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ORIGINAL ARTICLE

A noninvasive method to quantify the impairment of spinal motion ability in Parkinson's disease

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Abstract

Purpose There is a high demand on spinal surgery in patients with Parkinson's disease (PD) but the results are sobering. Although detailed clinical and radiological diagnostics were carried out with great effort and expense, the biodynamic properties of the spine of PD patients have never been considered. We propose a noninvasive method to quantify the impairment of motion abilities in patients with PD.

Methods We present an analytical cross-sectional study of 21 patients with severe PD. All patients underwent a biodynamic assessment during a standardized movement-choreography. Thus, individual spinal motion profiles of each patient were objectively assessed and compared with a large comparative cohort of individuals without PD. Moreover, clinical scores to quantify motor function and lumbar back pain were collected and X-ray scans of the spine in standing position were taken and analysed.

Results Biodynamic measurement showed that 36.9% of the assessed motions of all PD patients were severely impaired. Men were generally more functionally impaired than women, in 52% of all motion parameters. The neurological and radiological diagnostics recorded pathological values, of which UPDRS-III ON correlated with findings of the biodynamics assessment ($R=0.52$, $p=0.02$).

Conclusions The decision to operate on a PD patient's spine is far-reaching and requires careful consideration. Neurological and radiological scores did not correlate with the biodynamics of the spine. The resulting motion profile could be used as individual predictive factor to estimate whether patients are eligible for spinal surgery or alternative therapies.

Keywords Parkinson's disease · Spine · Motion capture · Spinal kinematics · Human posture

Introduction

Parkinson's disease (PD) is the second most common neurodegenerative disease and the second most common movement disorder, affecting 1% of the population over the age of sixty with increasing prevalence [1]. Beside characteristic features of PD (bradykinesia, rigidity and tremor) patients exhibit alterations in their posture, which can in several cases give rise to spinal deformities [2, 3]. The stooped posture with flexing of the hips and knees as well as some degree of the trunk and neck is indeed one of the most noticeable signs of PD. As expected, the demand for spinal surgery in patients with PD increases rapidly, but the results are disappointing with failure rates of 25.8–100% [4–7]. It is already well understood that spinal deformity in PD is unique from degenerative deformity. This is intuitive as the underlying aetiology in degenerative deformity is structural, as opposed to neuromuscular impairment with PD. Nevertheless, the pre-operative work-up before spinal surgery in PD patients is no different than in other patients. The decision whether and

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how to operate on a PD patient's spine is based on clinical evaluation and radiographic diagnostic.

A typical part of pre-operative clinical evaluation is the assessment of clinical scores. However, approved PD-specific rating scales of motor function have shortcomings in the description of spinal column-related symptoms. Viewed from the spinal surgeon's, rather than the neurologist's perspective, the approved evaluation scales for spinal symptoms also have shortcoming in the evaluation of PD patients. A large intersection of symptoms caused by back pain and typical Parkinson's symptoms (e.g. limited walking distance, need for assistance with personal care) make an exact characterization of which impairment is due to spinal symptoms or due to PD symptoms inadequate.

The second pillar of the pre-operative work-up before spinal surgery are radiographic diagnostics. Recent studies on postural changes of PD patients describe spinal malalignment in radiographic diagnostics in relation to clinical and demographic data [8–10]. The assessment of spinal alignment is usually based on full-length radiographs in standing position which offer a solid yet complicated opportunity to analyse the static conditions of the vertebra column.

In addition to clinical scores and radiographic diagnostics, observation of lumbo-pelvic motion should be a basic component of future physical examination of PD patients, because of a common belief that correcting motion aberrations and restoring functional capacity can reduce pain and improve the quality of life. However, functional diagnostics play almost no role in current clinical observations.

In our study, we aimed to analyse the spinal motion abilities of patients with PD by use of a noninvasive measurement device. During a standardized motion choreography in standing position the kinematics of the lumbo-pelvic complex were systematically recorded. We hypothesize that biodynamic assessment of motion abilities can be used as predictive marker in the pre-operative work-up to estimate which patients are eligible for alternative therapies rather than spinal surgery.

Methods

Study design

This study was approved by the local ethics committee (Charité - Universitätsmedizin Berlin, Germany, EA4/178/18), the federal office for radiation protection (Bundesamt für Strahlenschutz, Salzgitter, Germany, Z5-22464/2019-052-A) and was conducted in accordance with the Declaration of Helsinki. The study is registered with ClinicalTrials.gov (Identifier NCT04524377). The procedures of the study were explained to each participant in detail and an informed consent sheet was signed, which allows collection and storage of medical data, full-length standing spine radiographs with the EOS® imaging system, and spinal shape and mobility measurements with the Epionics® SPINE device.

Study population

Twenty-one adult PD patients (14 males, 7 females) with a median age (± SD) of 61.0 (± 7.4) years were included in the study. All patients were recruited via our institution's movement disorder department where they were assessed for their eligibility for deep brain stimulation (DBS) between July 2019 and March 2021.

Biodynamic assessment

Patients performed a standardized motion choreography of six different movements that were explained and demonstrated by an instructor prior to each movement. During the choreography, Epionics SPINE was used to measure patients' range (in °) and velocity (°/s) of motions (RoM and VoM). The device as well as the validation is extensively described in previous studies [11, 12]. Briefly, the Epionics SPINE device consists of two flexible sensor strips attached to the back paravertebrally from the midline on each side. Each sensor strip consists of sensor segments, which employ strain-gauges and a tri-axial acceleration sensor (Fig. 1). Patients were asked to perform maximal upper body flexion to the front and lateral, dorsal extension and rotation to both sides. Movements were started from relaxed upright standing position with extended knees for reference and repeated three times. All patients were in ON-status during the measurement.

Analysis of biodynamics

The lumbar lordosis (Cobb) angle was individually calculated by summing all Epionics' segments that were lordotically curved in the individual patient. The total angles (RoM) for flexion, extension, lateral bending, and axial rotation were calculated individually as the sum of the segments, which were identified as being lordotic during upright standing. The angles of these segments were then summed at every time frame during upper body motion, and derivatized with respect to time to compute the angular velocities (VoM). In this way an individual movement profile was created for each PD patient. The profiles were analysed according to a normative database, that was created from a large comparative group of 800 individuals. A comparison of the individual motion choreography of an individual patient with this reference database results in a radar chart for all motion directions. The inner hexagon describes a strong motion restriction (red), the middle hexagon a

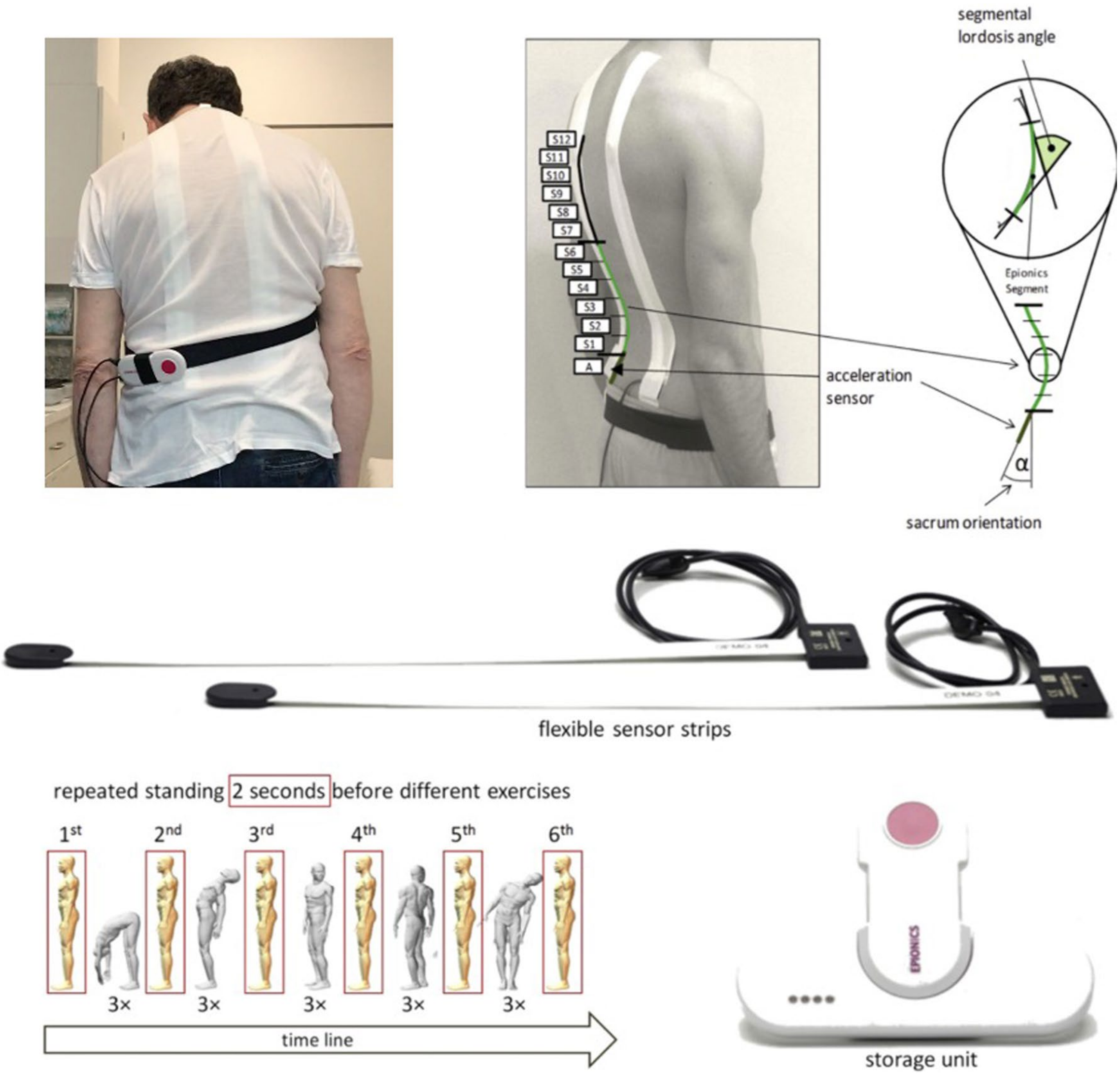


Fig. 1 The Epionics SPINE system affixed to a PD patient's back in standing. The system consists of two flexible sensor strips utilizing strain-gauge sensors, tri-axial accelerometers and a storage unit. Demonstration of the assessment of the total lordosis angle, which is the sum of all lordotically curved segments during standing (average lordosis range highlighted in green: S1–S6 as well as the orientation of the sacrum given by "a", with respect to the vertical direction. The measurement protocol consisted of six standing phases and six exercises. Each exercise was repeated three times before going to the next exercise. Standing was recorded before the first flexion and after each exercise

medium motion restriction (grey), and the outer hexagon no motion restriction (green). Since in the present study, RoM and VoM of each motion direction were recorded, a dodecagon (a spider-web-diagram) was calculated for each patient (Fig. 2).

Clinical evaluation

The severity of PD was assessed by Movement Disorder Society—Unified Parkinson's Disease Rating Scale—Part III (MDS-UPDRS-III) and Parkinson's disease Questionnaire (PDQ-39) [13, 14]. Regarding spine-related morbidity, the Visual Analogue Scala (VAS) and the Oswestry Disability Index (ODI) were collected [15, 16].

Radiographic diagnostics

Simultaneous anteroposterior and lateral X-ray scan of the spine in standing position with EOS® imaging system was taken of each patient in ON-status and analysed according to the SRS-Schwab classification system [17].

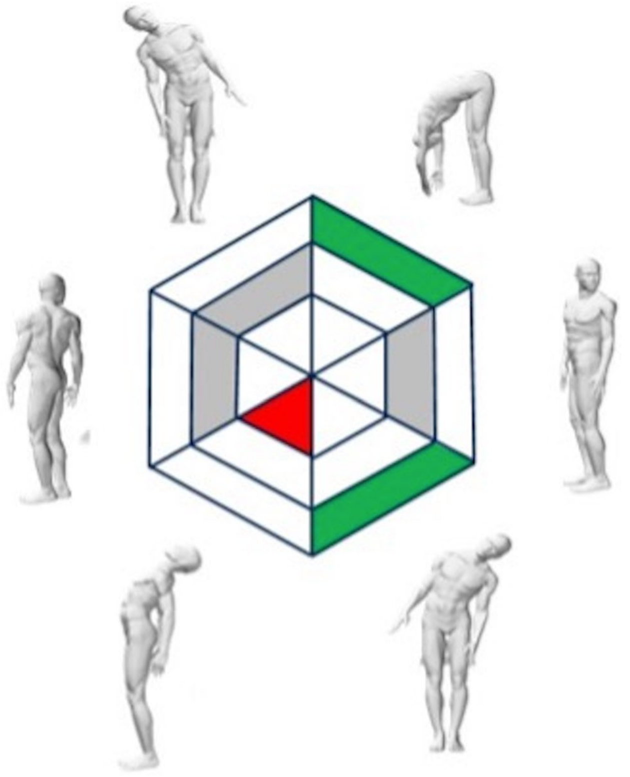


Fig. 2 Radar chart for all motion directions. In this case, the study participant in functionally impaired regarding extension

Statistical analysis

Analyses were performed with the use of GraphPad Prism (version 8.4.2.(464)). Students unpaired t-test, fraction of total analysis and Pearson correlation calculation with two-tailed p-values were used with $p < 0.05$ as definition of statically significant and assumption that all values were sampled from a population with a Gaussian distribution.

Results

Demographic data and clinical results

Median age (± SD) was 61.0 (±7.3) years. Seven patients (i.e. 33.3%) were females. Median (± SD) height was 173 (±9.6) cm, weight 83 (±16.8) kg and BMI 27.7(±5.0) kg/m^2. Median (± SD) scores for PD severity were MDS-UPDRS-III ON: 23 (±15.1), OFF: 51 (±12.2), PDQ-39: 32.7 (±11.8). Evaluation of spine morbidity were VAS 2.0 (±2.0) in ON-status and ODI was 24.0 (±15.4) in relation to the previous 4 weeks. Thirteen patients (i.e. 61.9%) of the patients had an ODI of > 20%, which equals a moderate disability LBP.

Biodynamical results

Twelve motion parameters (VoM and RoM in six motion directions) of 21 PD patients, which is a total of 252 motion parameters were measured. Of those n = 93 (i.e. 36.9%) were impaired (red areas in the spider-web diagram), with equal level of impairment regarding VoM and RoM ($n = 47$, vs. $n = 46$) (Fig. 3A). Women had a significantly better functional performance in 52% of all investigated parameters of the motion choreography than men (Fig. 3B).

Radiological results

Two patients (i.e. 9.5%) had a pathological curve type (L) with a thoracolumbar major curve > 30°. Sagittal modifiers

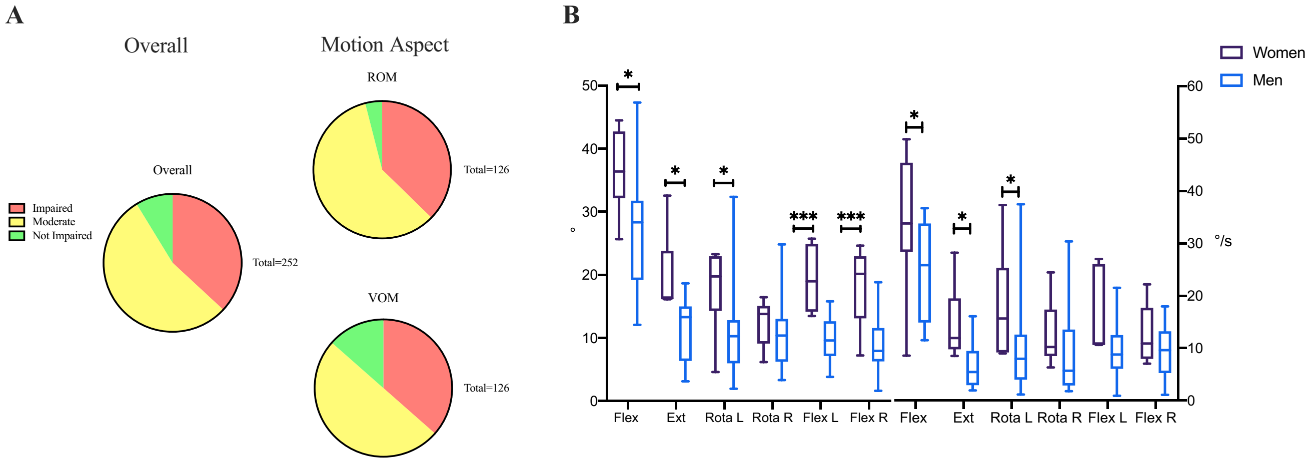
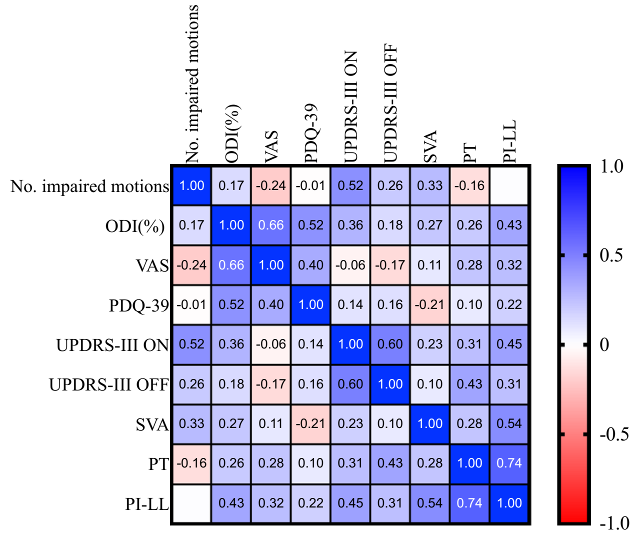


Fig. 3 **A** Proportion of strong (red), medium (yellow), and no (green) motion restrictions in the overall assessment and divided by motion aspect (VOM vs. ROM). **B** Particular ranges of motion (RoM, left side) and velocities of motion (VoM, right side) of women and men

revealed a mismatch of PI-LL (modifier "+" and "++") in 28.6% and 9.5%, respectively. Median (± SD) PI-LL was 6 (± 12.8, range – 4 to 52°). The same distribution of sagittal modifiers was measured regarding compensatory retroversion of the pelvis (61.9% modifier "0", 28.6% modifier "+" and 9.5% modifier "++") with a median (± SD) PT of 17 (± 7.6, range 5–35°). Physiological global alignment (modifier "0") was measured in 42.9% of the patients. 47.6% had an SVA between 40 and 95 mm which was defined as modifier "+" and 9.5% had a global malalignment (modifier "++"). The median (± SD) SVA of all patients was 40 (± 41.9, range – 27 to 150) mm.



	No. impaired motions	ODI(%)	VAS	PDQ-39	UPDRS-III ON	UPDRS-III OFF	SVA	PT	PI-LL
No. impaired motions	1.00	0.17	-0.24	-0.01	0.52	0.26	0.33	-0.16	
ODI(%)	0.17	1.00	0.66	0.52	0.36	0.18	0.27	0.26	0.43
VAS	-0.24	0.66	1.00	0.40	-0.06	-0.17	0.11	0.28	0.32
PDQ-39	-0.01	0.52	0.40	1.00	0.14	0.16	-0.21	0.10	0.22
UPDRS-III ON	0.52	0.36	-0.06	0.14	1.00	0.60	0.23	0.31	0.45
UPDRS-III OFF	0.26	0.18	-0.17	0.16	0.60	1.00	0.10	0.43	0.31
SVA	0.33	0.27	0.11	-0.21	0.23	0.10	1.00	0.28	0.54
PT	-0.16	0.26	0.28	0.10	0.31	0.43	0.28	1.00	0.74
PI-LL		0.43	0.32	0.22	0.45	0.31	0.54	0.74	1.00

Fig. 4 Correlation Matrix of Number of impaired motions (in the biodynamic assessment), clinical scores and sagittal parameters

Intermodal correlation

There was a significant correlation between the number of impaired motion parameters in the biodynamic assessment and UPDRS-III in ON-status ($R = 0.52$, $p = 0.02$). The other clinical scores, or radiological diagnostics did not correlate with the biodynamic assessment. A correlation matrix (Fig. 4) shows the correlation coefficients of each pair of variables.

Illustrative cases

An individual mobility profile in form of a spider-web-diagram was calculated for each patient, which will be explained using the following two case reports:

1st: A 57-years-old patient with PD and severe disability through LBP (VAS 5/10, ODI 56%). Biodynamic assessment showed RoM impairment in all 6 motion directions (5 moderate, 1 severe). VoM was also impaired in all motion directions (1 moderate, 5 severe) (Fig. 5). In line with the poor VoM scores, bradykinesia was the patient's main symptom. The patient underwent STN-DBS. One year after DBS he markedly improved regarding bradykinesia as well as in terms of disability through LBP (VAS 2/10, ODI 32%). Reassessment of biodynamic measurements showed amelioration of all motion parameters. This case is an example of how LBP caused by bradykinesia rather than morphological pathologies should not primarily be subjected to spinal surgery, but rather benefit from further neurological or functional neurosurgical therapy.

2nd: A 62-years-old patient with PD and severe disability through LBP (VAS 3/10, ODI 41%). Biodynamic assessment showed RoM impairment in all six motion directions (1 moderate, 5 severe). VoM was also impaired in all motion directions (4 moderate, 2 severe) (Fig. 6). The patient rather

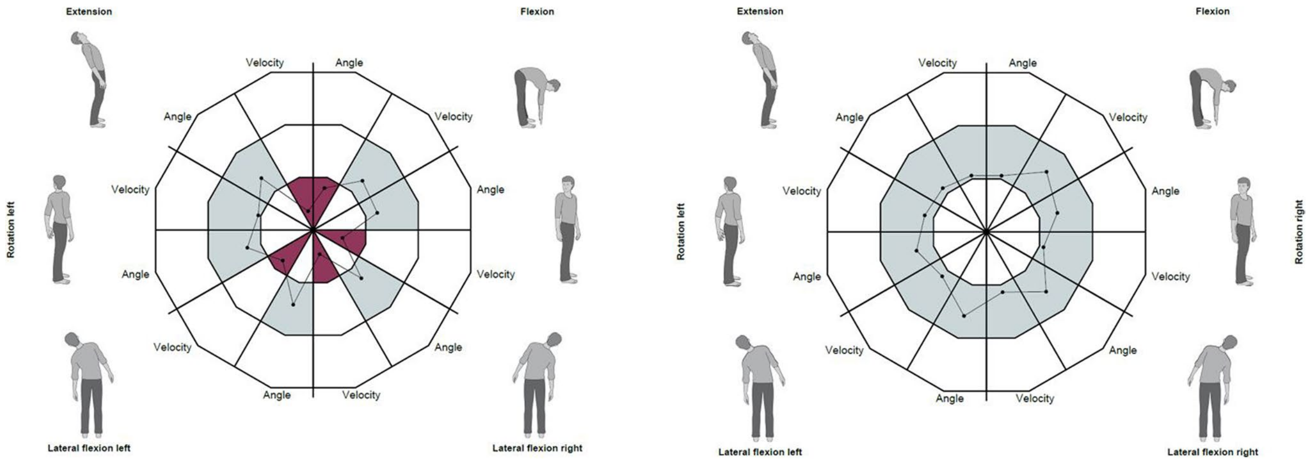


Fig. 5 Individual motion profile of a patient before (left) and 1 year after DBS-therapy (right)

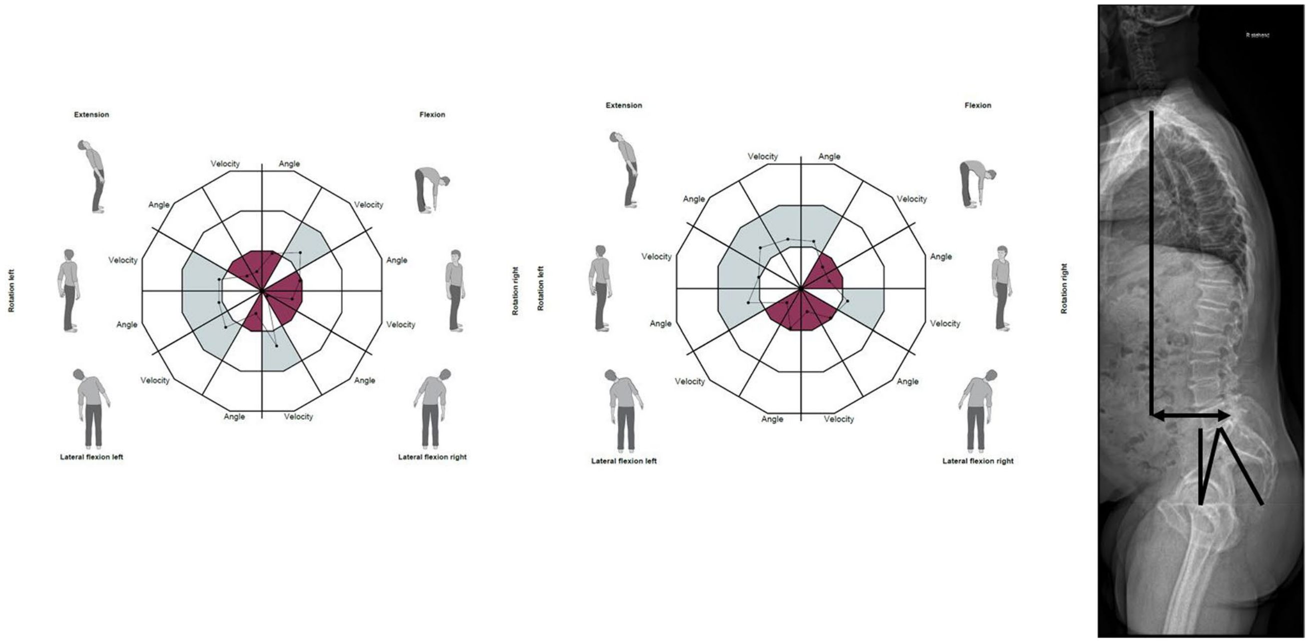


Fig. 6 Individual motion profile of a patient before (left) and 1 year after DBS-therapy (middle). X-ray in standing position with SVA, PT, and PI (right) before DBS-therapy

suffered from tremor than from bradykinesia. One year after DBS the tremor improved yet disability through LBP even got worse (VAS 4/10, ODI 52%). Re-assessment of biodynamic measurements showed that six/twelve motion parameters (three RoM) were still impaired. Although the values for movement in the sagittal plane had improved, the ability to move in the coronal plane was globally severely restricted. On X-ray scan of the spine in standing position the patient had a normal coronal curve type but global sagittal malalignment (SVA: 101 mm), a mild compensatory retroversion of the pelvis (PT: 16°) and a mismatch of PI-LL (51–40 = 2°). This case shows that morphologically induced LBP does not necessarily improve with neurological amelioration through DBS. In this case, another strategy for the treatment of LBP should be considered. Since the patient was overweighted (BMI 29.9 kg/m^2) and naïve for conservative LBP treatment he would primary be a candidate for weight reduction and physiotherapy but might be further assessed for spinal surgery in case conservative treatment strategy fails.

Discussion

To operate on a PD patient's spine is a far-reaching decision and requires careful consideration based on pre-operative evaluation. Classically, in addition to a thorough clinical evaluation, standardized analyses of radiographic diagnostics [18] are used to give an individual therapy recommendation. One difficulty in the clinical evaluation of spinal symptoms in PD patients is that the established clinical scores do not distinguish whether certain symptoms are PD-related or are based on a pathological morphology of the spine. For instance, UPDRS-III, PDQ-39 and ODI evaluate the patient's ability to walk. Whether the walking of a PD patient is impaired through akinesia or through LBP is not specified within the scores. The interpretation of radiographic diagnostic is difficult since spinal deformities in PD are unique from degenerative deformities, which is intuitive as the underlying aetiology in degenerative deformity is structural, as opposed to neuromuscular impairment with PD. Therefore, conventional spine modalities (e.g. static upright X-rays) are not effective for PD patients. Despite the detailed and, as described, difficult pre-OP diagnostics, the results of spinal surgery in PD patients are disappointing [4–6]. Yet in view of the increasing demand [1], there is an obvious gap of knowledge which must take considerations of further pre-operative aspects into account.

In an analytical cross-sectional study of 21 patients with severe PD, who were evaluated for STN-DBS in our institution's movement disorder department, we developed a concept to assess biodynamic aspects of the spine in addition to classical clinical and radiological diagnostics. As expected, many PD patients complained about LBP as burdensome secondary disease in addition to PD. About every second patient had deformities or at least beginning biostatic compensation mechanisms of their spines in the radiological examinations. This finding is in line with recent studies that reported high rates of spinal malalignment in patients with

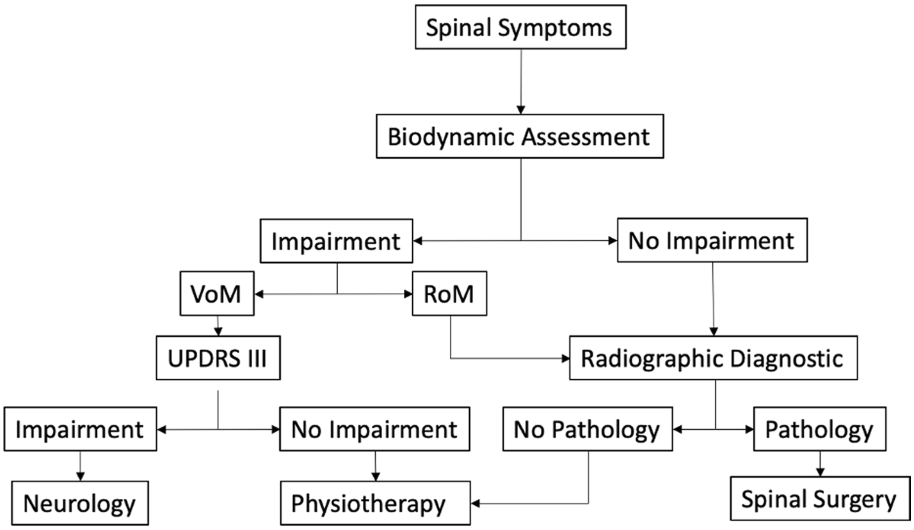


Fig. 7 Decision tree how biodynamic assessment could augment pre-operative work-up

PD in the sagittal [9] and coronal [19] plane. However, there was no correlation between disability through LBP and pathological findings in radiological diagnostics. Although we found a high rate of impaired motion parameters in the biodynamic measurements, especially in men, there was neither a correlation between disability though LBP and biodynamic restrictions. Interestingly we found some aspects of motion impairment (mostly VoM) improved following DBS. Consequently, in those patients' spinal symptoms ameliorated as well. On the other hand, patients who complained about LBP and had mostly restrictions regarding RoM did not improve through DBS in terms of spinal symptoms and/or biodynamic performance. Biodynamic measurements might serve as a predictive factor to estimate which patients are more suitable for alternative forms of therapy such as exercise training [6, 7, 20] or functional neurosurgical options than for spinal surgery. However, it must be noted that the effect of DBS on spinal symptoms has not yet been structurally investigated [21, 22].

We therefore suggest biodynamic measurement in the pre-operative assessment of spine surgery in patients with PD. In Fig. 7, we demonstrate a decision tree how biodynamic measurement could complement the pre-operative assessment.

Assumptions and limitations

In accordance with other noninvasive measurement tools, Epionics SPINE has certain limitations. It should be noted that the Epionics SPINE system measures the back shape and not directly the curvature of the spine and the orientation of the sacrum. Recent studies have found a significant correlation between lumbar lordosis assessed via the back shape and determined radiologically only for subjects with a body mass index (BMI) < 27.0 kg/m^2 [23]

In this study, no information about the targeted velocity of motion was provided to the patients prior to the measurements. As a result, some patients conducted the exercises slowly and with caution. Here, this subject specific response might have proved beneficial to the reliability of the study, since each patient's preferred pace is known to be the best choice for consistent results [24].

Conclusions

The demand on spinal surgery in patients with PD increases. Despite great effort in the pre-operative work-up, the results of spinal surgery in PD patients are sobering. To our knowledge, we present the first report that describes a structured biodynamic assessment of spinal motion ability of patients with severe PD. We found severely impairment of motions in a considerable amount of PD patients and present individual motion profiles of single patients in a simple and objective diagram. Our results did not correlate with any of the established neurological and radiological diagnostic that belong to a standard pre-operative work-up. Integration of biodynamic assessment is a novel approach and might be the missing piece in the pre-operative work-up to select suitable PD patients for spinal surgery or alternative therapies.

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Declarations

Conflict of interest All authors have no conflicts of interests to report.

References

1. Tysnes OB, Storstein A (2017) Epidemiology of Parkinson's disease. J Neural Transm. https://doi.org/10.1007/s00702-017-1686-y
2. Doherty KM, van de Warrenburg BP, Peralta MC, Silveira-Moriyama L, Azulay JP, Gershanik OS et al (2011) Postural deformities in Parkinson's disease. Lancet Neurol. https://doi.org/10.1016/S1474-4422(11)70067-9
3. Ha Y, Oh JK, Smith JS, Ailon T, Fehlings MG, Shaffrey CI et al (2015) Impact of movement disorders on management of spinal deformity in the elderly. Neurosurgery. https://doi.org/10.1227/NEU.0000000000000940
4. Watanabe K, Katsumi K, Ohashi M, Shibuya Y, Izumi T, Hirano T et al (2019) Surgical outcomes of spinal fusion for osteoporotic thoracolumbar vertebral fractures in patients with Parkinson's disease: what is the impact of Parkinson's disease on surgical outcome? BMC Musculoskelet Disord. https://doi.org/10.1186/s12891-019-2473-8
5. Schroeder JE, Hughes A, Sama A, Weinstein J, Kaplan L, Cammisa FP et al (2015) Lumbar spine surgery in patients with parkinson disease. J Bone Jt Surg Am. https://doi.org/10.2106/JBJS.N.01049
6. Malla HP, Kim MK, Kim TS, Jo DJ (2016) Multiple spinal revision surgery in a patient with Parkinson's disease. J Korean Neurosurg Soc. https://doi.org/10.3340/jkns.2016.59.6.655
7. Kimura H, Fujibayashi S, Otsuki B, Takemoto M, Shikata J, Odate S et al (2017) Lumbar spinal surgery in patients with Parkinson disease a multicenter retrospective study. Clin Spine Surg. https://doi.org/10.1097/BSD.0000000000000455
8. Obeid I, Berjano P, Lamartina C, Chopin D, Boissière L, Bourghli A (2019) Classification of coronal imbalance in adult scoliosis and spine deformity: a treatment-oriented guideline. Eur Spine J. https://doi.org/10.1007/s00586-018-5826-3
9. Oh JK, Smith JS, Shaffrey CI, Lafage V, Schwab F, Ames CP et al (2014) Sagittal spinopelvic malalignment in parkinson disease: prevalence and associations with disease severity. Spine. https://doi.org/10.1097/BRS.0000000000000366
10. Ye X, Lou D, Ding X, Xie C, Gao J, Lou Y et al (2017) A clinical study of the coronal plane deformity in Parkinson disease. Eur Spine J. https://doi.org/10.1007/s00586-017-5018-6
11. Schmidt H, Bashkuev M, Weerts J, Graichen F, Altenscheidt J, Maier C et al (2018) How do we stand? Variations during repeated standing phases of asymptomatic subjects and low back pain patients. J Biomech. https://doi.org/10.1016/j.jbiomech.2017.06.016
12. Taylor WR, Consmüller T, Rohlmann A (2010) A novel system for the dynamic assessment of back shape. Med Eng Phys. https://doi.org/10.1016/j.medengphy.2010.07.011
13. Goetz CG, Fahn S, Martinez-Martin P, Poewe W, Sampaio C, Stebbins GT et al (2007) Movement disorder society-sponsored revision of the unified Parkinson's disease rating scale (MDS-UPDRS): process, format, and clinimetric testing plan. Mov Disord. https://doi.org/10.1002/mds.21198
14. Jenkinson C, Fitzpatrick R, Peto V, Greenhall R, Hyman N (1997) The Parkinson's disease questionnaire (PDQ-39): Development and validation of a Parkinson's disease summary index score. Age Ageing. https://doi.org/10.1093/ageing/26.5.353
15. Grant S, Aitchison T, Henderson E, Christie J, Zare S, McMurray J et al (1999) A comparison of the reproducibility and the sensitivity to change of visual analogue scales, Borg scales, and likert scales in normal subjects during submaximal exercise. Chest. https://doi.org/10.1378/chest.116.5.1208
16. Fairbank JC, Pynsent PB (2000) The oswestry Disability Index. Spine. https://doi.org/10.1093/occmed/kqw051
17. Schwab F, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D et al (2012) Scoliosis research society-schwab adult spinal deformity classification: a validation study. Spine. https://doi.org/10.1097/BRS.0b013e31823e15e2
18. Ames CP, Smith JS, Eastlack R, Blaskiewicz DJ, Shaffrey CI, Schwab F et al (2015) classification system. J Neurosurg Spine. https://doi.org/10.3171/2014.12.SPINE14780
19. Choi HJ, Smith JS, Shaffrey CI, Lafage VC, Schwab FJ, Ames CP et al (2015) Coronal plane spinal malalignment and Parkinson's disease: Prevalence and associations with disease severity. Spine J. https://doi.org/10.1016/j.spinee.2014.07.004
20. Gandolfi M, Tinazzi M, Magrinelli F, Busselli G, Dimitrova E, Polo N et al (2019) Four-week trunk-specific exercise program decreases forward trunk flexion in Parkinson's disease: a single-blinded, randomized controlled trial. Park Relat Disord. https://doi.org/10.1016/j.parkreldis.2019.05.006
21. Lizarraga KJ, Fasano A (2019) Effects of deep brain stimulation on postural trunk deformities: a systematic review. Mov Disord Clin Pract. https://doi.org/10.1002/mdc3.12829
22. Schulz-Schaeffer WJ, Margraf NG, Munser S, Wrede A, Buhmann C, Deuschl G et al (2015) Effect of neurostimulation on camptocormia in Parkinson's disease depends on symptom duration. Mov Disord. https://doi.org/10.1002/mds.26081
23. Guermazi M, Ghroubi S, Kassis M, Jaziri O, Keskes H, Kessomtini W et al (2006) Validité et reproductibilité du Spinal Mouse® pour l'étude de la mobilité en flexion du rachis lombaire. Ann Readapt Med Phys. https://doi.org/10.1016/j.annrmp.2006.03.001
24. McGregor AH, Hughes SPF (2000) The effect of test speed on the motion characteristics of the lumbar spine during an A-P flexion-extension test. J Back Musculoskelet Rehabil. https://doi.org/10.3233/BMR-2000-14304