is often resistant to levodopa therapy (Jankovic *et al.*, 1990; Marsden, 1994). Posteroventral pallidotomy (PVP) has become a viable treatment alternative for the alleviation of symptoms due to long-term use of levodopa and the debilitation associated with progression of the disease, but its effects on postural stability are unclear. Reduction in the other cardinal signs of Parkinson's disease such as bradykinesia, tremor and rigidity, during the 'off' state as well as decreased dyskinesias due to levodopa ('on' state) have been observed after unilateral PVP (Laitinen *et al.*, 1991; Dogali *et al.*, 1995; Lozano *et al.*, 1995; Baron *et al.*, 1996; Olanow, 1996; Fazzini *et al.*, 1997; Kishore *et al.*, 1997; Krauss *et al.*, 1997; Lang *et al.*, 1997; Jankovic *et al.*, 1998; Ondo *et al.*, 1998; Lai *et al.*, 2000). The major improvement occurs on the contralateral side, but changes may also occur ipsilaterally. Postural stability and gait dysfunction have also been reported to improve in the 'off' state immediately after unilateral PVP (Laitinen *et al.*, 1991; Dogali *et al.*, 1995; Baron *et al.*, 1996; Kishore *et al.*, 1997; Vitek *et al.*, 1997), although one study reported that this improvement was not significant with blinded videotape review (Lozano *et al.*, 1995). The benefits for postural stability and gait, however, are generally reported as not sustained with declines from initial improvement usually evident by 12 months after PVP (Baron *et al.*, 1996; Lang *et al.*, 1997; Vitek *et al.*, 1997). Improvements in postural stability, gait and other Parkinson's disease features after PVP have been documented by the Unified Parkinson's Disease Rating Scale (UPDRS) (Fahn *et al.*, 1987) and with timed tasks from the Core Assessment Program for Intracerebral Transplantation (Langston *et al.*, 1992). However, these measures are not sufficient to provide a comprehensive assessment of postural control. Such analysis should include functional aspects as well as specific components of postural control (Winter *et al.*, 1990; Shumway-Cook, 1996). Tests such as the Functional Reach (FR) (Duncan *et al.*, 1992) or the Performance-Oriented Assessment (Tinetti, 1986) are screening tools that can detect potential postural stability problems that interfere with functional capabilities. The component aspect investigates the role of parcelled constituents of postural stability that can be measured by posturography, such as sway or the limits of stability (LOS) (Nashner, 1993). The purpose of this study was to investigate postural control changes seen in patients with advanced Parkinson's disease before and after unilateral PVP using measures that permitted a comprehensive view of postural stability. These changes were followed from baseline before surgery to 12 months post-PVP and assessed in the 'on' and 'off' states.

Table 1 *Mean ADL*, motor and PIGD† subscores from the UPDRS* of patients before and after unilateral PVP 'on' and 'off' medication*

	Pre-PVP	3 months	6 months	12 months
'Off'				
ADL	31.7	17.4	16.9	17.6
Motor	57.8	32.9	30.4	32.2
PIGD	13.2	7.1	6.9	7.7
'On'				
ADL	16.3	7.4	7	7.5
Motor	29.3	14.4	13	13.6
PIGD	6.44	3	2.8	3.3

*ADL = activities of daily living; UPDRS = Unified Parkinson's Disease Rating Scale. †PIGD = Postural Instability and Gait Dysfunction Index from the following UPDRS items: falling, freezing and walking difficulty by history, gait and postural instability by examination.

Methods

Subjects

Thirty-eight patients with Parkinson's disease involved in a multidisciplinary study to determine the effectiveness of unilateral PVP were referred for posturography and balance testing from the Baylor College of Medicine, Parkinson's Disease Center and Movement Disorders Clinic. The Baylor Affiliates Review Board for Human Subject Research approved the study and informed consent was obtained from each patient prior to participation. Inclusion criteria for the overall study as well as the balance testing were: (i) Hoehn and Yahr stage 3 or greater while 'off' levodopa, (ii) levodopa responsiveness as determined by the clinical judgement of the neurologist investigator by observation of meaningful clinical improvement in parkinsonian symptoms, (iii) history of levodopa-induced dyskinesias, and (iv) absence of other neurological disease including dementia or autonomic dysfunction. The patients underwent unilateral microelectrode-guided stereotactic PVP. Lesion location was chosen to improve the side most affected by parkinsonism. Accuracy of lesion sites was verified by MRI 1–3 days post-PVP and at the 6 month follow-up examination (Krauss *et al.*, 1997). Three patients who underwent the surgery sustained injuries due to a fall within the first 4 months post-PVP (despite improved UPDRS scores) and were discontinued from the study. These injuries required a recovery process that precluded further participation in the study and would have confounded any effect due to pallidotomy. Two of the individuals had marked kyphotic deformity due to osteoporosis, perhaps making them more vulnerable to injurious falls with an increased activity level post-PVP; while the other patient moved from a nursing home to independent living in an apartment, placing him at greater risk for falls. Eight patients withdrew by choice at subsequent follow-up periods because of personal constraints such as distance travelled or the time involved in testing. When post-operative performance was analysed with inclusion of these patients for the available follow-up sessions, there was no difference in the outcome of the results when compared with analysis for the same time frame (6 months post-PVP) without their inclusion. There was also no difference in the activities of daily living and motor subsection scores of the UPDRS between the patients who chose to remain in the study and those who withdrew.

Twenty-seven patients (16 male and 11 female) completed postural control testing at 12 months post-PVP. Mean age was 60.4 ± 9.4 years with a mean disease duration of 14.7 ± 5.6 years and a mean Hoehn and Yahr score of 2.6 'on' and 4.1 'off' medications. Scores for the activities of daily living, motor and Postural Instability and Gait Disorder subsections of the UPDRS pre-PVP and post-PVP for these patients are presented in Table 1. The Postural Instability and Gait Disorder scores were calculated from the means of the following five items of the UPDRS: falling, freezing and walking difficulty by history, as well as gait and postural instability by examination (Jankovic *et al.*, 1990).

Surgical procedure

All patients were operated on under local anaesthesia. Operative techniques are described in detail elsewhere (Krauss and Grossman, 1998, 1999). After fixation of a Leksell G-frame to the patient's head stereotactic CT scans were obtained with a helical CT scanner (General Electric Medical Systems, Milwaukee, Wis., USA). Scans were transferred to a workstation to identify the anterior and posterior commissures. The tentative target in the posteroventral globus pallidus internus was located 2–3 mm anterior to the midcommissural point, 19–21 mm lateral and 4–5 mm below the intercommissural line. Frame coordinates were calculated, taking into account deviations of the intercommissural line in relation to the frame with the help of a misalignment correction algorithm (Krauss *et al*., 1998). Position of the preliminary target was checked and corrected on interactive axial, coronal and sagittal CT images. The final target was delineated by microelectrode recording, microstimulation and macrostimulation. In the majority of patients one or two microelectrode pathways were investigated. One or more lesions (mean of two lesions) were placed with a 1.1 mm unipolar electrode with a 3 mm uninsulated tip heated to 75°C for 60 s. The lowest lesion was within 1 mm of the ventral pallidal border. Location of the lesion was confirmed by postoperative MRI studies (Krauss *et al*., 1997). MRI studies were scheduled in the early postoperative period (within 1 and 3 days) and at the subsequent 6 months follow-up evaluation (Krauss and Grossman, 1999). The early-phase lesion involved the globus pallidus internus in all cases. The mean volume of the outer zone of the lesion was 262 ± 111 mm^3. The late-phase lesion was located in the globus pallidus internus except for one patient in whom it was confined to the globus pallidus externus. This patient was not available for the 12 months posturography follow-up. The mean volume of the late-phase lesion was 22 ± 28 mm^3. There were no volume differences between the patients as mentioned above.

Postoperative complications were seen in six of the original 38 patients. These adverse events were transient mild expressive aphasia due to small ischaemic infarction (one), aspiration pneumonia and respiratory distress (one), confusion and agitation (four), exacerbation of knee pain (one) and a greenish visual perception (two). All of the complications were completely resolved by the time of the patients' discharge. Two other patients had small asymptomatic infarctions (periventricular white matter and venous infarction in the frontal region) ipsilateral to the PVP. These events were discovered incidentally on the second day post-PVP by MRI scans.

Clinical assessment

Preoperative baseline evaluation was conducted 2–7 days prior to surgery. Follow-up evaluations were performed at 3, 6 and 12 months post-PVP. Patients were first tested during the practically defined 'off' phase (in the morning, at least 12 h after their last dose of levodopa). This was followed by testing in the 'on' phase which was defined as observance of a clinical effect consistent with the patient's optimum improvement typically occurring at 45–60 min after taking the levodopa dose.

Selected evaluation tests focused on functional and motor control components of Parkinson's disease related postural stability. Patients performed timed functional performance tests of a 25-foot walk (Podsiadlo and Richardson, 1991), five repeated chair sit-to-stand movements (Guralnik *et al.*, 1994), and five repeated step-ups onto a 7.5 inch ledge (Skelton *et al.*, 1995). If a patient complained of knee pain, he or she was exempted from the chair stands and step-ups. The gait section of the Performance-Oriented Assessment (POAG) was performed to determine changes in gait pattern. The Performance-Oriented Assessment is a screening tool that looks at both gait and balance components of mobility in the elderly (Tinetti, 1986). The POAG consists of seven items including hesitancy, step length, step symmetry and step height.

Patients performed functional balance tests with the balance section of the Performance-Oriented Assessment (POAB), the FR and timed turning in a 360° circle. The POAB consists of nine items that assess sitting balance, standing balance with a progressively narrowed base of support, external perturbations and turning in a 360° circle (Tinetti, 1986). It has significant correlations in both the 'on' and 'off' states (r = –0.550 and –0.832, respectively) with the Postural Instability and Gait Disorder Index of the UPDRS. FR evaluates the individual's ability to reach forward without stepping and has been correlated with risk of falling in the elderly (Duncan *et al.*, 1990, 1992). Significant negative correlations have been reported for the FR test with the Hoehn and Yahr scale as well as the motor and activities of daily living subscores of the UPDRS (Overby *et al.*, 1998). During performance of the FR test the patient stands behind a line and is asked to reach as far forward as possible while maintaining his or her balance. Distance of the forward reach is measured along a yardstick that is placed at the level of the subject's acromion and secured to a wall and is the distance from the start point to the end point of the reach. Intraclass correlation coefficients for test/re-test reliability of 0.84 and 0.80 have been reported for persons with Parkinson's disease for FR and timed turning in a 360° circle, respectively (Schenkman *et al.*, 1997). FR has also been found to be discriminatory between a normal elderly control group and a Parkinson's disease group (mean Hoehn and Yahr stage 3.0) as well as between fallers and non-fallers within a Parkinson's disease group (Smithson *et al.*, 1998)

Posturography (Smart Balance Master; Neurocom, Int.; Clackamas, Oreg., USA) was performed using the limits of stability test. The LOS test presents an ellipse of eight targets arrayed around a centre target on a computer screen with the targets placed at 75% of the theoretical LOS as determined by each individual's height. Patients were asked to shift their centre of gravity toward the cued target while keeping their feet in place on a force plate. Significant correlations have been reported with both the Hoehn and Yahr scale and the Postural Instability and Gait Disorder Index for LOS measures of average time to target, path deviation during target attempts, and the number of targets missed (Overby *et al.*, 1998).

Statistical analysis

Data for all of the variables were analysed separately for the 'on' and 'off' states. Variables were grouped according to the constructs of functional performance, functional balance and posturography (Overby *et al.*, 1998). Functional performance variables were chair stands, step-ups onto a ledge, a timed walk and the POAG. Functional balance variables were the FR, the POAB and turning in a 360° circle. Posturography variables, because of their precision and narrow focus, were considered a separate balance construct from the functional balance tests. Significance levels were determined for the LOS variables of average path length in percentage LOS, average time to reach a target in seconds, and the ratio of targets missed to the number of targets attempted as a construct since all of the patients were measured for these variables. A maximum time of 8 s was available for attainment of each LOS target. A subset of 22 patients was able to centre target independently 'off' medication for the posturography variables of movement velocity in degrees per second, end-point excursion in percentage LOS, and maximum end-point excursion in percentage LOS. These variables were, therefore, analysed separately from average path length, average time to target, and the ratio of targets missed measured 'off' medication.

If a person was unable to perform a timed task, such as the step-up, chair stand, timed walk and turning, he or she was omitted from the data analysis for time changes before and after PVP. A one factor (four levels of time—presurgery, and postsurgery at 3, 6 and 12 months) repeated measures analysis of variance with a multivariate approach was used for all of the tests except for the non-parametric POAB, POAG and targets missed ratio. These variables were analysed using the Friedman's two-way analysis of variance. Since each construct was designed to represent very different concepts, the 0.05 level of significance with a Bonferroni adjustment was carried out among the variables representing each construct in both 'on' and 'off' states.

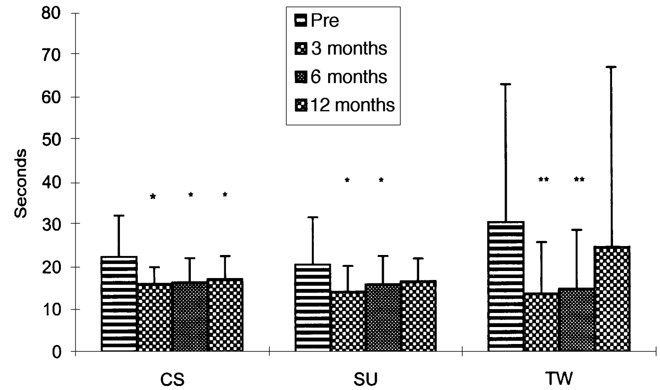

Fig. 1 Mean times and standard deviations for chair stands (CS), step-ups (SU) and timed walk (TW) in seconds when patients are 'off' parkinsonian medications at presurgical baseline and 3, 6 and 12 months post-PVP. $*P \leqslant 0.010$, $**P \leqslant 0.05$.

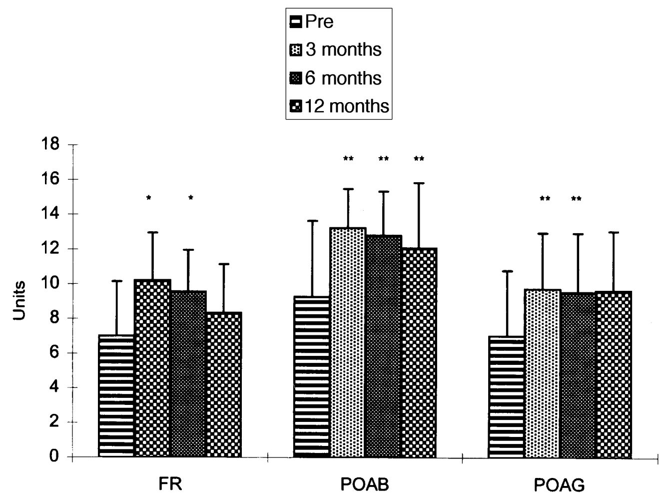

Fig. 2 Means for functional reach (FR) in inches and POAB and POAG in ordinal units (higher score is the better score) when patients are 'off' parkinsonian medications at presurgical baseline and 3, 6 and 12 months post-PVP. $*P \leqslant 0.001$, $** P \leqslant 0.025$.

Results

There was not a significant difference in the mean dosage of Sinemet for the group before and after surgery (545 mg pre-PVP, 583 mg at 3 months, 561 mg at 6 months, and 627 mg at 12 months post-PVP). Means and standard deviations for the functional performance and functional balance constructs during the 'off' state are presented in Figs 1 and 2.

Functional performance

During the 'off' medication state the variables of step-up, chair stand, timed walk, and the POAG improved post-PVP. The ability to step-up onto a ledge [$F(3,17) = 8.48$, $P = 0.001$] and to stand from a chair [$F(3,18) = 5.21$, $P = 0.009$] were performed 25% faster post-PVP. Stepping up onto a ledge was improved from the baseline presurgical assessment when compared with both the 3 month ($P = 0.001$) and the 6 month ($P = 0.007$) follow-up, but this improvement was not statistically significantly different from baseline at 12 months post-PVP ($P = 0.097$). Standing up from a chair was improved from the presurgical baseline when compared with all of the subsequent follow-up evaluations (3 month: $P = 0.001$, 6 month: $P = 0.001$, and 12 month: $P = 0.006$). Before surgery two patients were unable to perform either task and one patient was unable to step up onto a ledge, but all were able to do the tests throughout the post-PVP follow-up period. One patient who could perform both tasks at baseline was unable to do either task at the 12 month follow-up. Patients performed the 25-foot walk 42% faster [$F(3,21) = 3.872$, $P = 0.024$]. Improvement occurred at the 3 month ($P = 0.007$) and 6 month follow-up visits ($P = 0.016$) when compared with the presurgical baseline. The group mean time to complete the walk increased by the 12 month follow-up but was still faster than the presurgical baseline mean. One patient was unable to walk at baseline and was able to walk the 25 foot distance in an average of 15.5 s throughout the post-PVP follow-up. The POAG improved 45% after surgery [$\chi^2(3) = 22.68$, $P < 0.0005$]. All the follow-up evaluations had significantly better scores than the presurgical

Table 2 *Means for posturography 'on' and 'off' parkinsonian medications before and after unilateral PVP*

Variable	Pre-PVP	3 months	6 months	12 months
'Off'				
APL	199.4 ± 40	185.4 ± 44	175.9 ± 38*	180.4 ± 50
ATM	6.6 ± 1.3	5.7 ± 1.4***	5.7 ± 1.5***	5.9 ± 1.4***
TM	0.49 ± 0.34	0.28 ± 0.33**	0.27 ± 0.31**	0.30 ± 0.34**
EPE	437.8 ± 92	487.8 ± 75*	492.4 ± 75***	474.7 ± 86*
MXE	524.2 ± 97	569.3 ± 65**	563.8 ± 66**	545 ± 82
MV	12.7 ± 4.9	15 ± 5.4*	15.4 ± 5.8*	13.9 ± 5.3
'On'				
APL	335 ± 255	198 ± 33**	188 ± 42**	223.2 ± 84*
ATM	5.87 ± 1.4	5.1 ± 1.4**	5 ± 0.4**	5.2 ± 1.4**
TM	0.35 ± 0.33	0.19 ± 0.25**	0.16 ± 0.21**	0.20 ± 0.27**

APL = average path length in percentage LOS; ATM = average time in seconds; TM = percentage targets missed; EPE = end-point excursion in percentage LOS; MXE = maximum end-point excursion in percentage LOS; MV = movement velocity in degrees/second.
*$P < 0.05$, **$P < 0.015$, ***$P < 0.0005$.

baseline ($P = 0.025$). There was no significant difference 'on' medication for the tasks of chair stand, step-up, timed walk or the POAG.

Functional balance

'Off' medication FR and the POAB showed significant improvement post-PVP. Patients reached 33% further in the FR test [$F(3,22) = 13.16$, $P < 0.0005$)]. This increase in reach distance occurred by 3 months post-PVP ($P < 0.0005$) and was sustained until 6 months post-PVP ($P = 0.001$) but not by the 12 month follow-up evaluation. POAB was 37% improved post-PVP [$\chi^2(3) = 19.78$, $P = 0.0002$] with a significant improvement from baseline when compared with all of the post-PVP test sessions ($P = 0.0167$). Turning both directions in a 360° circle did not demonstrate a significant change post-PVP, even though the mean time to turn in either direction was 52% faster at 12 months post-PVP when compared with baseline. Four patients were unable to turn in either direction before surgery and were able to turn post-PVP. One patient was unable to turn left at baseline and was able to turn left post-PVP; however, at the 12 month follow-up he was unable to turn left again. Another patient was able to turn in either direction before surgery, but at the 12 month follow-up was unable to turn. There was no significant change for the FR, the POAB or turning during the 'on' state.

Posturography

Means and standard deviations for the posturography variables are shown in Table 2. Average path length and average time to target were improved post-PVP both during the 'on' [$F(6,18) = 4.013$, $P = 0.010$] and 'off' [$F(6,19) = 7.26$, $P < 0.0005$] states. Path length deviation as indicated by the average path length when 'off' medication decreased 9% from the presurgical baseline to the 6 month follow-up ($P = 0.001$) and also showed improvement from 3–6 months ($P = 0.010$). Figure 3 shows the difference in LOS tracings for two patients at baseline and 12 months post-PVP during the 'off' state. The average time to reach a target was 13% faster than the presurgical baseline for all of the postsurgical follow-up sessions ($P < 0.0005$) when 'off' medication. There was a 43% improvement during the 'off' state in the number of targets missed [$\chi^2(3) = 26.87$, $P < 0.0005$] between the presurgical baseline and all of the follow-up time periods including 12 months ($P = 0.0125$ for all follow-up sessions).

During the 'on' state average path length showed an average 39% improvement when the presurgical baseline was compared with all follow-up sessions (3 months, $P = 0.014$; 6 months, $P = 0.006$; 12 months, $P = 0.041$). Figure 4 shows the difference in LOS tracings for two patients at baseline and 12 months post-PVP during 'on' time. The average time to target improved by an average of 13% from the presurgical baseline for all of the postsurgical follow-up sessions (3 months, $P = 0.001$; 6 months, $P = 0.002$; 12 months, $P = 0.012$). The missed targets ratio improved 47% after surgery [$\chi^2(3) = 11.51$, $P = 0.0093$] with improvement throughout all of the postsurgical evaluations with the greatest improvement found between baseline and 6 months ($P = 0.0125$) post-PVP.

There was a significant change in movement velocity, initial end-point excursion, and the maximum end-point excursion toward the LOS targets after surgery during the 'off' state [$F(9,13) = 5.49$, $P = 0.003$]. Movement velocity towards a target improved by an average of 18% during the first 3 months ($P = 0.020$) and 6 months post-PVP ($P = 0.018$) with a decrease in the movement velocity observed by the 12 month follow-up evaluation ($P = 0.108$). Initial end-point excursion distance improved 11% from the presurgical baseline for the 3 month ($P = 0.002$), 6 month ($P < 0.0005$) and 12 month ($P = 0.029$) follow-up sessions. Maximum end-point excursion improved by an average of 7% during the first 3 months post-PVP ($P = 0.012$) with maintenance

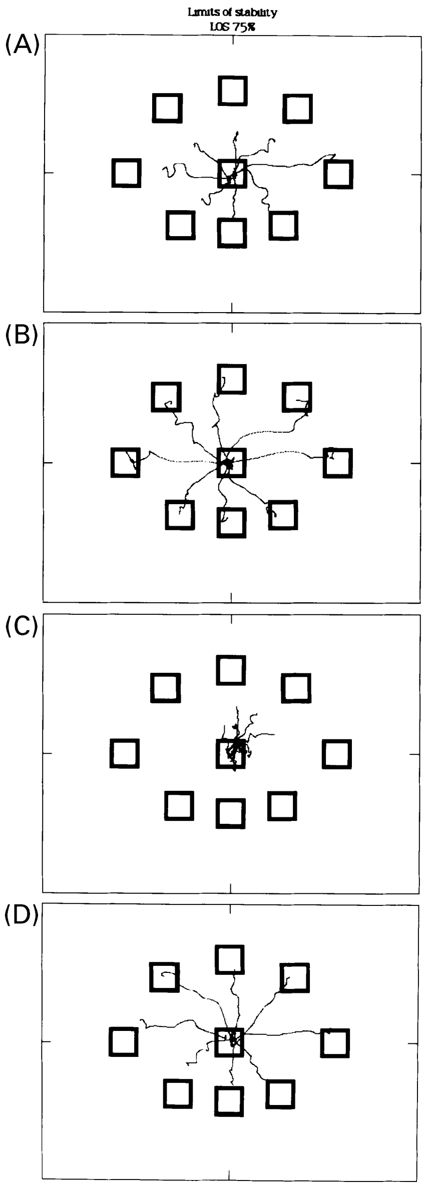

Fig. 3 LOS path tracings of two patients' performances during the 'off' state. The lines indicate the path trajectory of the individuals' attempts to shift their weight towards the cued target. Baseline tracings are represented by **A** and **C** for Patients 1 and 2, respectively. Twelve month follow-up tracings are represented by **B** and **D** for Patients 1 and 2, respectively. The range of excursion is very restricted pre-PVP with the pattern of path trajectory for Patient 2, indicating a disturbance of the motor programme in addition to postural hypometria. Maintenance of increased range is evident at the 12 month follow-up. The path trajectory for Patient 2 also reflects improvement in the motor programme.

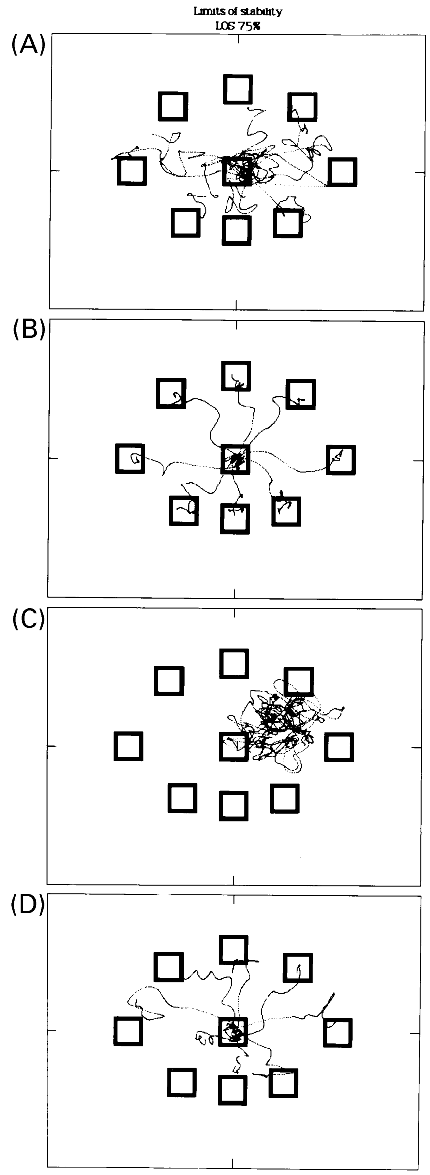

Fig. 4 LOS path tracings of two patients' performances during the 'on' state. The lines indicate the path trajectory of the individuals' attempt to shift their weight towards the cued target. Baseline tracings are represented by **A** and **C** for Patients 1 and 2, respectively. Twelve month follow-up tracings are represented by **B** and **D** for Patients 1 and 2, respectively. Range of excursion is increased in the 'on' state but is not controlled and restrictions in some directions are still evident pre-PVP. Maintenance of excursion towards all directions with more control is seen at the 12 month follow-up.

of the maximum distance at the 6 month follow-up (P = 0.011), but improvement from baseline was not maintained by 12 months post-PVP (P = 0.248).

Discussion

This study assessed the impact of PVP on balance and functional movements associated with postural control in persons with Parkinson's disease. This aspect of Parkinson's disease has not been specifically addressed by previous studies, and the results of this study should be interpreted cautiously since it was an open trial and there was not a control group for comparison. Nevertheless, the study showed that during the 'off' state, the patients' balance and functional performance improved soon after surgery and this improvement was sustained for at least 6 months. This time frame of improvement is consistent with other studies that reported improvements in the 'off' state for basic parkinsonian signs, activities of daily living, gait and postural stability (Laitinen *et al*., 1991; Vitek *et al*., 1994; Dogali *et al*., 1995; Baron *et al.*, 1996; Fazzini *et al*., 1997; Kishore *et al*., 1997; Melnick *et al*., 1999; Fine *et al*., 2000). Sustained improvement at the 12 month follow-up evaluation was observed in postural control variables from each construct category. Standing from a chair and the POAG (functional performance), POAB (functional balance), and average time to target, the ratio of targets missed, and the initial end-point excursion toward a target (posturography) retained significant improvement. At the 12 month follow-up a decline in performance was observed across construct categories for stepping up onto a ledge and timed walk (functional performance), FR (functional balance), and average path length, movement velocity and maximum end-point excursion toward a target (posturography). This decrement essentially eliminated the significance of the improvement that was noted earlier for these variables, although the 12 months mean scores remained above baseline. Thus, post-PVP improvement in postural control was sustained for some variables and declined for others. Variables that demonstrated decline, however, still showed improvement as compared with baseline and the deterioration of postural control seemed to be arrested for a period of time. Maintenance of performance at or above baseline after PVP is consistent with the findings of other studies (Dogali *et al*., 1995; Fine *et al*., 2000). Dogali and colleagues reported deterioration of performance on the UPDRS at 12 months after baseline assessment in a small non-surgical group of Parkinson's disease patients who were compared with a group of Parkinson's disease patients who underwent pallidotomy. The patients who had PVP maintained their UPDRS scores above the presurgical baseline (Dogali *et al*., 1995).

Variability in the retention of benefits from PVP in this study could explain why other studies differ in the long-term outcome related to postural stability and gait. Some studies have reported waning of improvements associated with postural instability and gait within 3–6 months or by 12–52 months post-PVP (Baron *et al*., 1996; Lang *et al*., 1997; Fine *et al*., 2000), while other studies have reported maintenance of improvement for aspects of these parameters at 12 months (Dogali *et al*., 1995; Vitek *et al.*, 1997). The best scores in this study for the timed functional, balance and gait measures were at the 3 month follow-up evaluation, while the best scores for the posturography LOS variables were at the 6 month follow-up evaluation. This difference in achievement of the best performance between functional measures and posturographic standing balance variables could indicate that, even though maximum functional improvement had been reached by 3 months post-PVP, there was still continuing improvement for motor adaptations of balance mechanisms.

Functional performance for getting out of a chair and stepping onto a ledge improved after PVP, but the same profile was not maintained at 12 months. Improvement was maintained in standing from a chair until the 12 month follow-up but not with stepping onto a ledge. Both tasks require lower extremity strength, but since stepping onto a ledge was performed in the upright position, different postural and strength demands on task performance could have affected the outcome at 12 months. Additionally, getting up and down from a chair is a continually reinforced daily activity while going up a step or curb can be avoided. This daily access to a familiar motor programme could have contributed to the retention of its benefit at 12 months post-PVP. Without easy access to a motor programme time delay will occur due to choosing the multiple degrees of freedom (joints, muscles, synergies, etc.) necessary to complete a task. POAG scores maintained improvement in overall gait characteristics indicating that improvements in gait pattern were retained; however, the timed walk did not sustain significant benefit by the end of 12 months. Re-emergence of akinesia, freezing or bradykinesia in some of the patients could have had an impact on the time needed to complete the 25-foot walk. This study did not specifically measure hypokinetic aspects of gait, but other investigators have found that improvement in patient-rated freezing was not sustained beyond 12 months post-PVP (Baron *et al.*, 1996; Lang *et al*., 1997; Fine *et al*., 2000).

The functional balance category demonstrated a similar pattern with the POAB retaining significant improvement, while the FR did not retain its improvement at a significant level by 12 months post-PVP. Maintenance of the improvement gained with the POAB indicated that several aspects of balance sustained their benefit since the test is a composite of nine items dealing with sitting, standing and turning balance. FR is considered a pure balance measure, particularly useful in evaluating the forward LOS without sophisticated equipment (Overby *et al*., 1998). Reversion to a flexed standing posture or increased body stiffness could have contributed to the decreased reach by 12 months post-PVP. However, previous studies have reported that UPDRS measures of rigidity remain improved at 12 months up to 52 months post-PVP (Laitinen *et al*., 1991; Iacono and Lonser, 1994; Dogali *et al*., 1995; Baron *et al*., 1996; Vitek *et al*., 1997; Fine *et al*., 2000). Lack of significant improvement for turning in a 360° circle could be related to the widespread variability in the subjects' timed performances as well as reduced power due to the exclusion of individuals who were unable to perform the task presurgically.

In the majority of the posturography LOS variables peak performance was demonstrated at the 6 month follow-up except for the maximum end-point excursion distance which peaked by 3 months. These variables are meant to reflect changes in motor control and timing components of balance post-PVP. A training effect might have contributed to the 6 months peak scores, but it is an unlikely explanation since it was a novel balance task tested every 3 months. Patients could shift further towards the targets with both initial and maximum excursion with less deviation as well as moving faster towards the targets. At 12 months, the initial excursion range towards a target was maintained, but the patient's speed had slowed and the maximum distance they could shift towards the targets had declined. However, they were still able to reach more targets than at baseline. Since movement velocity is calculated for the initial end-point excursion distance the decrement in the maximum excursion distance towards a target attained at 12 months was probably related to the individual moving more slowly to the initial end-point excursion distance, leaving less time available to go further towards the target. This observed increase in the initial end-point excursion postural range of motion could be attributed to improved postural force production, improved organization of the motor plan or a change in the motor strategy used to attain the target. Persons with Parkinson's disease have impairment of postural torque (Horak *et al*., 1996), but force production has not been systematically studied after PVP. Difficulty with postural motor response adaptability (Beckley *et al*., 1990; Horak *et al*., 1992) and with organization of the motor plan for postural range of motion tasks (Schieppati *et al*., 1994) have also been reported. Melnick and colleagues observed that after pallidotomy some patients regained the ability to appropriately adapt balance strategy (ankle or hip strategy) for the Sensory Organization Test (Melnick *et al.*, 1999). Although further research is needed, the findings from our study and the other studies suggest that compensatory balance and postural mechanisms are improved following PVP.

Levodopa improves several aspects of balance performance in persons with Parkinson's disease, but it does not usually improve motor control for tasks such as the LOS, particularly when dyskinesias are present (Roberts-Warrior *et al*., 1996). The decrease in the average path length deviation during the 'on' phase could be explained by a decrease in dyskinesias after unilateral PVP with improvement in control of path trajectory. Since the 'on' phase was defined by the observation of a clinical effect this improved trajectory control towards a target could be explained by variation in the onset of clinical effect. However, the time of testing relation to the onset of clinical effect was consistent indicating that a decrease in dyskinesias was a probable contributing factor to retention of this improvement. Sustained improvement in dyskinesia reduction is consistent with other studies (Dogali *et al*., 1995; Kishore *et al*., 1997; Lang *et al*., 1997; Fine *et al*., 2000).

Increased brain activity in the supplementary motor area and the premotor cortex has been observed by PET scan after PVP (Grafton *et al*., 1995; Eidelberg *et al*., 1996). Since a gait-induced increase in activity has been seen in the supplementary motor area and premotor areas of normal control subjects (Hanakawa *et al*., 1999), the improvements seen in gait pattern and speed may be related to this post-PVP increased activation in the supplementary motor area and the premotor cortex. Interruption of inhibitory pallidal projections may also have downstream effects on the pedunculopontine nucleus (Iacono *et al*., 1994; Shima *et al*., 1996), which has been thought to represent the mesencephalic locomotor centre (Masdeu *et al*., 1994). Partial restoration of activity in the pedunculopontine nucleus may be a factor in the improved gait seen post-PVP. Our study shows that postural stability improves after PVP in both the 'on' and 'off' states of medication. Improvement during the 'on' phase may be due to a reduction in dyskinesias while the improvement in the 'off' state can be due to various factors, such as decreased bradykinesia, improvement in basic balance mechanisms or motor programs or an improvement in force production. The shorter duration of sustained benefit in postural control as compared to other cardinal signs and dyskinesias could indicate that pathways other than dopaminergic pathways may contribute to postural stability mechanisms associated with Parkinson's disease.

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