Quantification of Rigidity in Parkinson's Disease, an Objective Evaluating Method

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ABSTRACT

In this paper, a new method for quantification of rigidity in elbow joint of Parkinsonian patients is introduced. One of the most known syndromes in Parkinson's disease is increased passive stiffness in muscles, which leads to rigidity in joints. Clinical evaluation of stiffness in wrist and/or elbow, commonly used by clinicians, is based on Unified Parkinson's Disease Rating System (UPDRS). Subjective nature of this method may influence the accuracy and precision of evaluations. Hence, introducing an objective standard method based on quantitative measurements may be helpful. A test rig was designed and fabricated to measure range of motion and viscous and elastic components of passive stiffness in elbow joint. Measurements were done for 41 patients and 11 controls. Measures were extracted using Matlab-R14 software and statistical analyses were done by Spss-13. Relation between each computed measure and the level of illness were analyzed. Results showed a better correlation between viscous component of stiffness and UPDRS score compared to the elastic component. Results of this research may help to introduce a standard objective method for evaluation of Parkinson's disease.

KEYWORDS

Measurement, Stiffness, Viscous, Elastic, Parkinson's disease, UPDRS.

1. INTRODUCTION

Measurement of stiffness in human joints caused by the stiffening of muscles is one of diagnostic methods to evaluate illnesses involving rigidity. In some cases, the rigidity occurs when a voluntary movement is performed. This kind of rigidity is called *active rigidity*, which is the result of activation of muscles. On the other hand, in many illnesses including Parkinson's Disease (PD), rigidity in muscle and joints exists even when there is no voluntary movement. This is called rigidity at rest or *passive rigidity*, which is the result of alteration in mechanical properties of tissues.

Parkinson's disease affects both men and women equally and usually manifests itself at a larger age, between 50 and 60 years. In this age group roughly 1 in 50 people suffer from the disease [1]. The principal symptoms of Parkinson's disease are rigidity, tremor, bradykinesia, and postural instability [2]. Rigidity responds well to levodopa and is a main parameter monitored to evaluate the efficacy of pharmacological and surgical treatments [3]. However, there is currently no standardized objective method of measuring rigidity. At present, the clinician manipulates patient's limbs and rates the evoked stiffness according to a rating scale such as Unified Parkinson's Disease Rating System (UPDRS), which classifies the joint stiffness from zero to four in an ordinal manner. Zero indicates no rigidity and four is for the highest rigidity with limited range of motion. However, the subjective nature of such scale makes it open to the interpretation of the examiner.

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Efforts have been made to examine quantified measures, which verify the level of the illness. Some researchers were concentrated on the work done to move the limb [4]-[6], while others used stiffness index in joints [7]-[9]. Patrick and co-workers[3], implemented Mechanical Impedance which is the vector sum of elastic and viscous coefficients in a model fitted on torque-displacement behavior, but there have been limitations in their method. In a research done by Lauk and co-workers [10], stiffness of whole body was used to differentiate between controls and PDs. Due to the expense, complicity and time-consuming nature of these methods, none of them have led to a standard clinical method [11].

Stiffness index, which is implemented clinically, has been the principal index in recent studies. Esteki and co-workers [12] introduced a device and measured viscous and elastic components of stiffness in passive movement of ankle joint. The aim of their work was to determine the relation between the above measures and the history of diabetes, but the method implemented was considered as a novel method for similar measurements in joints of upper extremity to find the relation among indices and the level of PD progression.

In this research, we aimed at extracting the elastic and viscous indices of passive stiffness in the elbow joints of controls and people involved with Parkinson's disease and to compare each index in the described groups. The elastic index is a measure of energy storage which is obtained from the slope of the hysteresis loop while the viscous index is a measure of energy loss and is measured as the area between the loading and un-loading curves of hysteresis loop.

2. MATERIALS AND METHODS

To measure the passive torque and angular position of elbow joint in flexion-extension movement simultaneously, a test rig based on the one previously implemented in ankle joint [12], was designed and fabricated(Fig. 1). Mechanical unit consisted of a fixed support jointed to a moving part using two bearings. Arm was placed in the horizontally fixed support and forearm was mounted on the moving part so that the axis of rotation of elbow joint was aligned with the center of bearings.

The axis of rotation of elbow was considered as the line crossing the medial and lateral epicondyls of humerus [13],[14]. Both the arm and forearm were fixed using fastening belts to prevent relative motions of limbs to the device.

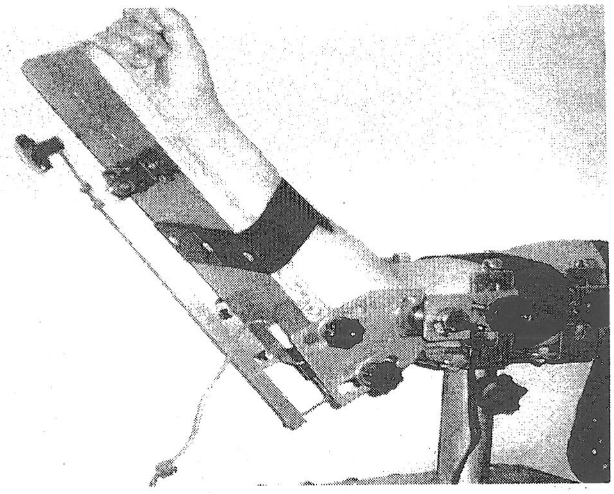

Figure 1 : Test rig with arm and forearm placed in it.

To measure the torque, a balanced strain gage force transducer (Fort 1000, World Precision Instruments, USA) was implemented. The force exerted by the examiner to flex and extend the joint transmits to the force transducer through a cantilever mounted to the moving part of the device so that the torque could be measured. Angular position was measured using a 10kΩ potentiometer mounted aligned with one of the bearings. The flexion-extension cycle was performed by the operator in a relatively constant speed of 1 cycle/sec and was repeated for at least 12 cycles. Patients were trained not to exert any force during flexion-extension. In some cases, surface EMG of flexor and extensor muscles was recorded and measurements were repeated if high spikes due to voluntary contraction were seen (Fig. 2).

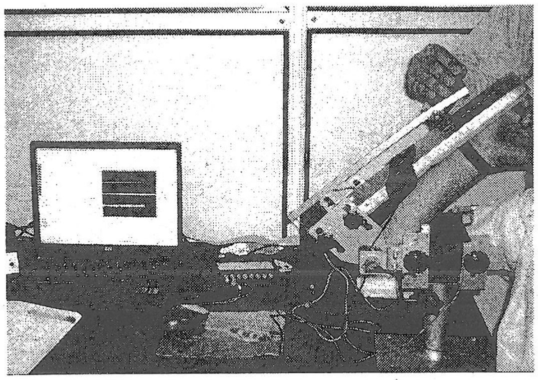

Figure. 2 : Passive measurement of stiffness simultaneously with SEMG.

Data were digitized at 100 Hz and fed to a PC via a parallel port. Labview-7 software was used to monitor the real time graphs and to store data. Providing an m-file in Matlab-R14, measures were calculated out of the stored row data. Measures used in this research were (Fig. 3):

- Total Slope, TS: slope of linear fit on both loading and un-loading curves of hysteresis loop

- Total Hysteresis, TH: surface covered by hysteresis loops
- Normalized Total Hysteresis, NTH: TH normalized to range of motion
- Range of Motion, ROM

Calculating each of the indices, data for 8 cycles were averaged. Also, in the calculation of indices 1-3, data corresponding to first and last 2 percents of range of motion were discarded to prevent inertial effects due to acceleration/deceleration at extremes. Data extracted using Matlab was stored in matrices grouped as Control/Patients, Men/Women, Right/Left side, with/without Reinforcement, and according to UPDRS scores. Using Spss-13, independent samples t-test was performed to find the significance of difference in each index between paired groups and one way ANOVA test and its variance robust tests were used to do the same among UPDRS groups. Because of scarce of data in group 4 of UPDRS, data of this group were not accounted in ANOVA tests. Finally, Pearson tests of correlation were examined to determine the relation of data in each index and UPDRS scores.

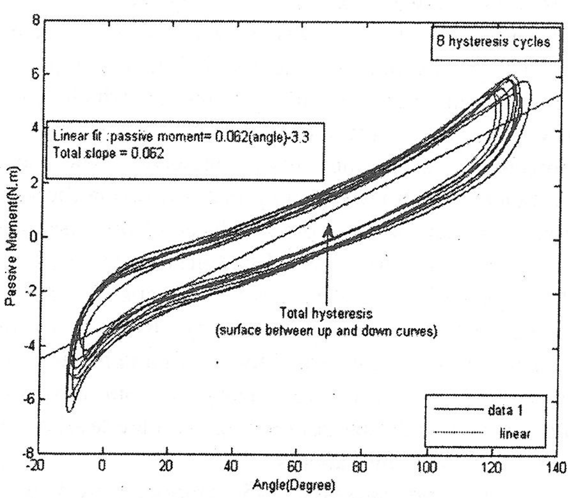

Figure 3 : A prototype of 8 hysteresis loops. Horizontal axis indicates the angular position in degree and vertical axis shows the changes in passive moment in N.m. The slope of linear fit (total slope) is considered as elastic index, and the surface covered by the loops (total hysteresis) is used as viscous index.

The process was done in groups of patients and controls. The former consistes of 41 rigidity dominant patients, 35 males and 6 females, aged 36 to 75. The later covered 10 males and 1 female aged 30 to 68 with no history of neuromuscular diseases. Rigidity dominant patients were choosing because tremor influences the examination of UPDRS rigidity factor. Measurements were performed in right and left sides, with and without reinforcement. Reinforcement was considered as a mirror voluntary movement in the contralateral side to the measured joint.

Parallel to measurements done with the test rig, clinical assessments of rigidity were performed by one of the two neurologists contributing in the research. Patients' elbow were flexed and extended to determine the UPDRS score.

3. RESULTS

The differences of mean values of indices in patients/controls groups were visible. In Men/Women and Right/left sides groups, differences were not remarkable, but reinforcement makes noticeable changes. Also, mean values of viscous and elastic indices in UPDRS groups were remarkably different.

Statistical tests confirm the significances (Table 1). Mean values were significantly different between patients and controls groups ($p<0.05$). In Men/Women and Right/left sides groups, differences were not significant. ROM index showed no significance in UPDRS groups ($p=0.258$). Except for the NTH ($p=0.013$), there were no sensitivity to sex in indices. Finally, in all indices differences between with/without reinforcement groups were significant (Table 1).

TABLE 1.
P-VALUES OF STATISTIC TESTS. C: CONTROL, P: PATIENTS, R: REINFORCED, NR: NON-REINFORCED, TS: TOTAL SLOPE, TH: TOTAL HYSTERESIS, NTH: NORMALIZED TOTAL HYSTERESIS, ROM: RANGE OF MOTION.

Index	C/P	Sex	Side	R/NR	UPDRS
TS	0.000	0.508	0.390	0.000	0.000
TH	0.000	0.058	0.258	0.000	0.000
NTH	0.000	0.013	0.455	0.002	0.000
ROM	0.000	0.554	0.925	0.034	0.258

For better comparison, bar diagrams of TS and NTH in all groups are shown in Figures 4 and 5.

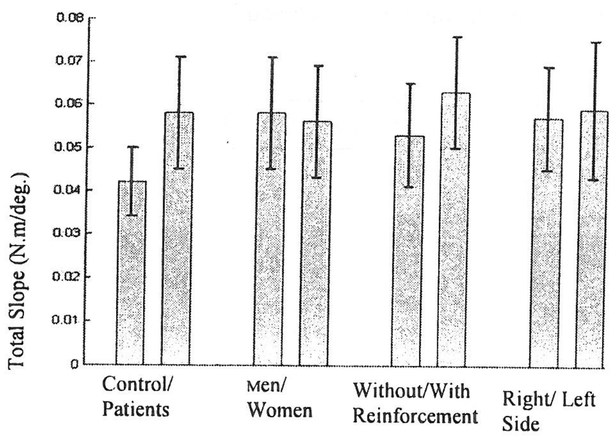

Figure 4 : Bar diagrams indicating mean and Std values of total slope in pre described groups.

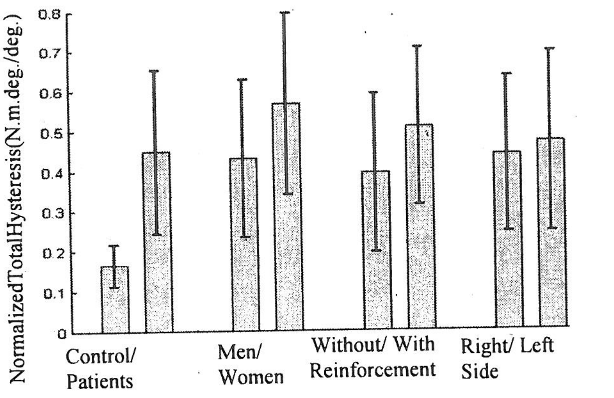

Figure 5: Bar diagrams indicating mean and Std values of normalized total hysteresis in pre described groups.

The level of correlation of the measures and UPDRS scores are shown in Table 4, where age is considered as an auxiliary index and data of controls were contributed as the zero level of UPDRS score. Results show the highest correlation between NTH and UPDRS score (r=0.860), while ROM and UPDRS have the lowest correlation (r = -0.326). Age and UPDRS have also low correlation.

TABLE 2.

PEARSON'S COEFFICIENTS OF CORRELATION BETWEEN INDICES AND UPDRS SCORE.

Index	r	p
Total Slope	0.740	0.000
Total Hysteresis	0.749	0.000
Normalized Total Hysteresis	0.860	0.000
Rang of Motion	0.326	0.000
Age	0.352	0.000

For the convenience of comparison, bar diagrams of Ts and NTH are shown in Figures 6 and 7.

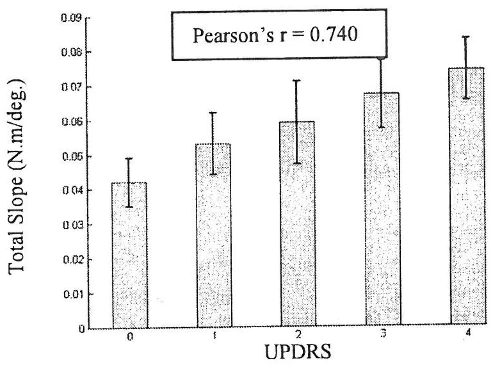

Figure 6 : Bar diagram indicating mean and std of total slope in various UPDRS levels of 0 to 4, and correlation coefficients of TS-UPDRS

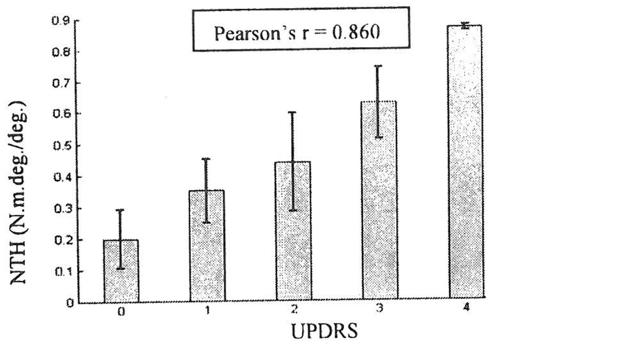

Figure 7 : Bar diagram indicating mean and std of normalized total hystersis in various UPDRS levels of 0 to 4, and correlation coefficients of NTH-UPDRS.

4. DISCUSSION

In this research, using a custom design test rig, viscous and elastic components of passive stiffness were measured. Some indices were extracted from these measures and the relations between each index and level of Parkinson's disease were studied.

Results showed that the test rig can be used to differentiate elastic and viscous indices well in control/ patients groups and among the UPDRS groups. Also, reinforcement increases stiffness indices, which has been proven to be a principal sign in Parkinson scoring clinically. Correlation tests indicated the highest coefficients for NTH implying that measuring the viscous properties may better score the level of the disease than elastic ones. Moreover, NTH had priority to TH, because of the physiologic differences in the range of motion in people, but decrease in ROM, by itself, may not be considered as a cardinal index. Although the risk of involvement increases with aging [1], our observations showed no correlation between age and the level of illness in rigidity dominant patients.

Kirollos and co-workers [5] examined work per unit displacement which was measured similar to what we did for NTH index. Mean ± STD of their index for patients with PD was 0.25±0.12 while our NTH index in patients was 0.447±0.205. It should be mentioned that they used only the end part of range of motion (115 to 155 degrees flexion) in calculation of their index while we used all range of motion in calculation of NTH.

Because of relatively big number of patients contributing in this research, the levels of significances in groups are very high which indicate the high reliability of tests. However, in this study the ordinal score of UPDRS for each patient was examined only by one physician. To decrease personal interpretation, in future researches it will be needed to make it possible that more than one professional physician perform clinical test on a patient at a same time. This process has been performed previously [2], but there have been other limitations: limited number

[7]of patients, using of model fitted index instead of real visco-elastic ones, and not to account for the weight of limb. Despite others [2, 8], we have accounted for the weight of the limb to calculate the net passive torque. In future studies, using sub components of visco-elastic indices (i.e. ,in flexion and extension ends), more precise results may be obtained.

5. CONCLUSION

Using results of this research, it may be possible to construct a standard objective method to score the level of PD. The method is not expensive and time consuming. To achieve a standard clinical method, more experiments and follow-ups are needed.

6. ACKNOWLEDGMENT

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