Comparing the effects of hydrotherapy and land-based therapy on balance in patients with Parkinson's disease: a randomized controlled pilot study

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Comparing the effects of hydrotherapy and land-based therapy on balance in patients with Parkinson's disease: a randomized controlled pilot study

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Abstract

Objective: Our aim was to evaluate the feasibility of a hydrotherapy treatment in patients with Parkinson's disease and the effectiveness of this treatment on balance parameters in comparison to a traditional land-based physical therapy.

Design: A randomized single-blind controlled trial.

Setting: Outpatients.

Subjects: Thirty-four patients with Parkinson's disease in Hoehn-Yahr stage 2.5–3.

Intervention: Group 1 hydrotherapy treatment, group 2 land-based rehabilitation treatment. The two groups underwent the same rehabilitation period (60 minutes of treatment, five days a week for two months).

Main measures: The primary outcome measures were the centre of the pressure sway area recorded with open and closed eyes, using a stabilometric platform. Secondary outcome measures were Unified Parkinson's Disease Rating Scale II and III, Timed Up and Go Test, Berg Balance Scale, Activities-specific Balance Confidence Scale, Falls Efficacy Scale, Falls diary and Parkinson's Disease Questionnaire-39.

Results: Hydrotherapy treatment proved to be feasible and safe. Patients in both groups had a significant improvement in all outcome variables. There was a better improvement in patients who underwent hydrotherapy than in patients treated with land-based therapy in the centre of pressure sway area closed eyes (mean SD change: 45.4 SD64.9 vs. 6.9 SD45.3, $p = 0.05$), Berg Balance Scale (51.2 SD3.1 vs. 6.0 SD3.1, $p = 0.005$), Activities-specific Balance Confidence Scale (16.8 SD10.6 vs. 4.1 SD5.4, $p = 0.0001$), Falls Efficacy Scale (−5.9 SD4.8 vs. −1.9 SD1.4, $p = 0.003$), Parkinson's Disease Quetionnaire-39 (−18.4 SD12.9 vs. −8.0 SD7.0, $p = 0.006$) and falls diary (−2.4 SD2.2 vs. −0.4 SD0.5, $p = 0.001$).

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Conclusion: Our study suggests that hydrotherapy may constitute a possible treatment for balance dysfunction in Parkinsonian patients with moderate stage of disease.

Keywords
Balance, hydrotherapy, Parkinson's disease

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Introduction

People with Parkinson's disease have reduced balance ability and are prone to falling. Even though pharmacological treatment has changed the natural course of the disease, drugs do not reverse balance dysfunction and this symptom worsens over time and leads to falls.[1,2]

At present, there is no treatment that is known to be very effective for postural instability in Parkinson's disease. Hydrotherapy in Parkinson's disease might be effective, but this has not been demonstrated yet. Only one study, reporting the effects of training using hydrotherapy on balance in Parkinson's disease patients has been published.[3]

Aquatic exercises have been widely used in physical therapy programmes for different diseases.[4,5] Water buoyancy reduces gravity and an aquatic environment can be considered a microgravity environment. Many authors have documented modifications of static and dynamic postural control in prolonged microgravity.[6,7] In particular, modifications of the control of body positions, owing to dysfunctions of vestibular information occurring under water, underline the main role of the proprioceptive system for postural control in this environment.[8] Aquatic environment permits balance training in safe conditions, avoiding falls and reducing the fear of falling.

The aim of this pilot study was to evaluate the feasibility of a hydrotherapy treatment in Parkinson's disease patients with moderate stage of disease and to compare the effectiveness of this treatment on balance parameters with traditional land-based physical therapy.

Methods

Enrollment criteria in this single blind study were: (i) diagnosis of 'clinically probable' idiopathic Parkinson's disease according to Gelb et al.,[9] (ii) Hoehn-Yahr stage 2.5 and 3, (iii) ability to walk without any assistance, (iv) at least two falls in the last year, (v) Mini-Mental State Examination score ≥25, (vi) no relevant comorbidity or vestibular/visual dysfunctions, limiting locomotion or balance, (vii) stable dopaminergic therapy in the last four weeks. Exclusion criteria were: history of deep brain stimulation surgery and other conditions limiting hydrotherapy (for example cardio pulmonary disease).

Patients were screened by a neurologist specialized in movement disorders, and eligible patients were admitted to the Rehabilitation Institute for treatment. The study was approved by the local Scientific Committee and Institutional Review Board ('Moriggia-Pelascini' Hospital).Written informed consent was obtained from all patients before participation.

Patients were randomized into two groups: the treatment group (Group 1), which underwent hydrotherapy; and the control group (Group 2), which underwent land-based standard rehabilitation.

For the allocation of the participants, a computer-generated list of binary random numbers was used. The sequence was concealed and the following number (0: Group 1; 1: Group 2) was disclosed by a person not involved in the enrolment process, every time a new patient was added.

The primary outcome measure was the posturographic evaluation. The posturography exam was assessed according to the current guidelines. Out of all the parameters provided by posturography, we considered the centre of pressure (COP) sway area (mm2) in the antero-posterior and medio-lateral directions. The patient was asked to bend forward, while maintaining the feet planted in a standing position with both open eyes and closed eyes

conditions, as an instrumental version of the functional reach test (FRT).

As secondary outcome measures, we used the Unified Parkinson's Disease Rating Scale II and III,[10] Timed Up and Go Test,[11] Berg Balance Scale,[12] Activities-specific Balance Confidence Scale,[13] Falls Efficacy Scale[14] and the falls diary. We also quantified health-related quality of life in all participants using the Parkinson's Disease Quetionnaire-39 (PDQ-39)[15].

We assessed outcomes at two time points: one week before and one week after rehabilitation treatment. Falls occurred two months before the trial and the ones that occurred during the two months of rehabilitative treatment were recorded either by a caregiver in the falls diary or by telephone interview. The acquisition of posturographic data and the evaluation of the different scales were performed one hour after the first dose of Levodopa, by a neurologist specialized in movement disorders, who was unaware of the study design.

Intervention

All patients received 60 minutes of treatment, five days a week for two months. Patients in Group 1 underwent hydrotherapy treatment. The session comprised a cardiovascular warm up and stretching exercises for 10 minutes, followed by 40-minute perturbation-based balance training and a 10-minute cool down. Patients in Group 2 underwent land-based traditional treatment with cardiovascular warm up and stretching exercises for 10 minutes, followed by 40 minutes with the same programmes of exercises for balance, focused on perturbation-based training and 10 minutes of cool down. The physiotherapy programme for balance training was in accordance with the The Royal Dutch Society for Physical Therapy (KNGF) guidelines for physical therapy in Parkinson's disease.[16]

In particular, in order to optimize balance during the performance of activities in static and dynamic conditions, we focused on exercises for training strength and perturbation-based balance training, with emphasis on functional reaching tests in protected conditions, and teaching patients how to activate postural responses to external perturbation.

Statistical analysis

Since we are not aware of studies estimating the standard error of measurement (SEM) for dynamic stabilometric platform data, we could not compute a sample size according to our primary outcome.

Published studies report a SEM equal to 1.8 for the Berg Balance Scale.[11] We expected an effect size around three for this variable. Hence, to detect a change with a two-tailed type I error of 0.05 and a power of 80%, the estimated sample size was 13 patients per group. Taking into account the possibility of a 30% rate of drop-out, we set our sample size to 17 + 17 patients.

The effect of the rehabilitation strategy on each considered outcome variable was assessed by a two factor analysis of variance (ANOVA): the first factor was treatment (hydrotherapy rehabilitation protocol vs. traditional physiotherapy) and the second factor was time (end of treatment vs. baseline), with repeated measures in the time factor. If a significant interaction effect for time and treatment was observed, a within-group comparison between end of rehabilitation and baseline was carried out for both groups by paired *t*-test or by Wilcoxon's matched pairs test in case of violation of the normality assumption. Between-group comparisons were carried out by unpaired *t*-test or by Mann–Whitney *U*-test, if appropriate. Descriptive statistics are given as mean SD. A p value <0.05 was considered statistically significant.

All analyses were carried out using the SAS/STAT statistical package, release 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

A total of 34 eligible patients, admitted to our movement disorder centre from January to June 2013, agreed to participate in the study. Seventeen patients were assigned to the group who underwent hydrotherapy (Group 1), and 17 were assigned to the control group (Group 2), which underwent land-based standard rehabilitation (Figure 1).

Hydrotherapy treatment proved to be feasible and safe. There were no drop-outs and compliance was good and comparable in both groups. Demographic

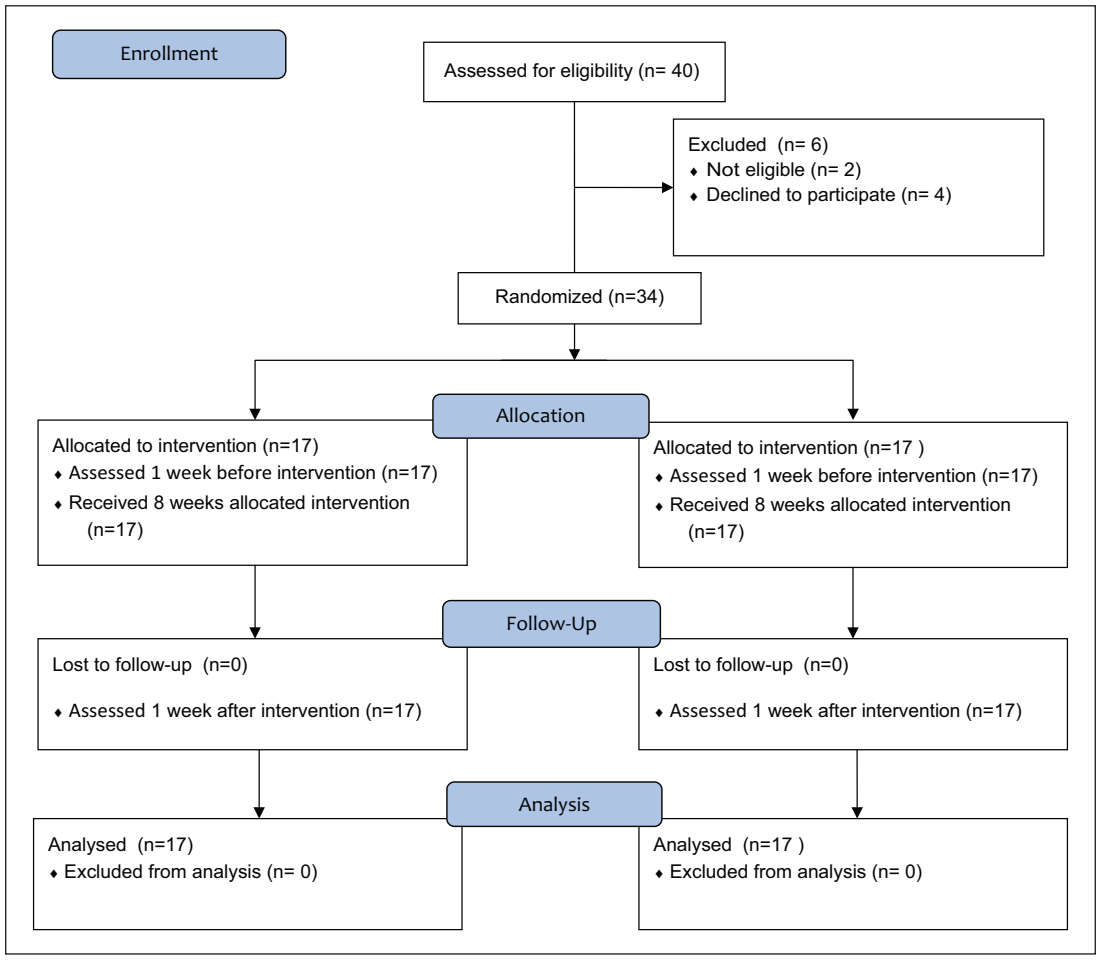

Figure 1. Flow diagram of the progress through the phases of the study. Follow-up.

and clinical characteristics of all patients are reported in Table 1.

No statistically significant differences were observed between the two groups in any variable at baseline ($p = 0.796$, $p = 0.493$, $p = 0.107$, $p = 0.216$, $p = 0.544$, $p = 0.957$, $p = 0.781$ for Unified Parkinson's Disease Rating Scale-II, Unified Parkinson's Disease Rating Scale-III, COP Sway Closed Eyes, Berg Balance Scale, Activities-specific Balance Confidence Scale, Falls Efficacy Scale, Time Up and Go Test, respectively), with the exception of a significant borderline difference for COP Sway Open Eyes ($p = 0.046$).

Results from repeated measurements ANOVA for all variables are summarized in Table 2.

The main finding of this study was the different time course for COP sway closed eyes, Parkinson Disease Questionnaire-39, Berg Balance Scale, Activities-specific Balance Confidence Scale, Falls and Falls Efficacy Scale in patients who underwent hydrotherapy with respect to patients who underwent traditional physiotherapy, as demonstrated by a significant time × treatment interaction in the repeated measurements ANOVA.

Posthoc analysis showed that these variables improved significantly in both groups of patients by the end of the rehabilitation protocol ($p < 0.002$ all), but the improvement was better in the hydrotherapy group than in patients who underwent physiotherapy. Between-group comparison of the

Table 1. Demographic, clinical and functional characteristics of the patients, at relevant observation times: Baseline (one week before intervention) and one week after rehabilitation treatment. Change: difference (after treatment – baseline).

	Group 1 (hydrotherapy)			Group 2 (land-based rehabilitation)		
	Baseline	After treatment	Change	Baseline	After treatment	Change
Age (years)	68 ± 7			66 ± 8		
Hoehn-Yahr	2.82 ± 0.3			2.65 ± 0.49		
Disease duration (years)	7.5 ± 5.1			7.6 ± 4.63		
L-dopa-equivalent (mg/die)	645.4 ± 206			625.2 ± 244.3		
COPSwayOE (mm2)	74.9 ± 55.2	124.6 ± 58.9	49.7 ± 67.1	117.0 ± 61.6	142.5 ± 106.4	25.4 ± 63.8
COPSwayCE (mm2)	45.6 ± 42.1	91.0 ± 56.9	45.4 ± 64.9	77.4 ± 67.1	84.3 ± 91.2	6.9 ± 45.3
UPDRS_II	20.2 ± 7.5	15.9 ± 6.3	−4.3 ± 3.4	19.6 ± 6.9	14.5 ± 6.4	−5.1 ± 2.6
UPDRS_III	41.9 ± 7.4	33.6 ± 8.0	−8.3 ± 4.4	39.2 ± 14.3	30.8 ± 13.8	−8.4 ± 4.3
BBS	41.3 ± 5.9	51.2 ± 3.1	9.9 ± 4.4	43.9 ± 6.1	49.9 ± 4.8	6.0 ± 3.1
TUG (s)	13.1 ± 3.8	11.0 ± 2.0	−2.0 ± 2.3	12.8 ± 3.0	11.6 ± 2.9	−1.1 ± 1.1
ABC	53.4 ± 15.8	70.2 ± 15.1	16.8 ± 10.6	56.4 ± 13.4	60.6 ± 13.9	4.1 ± 5.4
Falls	3.0 ± 2.4	0.6 ± 1.1	−2.4 ± 2.2	2.1 ± 2.4	1.6 ± 2.1	−0.4 ± 0.5
FES	11.9 ± 6.5	6.0 ± 4.2	−5.9 ± 4.8	11.8 ± 6.2	9.8 ± 5.6	−1.9 ± 1.4
PDQ39	60.3 ± 19.9	41.9 ± 20.9	−18.4 ± 12.9	64.4 ± 28.6	56.4 ± 26.8	−8.0 ± 7.0

ABC: Activities-specific Balance Confidence Scale; BBS: Berg Balance Scale; COPSwayCE: Sway area (mm2) with closed eyes at instrumental FRT; COPSwayOE: Sway area (mm2) with open eyes at instrumental FRT; Falls: number of falls from diary; FES: Falls Efficacy Scale; FRT: functional reach test; PDQ39: Parkinson's disease questionnaire-39; TUG: Timed Up and Go test; UPDRS II: Unified Parkinson's Disease Rating Scale section regarding activities of daily living; UPDRS III: Unified Parkinson's Disease Rating Scale section regarding motor performance.

Table 2. Summary of results from the repeated measurements ANOVA for all variables.

Variable	Treatment effect	Time effect	Interaction (time × treatment)
COPSwayOE (mm2)	0.1936	0.0021	0.2871
COPSwayCE (mm2)	0.5505	0.0105	0.0480
UPDRS_II	0.6458	<0.0001	0.4336
UPDRS_III	0.4742	<0.0001	0.9381
BBS	0.7076	<0.0001	0.0046
TUG (s)	0.8906	<0.0001	0.1511
ABC	0.4973	<0.0001	0.0001
Falls	0.9291	<0.0001	0.0010
FES	0.3255	<0.0001	0.0026
PDQ39	0.2612	<0.0001	0.0063

ABC: Activities-specific Balance Confidence Scale; BBS: Berg Balance Scale; COPSwayCE: Sway area (mm2) with closed eyes at instrumental FRT; COPSwayOE: Sway area (mm2) with open eyes at instrumental FRT; Falls: number of falls from diary; FES: Falls Efficacy Scale; FRT: functional reach test; PDQ39: Parkinson's disease questionnaire-39; TUG: Timed Up and Go test; UPDRS II: Unified Parkinson's Disease Rating Scale section regarding activities of daily living; UPDRS III: Unified Parkinson's Disease Rating Scale section regarding motor performance.

changes in the outcome variables after the treatment showed that these changes were significantly higher in the hydrotherapy group than in patients who underwent land-based physiotherapy for COP sway closed eyes (45.4 SD64.9 vs. 6.9 SD45.3, $p = 0.05$), Berg Balance Scale (9.9 SD4.4 vs. 6.0 SD3.1, $p = 0.005$), Activities-specific Balance Confidence Scale (16.8 SD10.6 vs. 4.1 SD5.4, $p = 0.0001$), Falls Efficacy Scale (−5.9 SD4.8 vs. −1.9 SD1.4, $p = 0.003$), Parkinson Disease Questionnaire-39 (−18.4 SD12.9 vs. −8.0 SD7.0, $p = 0.006$) and Falls (−2.4 SD2.2 vs. −0.4 SD0.5, $p = 0.001$).

A non-significant time × treatment interaction was observed for COP sway open eyes, Unified Parkinson's Disease Rating Scale-II, Unified Parkinson's Disease Rating Scale-III and Timed Up and Go Test, indicating no evidence of a different time course in the two groups of patients.[17] The highly significant time effect ($p = 0.0021$ for COP sway open eyes, $p < 0.0001$ for the other variables) indicates that both groups of patients had an improvement after the training programme, but between-group comparison of the changes revealed that these changes were not significantly different (49.7 SD67.1 vs. 25.4 SD63.8, $p = 0.29$, −4.3 SD3.4 vs. −5.1 SD2.6, $p = 0.44$, −8.3 SD4.4 vs. −8.4 SD4.3, $p = 0.94$ and −2.0 SD2.3 vs. −1.1 SD1.1, $p = 0.15$).[18]

All falls were not injurious and no medical attention was sought. None of the participants were admitted to hospital during their rehabilitation programme.[19,20]

Discussion

The results showed that this hydrotherapy treatment was feasible and it was more effective on balance than standard land-based rehabilitation therapy. In particular patients in the experimental group showed better results in COP sway closed eyes at the instrumental Functional Reaching Test, in balance scales (Berg Balance Scale, Activities-specific Balance Confidence Scale), in falls outcome (fall diary, Falls Efficacy Scale) and in Parkinson's Disease Questionnaire-39 scale in comparison with land-based treatment. Only the Timed Up and Go Test did not show a significant improvement because the obtained results did not reach, in both groups, the range of freely mobile (< 10 seconds).

We know only two recent studies about the treatment of patients with Parkinson's disease in the aquatic environment. The first one is a pilot study with only six patients in the experimental aquatic group. In this article, the authors showed a better improvement in the aquatic group for Unified Parkinson's Disease Rating Scale and Berg Balance Scale at the end of a four-week treatment in comparison with a land-based rehabilitation group.[3] On the contrary, the second study did not show any evidence of the beneficial effect of hydrotherapy on gait parameters in patients with a moderate stage of disease in comparison with a control group that underwent only land-based therapy.[17] In this second study the efficacy on balance was not evaluated.

The finding of this pilot study confirms a significant effect of hydrotherapy, not only on balance, but also on falls and quality of life.

With regard to the posturographic evaluation, there is lack of conclusive data linking static posturography with balance performance and falls in patients with Parkinson's disease.[18] In fact, studies have shown either reduced, normal or increased spontaneous body sway, suggesting that reliability of postural sway during static conditions could be influenced by many factors.[19,20] On the contrary, patients with Parkinson's disease seem to have a reduced limit of stability, particularly during dynamic conditions, and have a trend to exceed their limits of stability to a much greater extent.[21–23] The finding that patients with Parkinson's disease showed an increased limit of stability at instrumental Functional Reaching Test (after hydrotherapy also with closed eyes, which is a setting relying on the integrity of the proprioceptive system) seems to be an interesting result, if we consider the reduction of the falls rate and Activities-specific Balance Confidence Scale score, underling the relevant role that hydrotherapy could play on a proprioceptive system for postural control under water.[8] It is even more interesting if we consider that healthy subjects mainly rely on somatosensory information in

order to maintain an upright posture[24] and that impaired proprioception worsens postural stability and particularly reduces the COP displacements in response to external perturbations during visual deprivation.[25]

The reduction of falls rate in the hydrotherapy group could depend on hydrotherapy as a proprioceptive training that contributes to increase the limit of stability, giving the time to activate postural reactions to perturbations in protected conditions.

The different physical properties of water (density, specific gravity, hydrostatic pressure, buoyancy, viscosity and thermodynamics) can play an important role in improving balance control in patients with Parkinson's disease, permitting balance training in safe conditions, reducing the fear of falling and avoiding falls. Moreover, execution of exercises in a different gravity environment can lead patients to transform an automatic movement in a voluntary movement improving learning. Automatic movement is dysfunctional in patients with Parkinson's disease and we need to use the volitional phase of motor learning if we want them to re-learn dysfunctional movements.

Of note, hydrotherapy is a rehabilitation strategy that includes the most important aspects of a modern rehabilitation programme: it is aerobic, intensive (40 hours of treatment are planned in our programme) and goal-based.[26,27]

Even though the sample size was dimensioned a-priori, the relatively small number of patients enrolled is a limitation of this study, which should be considered an exploratory one. Another limitation of the present work is that only the acute effect of the hydrotherapic rehabilitation protocol was considered. It remains unexplored whether the treatment has prolonged clinical efficacy.

In conclusion, this study indicates that hydrotherapy may be a possible treatment for balance dysfunction in Parkinsonian patients with a moderate stage of disease, with the potential to improve postural stability, reducing falls rate in protected conditions. Further studies with a follow-up period are necessary in order to evaluate whether the balance improvement persists over time and which protocol of water exercises is more effective for balance training in Parkinson's disease.

Clinical message

- In patients with Parkinson's Disease, exercising in a hydrotherapy pool was associated with better balance and possibly less falls than exercising for the same time on land using Dutch national guidelines to guide exercise.

Contributors

Daniele Volpe was responsible for study design, data acquisition and analysis, article concept and design, drafting manuscript and revision. Maria Giulia Giantin was responsible for study design, data acquisition, article concept and design. Roberto Maestri was responsible for study design, data analysis, article concept and design, drafting manuscript and revision. Giuseppe Frazzitta was responsible for study design, data acquisition and analysis, article concept and design, drafting manuscript and revision.

Conflict of interest

None of the authors has potential conflict of interest to disclose related to research covered in this article.

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References

1. Hely MA, Morris JG, Traficante R, et al. The Sydney Multicentre Study of Parkinson's disease: a progression and mortality at 10 years. *J Neurol Neurosurg Psychiatry* 1999; 67: 300–307.
2. Bloem BR, Grimbergen YAM, Cramer M, Willemsen M and Zwinderman AH. Prospective assessment of falls in Parkinson's disease. *J Neurol* 2001; 248: 950–958.
3. Vivas J, Arias P and Cudeiro J. Aquatic therapy versus conventional land-based therapy for Parkinson's disease: an open-label pilot study. *Arch Phys Med Rehabil* 2011; 92: 1202–1210.
4. Gabrielsen A, Johansen LB and Norsk P. Central cardiovascular pressures during graded water immersion in humans. *J Appl Physiol* 1993; 75: 581–585.
5. Padula CA and Yeaw E. Inspiratory muscle training: integrative review. *Res Theory Nurs Pract* 2006; 20: 291–304.
6. Baroni G, Ferrigno G, Rabuffetti M, Pedotti A and Massion J. Long-term adaptation of postural control in microgravity. *Exp Brain Res* 1999; 128: 410–416.

7. Baroni G, Pedrocchi A, Ferrigno G, Massion J and Pedotti A. Static and dynamic postural control in long-term microgravity: evidence of a dual adaptation. *J Appl Physiol* 2001; 90: 205–215.
8. Massion J. Body orientation and regulation of the centre of gravity during movement under water. *J Vest Res* 1995; 5: 211–221.
9. Gelb DJ, Oliver E and Gilman S. Diagnostic criteria for Parkinson disease. *Arch Neurol* 1999; 56: 33–39.
10. Fahn S and Elton RL. Unified Parkinson's disease rating scale. In: Fahn S, Marsden CD, Calne D and Goldstein M (eds) *Recent developments in Parkinson's disease*. Macmillan Health Care Information, 1987.
11. Steffen TM, Hacker TA and Mollinger L. Age- and gender-related test performance in community-dwelling elderly people: Six-Minute Walk Test, Berg Balance Scale, Timed Up & Go Test, and gait speeds. *Phys Ther* 2002; 82: 128–137.
12. Berg KO, Wood-Dauphinee SL, Williams JI and Maki B. Measuring balance in the elderly: validation of an instrument. *Can J PublicHealth* 1992; 83: S7–S11.
13. Powell LE and Mayers AM. The Activities specific balance confidence scale. *J Gerontol Med Sci* 1995; 50: 28–34.
14. Tinetti M, Richman D and Powell L. Falls efficacy as a measure of fear of falling. *J Gerontol* 1990; 45: 239–243.
15. Jenkinson C, Fitzpatrick R, Peto V, Greenhall R and Hyman N. The Parkinson's Disease Quetionnaire (PDQ-39): development and validation of a Parkinson's disease summary index score. *Age Aging* 1997; 26: 353–357.
16. Keus SHJ, Hendriks HJM, Bloem BR, et al. KNGF Guidelines for Physical Therapy in Parkinson's disease. *Ner Tijdschr Fysiother* 2004; 114 (3 suppl)). Available at: www.kngf.nl-www.cebp.nl (accessed 29 March 2014).
17. Ayan C, Cancela JM, Gutierrez-Santiago A and Proeto I. Effects of two different exercise programs on gait parameters in individuals with Parkinson's disease: a pilot study. *Gait and Posture* 2014; 39: 648–651.
18. Nardone A and Schieppati M. Balance in Parkinson's disease under static and dynamic conditions. *Mov Disord* 2006; 21: 1515–1520.
19. Horak FB, Nutt JG and Nashner LM. Postural inflexibility in parkinsonian subjects. *J Neurol Sci* 1992; 111: 46–58.
20. Schieppati M and Nardone A. Free and supported stance in Parkinson's disease. The effect of posture and 'postural set' on leg muscle responses to perturbation, and its relation to the severity of the disease. *Brain* 1991; 114: 1227–1244.
21. Schieppati M, Hugon M, Grasso M, Nardone A and Galante M. The limits of equilibrium in young and elderly normal subjects and in Parkinsonians. *Electroencephalogr Clin Neurophysiol* 1994; 93: 286–298.
22. Nonnekes J, de Kam D, Geurts A, Weerdesteyn V and Bloem BR. Unraveling the mechanisms underlying postural instability in Parkinson's disease using dynamic posturography. *Expert Rev Neurother* 2013; 13: 1303–1308.
23. Menant JC, Latt MD, Menz HB, Fung VS and Lord SR. Postural sway approaches center of mass stability limits in Parkinson's disease. *Mov Disord* 2011; 26: 637–643.
24. Peterka RJ. Sensorimotor integration in human postural control. *J Neurophysiol* 2002; 88: 1097–1118.
25. Mohapatra S, Krishnan V and Aruin AS. Postural control in response to an external perturbation: effect of altered proprioceptive information. *Exp Brain Res* 2012; 217: 197–208.
26. Petzinger G, Fisher B, McEwen S, et al. Exercise-enhanced neuroplasticity targeting motor and cognitive circuitry in Parkinson's disease. *Lancet Neurol* 2013; 12: 716–726.
27. Frazzitta G, Balbi P, Maestri R, Bertotti G, Boveri N and Pezzoli G. The beneficial role of intensive exercise on Parkinson disease progression. *Am J Phys Med Rehabil* 2013; 9: 523–532.