Validation of Spiral Analysis in Assessing Motor Control in Early Parkinson’s Disease

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Objective
To determine whether indices of motor execution of spiral drawing correlate with motor severity of Parkinson’s Disease (PD) in patients with early PD.

Background
- Spiral Analysis is a novel method of analyzing upper limb kinematic behavior developed at Columbia that provides objective and reliable detection of small changes in motor function. Based on freely drawn Archimedian spirals acquired on a computerized digitizing graphics tablet, the standard clinical neurologic test of spiral drawing, commonly used but not always reliably interpreted, is converted into multiple objective measurements.
- As PD affects motor control, PD features, including variability in motor performance, may be detected using spiral analysis based on mean scores derived from 10 spirals per side.

Methods
Study Population
- 26 patients enrolled in a longitudinal observational study of PD, and who met criteria for the diagnosis of probable PD, were rated using the Unified Parkinson’s Disease Rating Scale (UPDRS) and performed spirals.

Spiral Acquisition
- Subjects were seated comfortably in front of the digitizing tablet and instructed to start in the center of a 10 x 10 cm box on an 8.5 x 11 inch white paper, aligned with the table, and freely draw a spiral within the box.
- Minimal instructions were given, but subjects were asked to avoid crossing the loops of the spiral, and not anchor their wrists on the table as they drew so that the entire forearm was involved.
- Ten spirals were collected from each side.
- Data acquisition tablet resolution was 100 points/mm with an accuracy of ±0.127 mm, an output rate of 200 points per second and 256 levels of measurable pressure.
- A total of approximately 50 indices were generated quantifying upper limb kinematics.
- A subset of 25 indices were chosen for investigation based on the range of reported motor manifestations in Parkinson’s disease.
- Indices deal with two-dimensional spatial patterns (including micrographia correlates and precise tremor quantification), speed patterns (including bradykinesia correlates), and pressure patterns.

Statistical Analysis
- Association between the motor scores and spiral indices was assessed using linear regression.
- Respective UPDRS score (either total motor, total arm sub-score, or worst arm sub-score) was used as the outcome variable, adjusted for age at exam and duration of PD.

Results
- Second-order smoothness was associated with total UPDRS in both unadjusted and adjusted models for duration of PD since diagnosis and age, (p=0.018, adjusted) and with worst arm UPDRS (p=0.003).
- First order smoothness was associated with worst arm UPDRS (p=0.016) and bilateral arm UPDRS (p=0.04), but not total UPDRS

Table 1: Regression Models for Correlation with UPDRS subsets

<table>
<thead>
<tr>
<th>P-values: Adjusted for duration of PD, and age</th>
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<tbody>
<tr>
<td>Total Motor UPDRS</td>
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<tr>
<td>Second order smoothness</td>
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<td>First order smoothness</td>
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<td>First order arm crossing</td>
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Indices
- Radius Angle Transformation

First order smoothness
\[ \ln \left( \frac{1}{\sigma} \sum \left( \frac{\Delta r}{d} - r \right)^2 \right) \]
\( \sigma \) = Total angle over which the spiral is drawn.
\( r = \) The arm’s radial value.

Second order smoothness
\[ \ln \left( \frac{1}{\sigma} \sum \left( \frac{\Delta r}{d} - \frac{\Delta r}{d} \right)^2 \right) \]
\( \sigma \) = Total angle over which the spiral is drawn.
\( d = \) The derivative of the arm’s radial value.

PD
Discussion
- Spiral analysis indices, particularly second order smoothness, correlate with motor UPDRS scores in patients with early PD.
- This suggests that spiral analysis may provide valid measures not only of upper arm motor function but overall motor function in early PD.
- Overall, there is a trend that the most predictive indices correspond best with the worse arm UPDRS, next with the bilateral arm UPDRS, and then with the total motor UPDRS, with the most predictive index, second order smoothness predicting all three, but the less predictive, first order smoothness predicting only isolated arm scores.
- Additional studies, including a larger sample size, as well as longitudinal studies are necessary, to confirm worsening in spirals within individuals and further assess the utility of this measure.
- Larger samples are also required to perform sub-analyses of groups will impairment which may be less well measured by spiral analysis (e.g. leg-predominant). Other models other than the linear regression may also better predict the motor scores.

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