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Knee Extensor Strength, Dynamic Stability, and Functional Ambulation: Are They Related in Parkinson's Disease?

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Abstract

Objective—To evaluate the relationship between knee extensor strength, postural stability, functional ambulation, and disease severity in Parkinson's disease (PD).

Design—A cohort study.

Setting—University research laboratory.

Participants—Patients (N = 44) with idiopathic PD.

Intervention—Not applicable.

Main Outcome Measures—Participants were evaluated on their isokinetic knee extensor strength. Additionally, participants completed an assessment of their postural stability (Functional Reach Test for static stability and a dynamic postural stability assessment as measured by the center of pressure–center of mass moment arm during gait initiation). Participants also underwent an evaluation of their functional ambulation as measured by a 6-minute walk test. Lastly, participants were evaluated by a neurologist specially trained in movement disorders to assess neurologic status and disease severity using the Unified Parkinson's Disease Rating Scale and the Hoehn and Yahr disability score.

Results—Knee extensor strength positively correlated with dynamic postural stability and negatively correlated with disease severity. Further, dynamic postural stability was negatively correlated to disease severity and positively correlated with functional ambulation in this cohort of patients with PD ($P < .05$). The results also suggest that the Functional Reach Test may be a valuable assessment tool to examine postural stability in PD.

Conclusions—These findings suggest a malleable relationship between knee extensor strength, dynamic stability, and disease severity in PD. Although strength is only one piece of the puzzle in the functional outcome of PD, these findings may assist clinicians in designing appropriate interventions aimed at increasing function and decreasing fall risk in PD.

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Keywords

Movement disorders; Neurodegenerative diseases; Rehabilitation

Parkinson's disease is a neurodegenerative disorder characterized by progressive bradykinesia, rigidity, tremor, and gait abnormalities. The combination of aging, disease-specific degeneration, and disuse is often manifested by reductions in muscle strength and postural instability, leading to a decreased functional capacity and an increased risk for falls. Previous research has demonstrated that patients with PD fall at a significantly higher rate than their healthy peers.¹ Indeed, Wood et al² have estimated that more than 68% of PD patients fall annually, and more than 50% fall 2 or more times a year. Patients with PD are also more likely to sustain a fracture, and similarly, the falls lead to higher health care expenditures.³ These findings emphasize the importance of understanding the relationship between the multiple underlying risk factors of falls in PD.

Several studies^{4–11} have examined the relationships between knee extensor strength, postural stability, and functional task performance in elderly and disabled populations. These investigations suggest that decreases in muscular fitness (mass, strength, endurance) associated with aging may contribute to decreased postural stability and increased fall risk.¹² For example, Salem et al⁶ observed a significant linear relationship between knee flexion/extension torque and performance in functional tasks, such as brisk walking and chair rising in older adults. In addition, Scarborough et al⁷ found similar results in disabled elderly adults without neurologic disease, where maximum isometric quadriceps strength was associated with gait and chair rise times. Moreover, knee extensor strength was associated with impaired stair negotiation in community-dwelling older adults without neurologic disease.¹³ Thus, knee extensor strength may influence postural stability during functional task performance in older populations.

However, despite a significant body of evidence supporting the relationships between knee extensor strength and performance of functional activities and postural stability in older adults, limited comprehensive investigations of these factors relating to persons with PD have been performed. Inkster et al¹⁴ were among the first to document that leg strength, particularly hip extensor strength, was associated with chair-rising performance in persons with PD. More recently, Schilling et al¹⁵ observed that leg extensor strength also relates to functional mobility as measured by the Timed Up & Go. Similarly, Mak and Pang¹⁶ showed that increased temporal parameters observed during the Timed Up & Go test were associated with an increased risk of falls in patients with PD. However, no studies have evaluated associations between significant contributors to falls (eg, lower-extremity strength, postural stability, and disease severity) in persons with PD. Studying these associations might help to determine specific exercises that should be included in intervention strategies aimed ultimately at improving balance control, increasing function, and increasing quality of life. Therefore, this study investigated the relationships among knee extensor strength, postural stability, functional ambulation tasks, and disease severity in persons with PD. Based on the documented finding in healthy older adults and the growing PD literature, it was hypothesized that knee extensor strength would positively correlate with postural stability and functional ambulation in patients with PD. Further, we hypothesized that knee extensor strength and postural stability would negatively correlate with disease severity in PD.

METHODS

Participants

Forty-four patients with idiopathic PD (mean age $\pm$ SD, 66 ± 11 y; mean weight $\pm$ SD, 82.1 ± 17.1 kg; mean height $\pm$ SD, 174.3 ± 9.2 cm; modified HY disability score $\pm$ SD, 2.3 ± 0.5) volunteered to undergo strength, balance, and performance testing. These patients were recruited via advertisements within the university's Movement Disorders Clinic and through advertisements in neurologists' offices in the surrounding metropolitan area. All participants were receiving stable doses of dopaminergics, and evaluations were conducted while the patients were clinically "on," or fully responding to their PD medications (1–1.5 h after taking their antiparkinson's medicines). At the time of testing, none of the patients exhibited any dyskinesia, dystonia, or other signs of involuntary movement. Further, all participants were able to complete the experimental trials without incident or other disruption, such as festination or freezing. All participants provided written informed consent before participating in the study as approved by the university's institutional review board.

Knee Extensor Strength Testing

Participants were seated in the upright position with their lateral femoral condyle aligned with the lever-arm axis of rotation of a KinCom Dynamometer.^a Stabilization straps around the thigh and chest were used to fix the knee and trunk, respectively. The resistance pad attached to the lever arm was secured around the distal tibia just proximal to the malleoli. Gravity correction procedures were followed in accordance with the manufacturer's guidelines. Knee range of motion was set between 10° and 90° of flexion using mechanical stops. Participants placed their hands on the side edges of the seat and then performed 3 submaximal concentric repetitions at 60°/s with increasing effort for familiarization. During the testing session, participants performed 3 sets of 3 maximal effort knee extensions with a 2-minute rest between sets. Highest peak torque values were recorded in newton meters at 60°/s for each repetition. These tests were conducted bilaterally. The average peak torque was calculated for each leg.

Postural Stability Measures

Postural stability is the ability to maintain and/or control the body COM with respect to the base of support. We have chosen to evaluate postural stability during both static and dynamic conditions to provide better insight into the interrelationship among our variables of interest as the task demands increase.

Static postural stability: functional reach—The Functional Reach Test was used to assess static anteroposterior stability by measuring the maximum distance that the participant could reach forward beyond arm's length while standing over a fixed base of support. After the examiner explained and demonstrated the Functional Reach Test (for a review see Duncan et al¹⁷), each subject performed 1 practice trial followed by 3 test trials. The mean value from the 3 testing periods was used for statistical purposes.

Dynamic postural stability: center of pressure—center of mass moment arm—Dynamic postural stability is often defined as the ability to tolerate separation of the COM and COP while transitioning from one posture to the next or between a static to a dynamic state.¹⁸ During quiet standing, changes in COP reflect the nervous system's response to movement of the whole-body COM. When the distance between the COM and the COP projections (known as the COP-COM moment arm) increase, mechanical stability decreases

^aChattecx Corp, Chattanooga Group, 4717 Adams Rd, Hixson, TN 37343.

and postural control must act to return the COM to a stable position.^{19–23} During many activities of daily living, such as gait initiation, walking, rising from a chair, or when changing from one posture to another, the COM moves outside the base of support. The ability of the postural control system to tolerate the separation of the COP-COM during these activities is often used as a measure of dynamic stability. During these tasks, persons with impaired dynamic postural control constrain the separation of the COP and COM. Indeed, there appears to be a continuum of values for the peak COP-COM distance that may be related to underlying disability in postural control. Previous research suggests that the largest COP-COM moment arms are observed in healthy young adults and that the separation magnitude decreases with age and with disability, such as vestibular hypofunction and PD.^{20,22,24–26} We chose to evaluate the COP-COM during gait initiation because of the known difficulties associated with this task in PD, and because many falls in PD occur as a result of an inability to control the COM during self-initiated movements.

Gait initiation trials were performed along an 8-m walkway, containing a force platform surrounded by a 6-camera (60Hz) Peak Motus 3D Optical Capture system.^b Ground reaction forces were collected using a multicomponent force platform^c mounted flush with the walkway. Forces and moments along the 3 principal axes were sampled at 300Hz. Force platform data were subsequently used to calculate the instantaneous COP. The cameras and force platform recordings were time synchronized using the Peak Motus video analysis system.^b

During the testing session, participants wore dark-colored tight-fitting shirts, shorts, and athletic shoes. Passive retro-reflective markers were placed over landmarks in accordance with the Helen Hayes marker system. In addition, markers were attached bilaterally to the subject's styloid process of the ulna, lateral epicondyle of the humerus, and the acromium process. The 21 markers were used to construct a simple 9-segment model. Estimates of segment mass centers were based on Dempster's anthropometric data, and the location of the whole-body COM was calculated using the Peak Performance Software. The distance between the vertical projections of the COM and the COP²¹ in the transverse plane (fig 1) was calculated using LabVIEW software^d developed in our laboratory and is referred to as the "COP-COM moment arm" in this investigation.

Participants began each trial standing quietly on the force platform in a relaxed position. Initial positioning of the feet was self-selected. In response to a verbal cue, the participants initiated walking and continued walking for 5m. For each participant, 1 to 2 practice trials were followed immediately by 3 data collection trials for each leg performed at a self-selected pace. Thus, a total of 6 experimental trials were evaluated per person. The maximum distance between the COP and COM during the period from the go signal until heel strike of the swing limb was calculated and recorded.

Neurologic Evaluation

All participants were rated by a movement disorders-trained neurologist using the UPDRS and the HY staging scale in the patient's "on" state. The UPDRS is designed to follow the longitudinal course of the disease and is considered the clinical criterion standard for quantifying signs and symptoms of PD. It is made up of 4 sections: (1) mentation, behavior, and mood; (2) activities of daily living; (3) motor; and (4) complications of therapy. These sections are evaluated by interview, and as the disease progresses, UPDRS scores are known

^bPeak Performance Technologies Inc, 7388 S Revere Pkwy, Centennial, CO 80112.

^cBertec Instruments, 6171 Huntley Rd, Ste J, Columbus, OH 43229.

to increase (106 maximum). The HY, a subsection of the UPDRS, is used to determine stage (1–5) of PD.

Functional Ambulation

Functional ambulation was measured using the 6-minute walk test on a separate day (minimum, 48h). The 6-minute walk test reflects aerobic (cardiorespiratory) endurance, speed, balance, and agility during ambulation.²⁷ It also correlates with maximal oxygen uptake and disease prognosis in many clinical populations²⁷ and has been shown to have high test-retest reliability in PD.²⁸ The 6-minute walk test was administered on a 30m-long segment of a quiet hallway. The subject was instructed to walk as fast as possible for up to 6 minutes, and the total distance walked was recorded. The subject was allowed to rest or stop before 6 minutes, as desired, during the test. After completing the walk test, the patients rested for 15 minutes and repeated the test procedure. The mean value from the 2 testing periods was used for statistical purposes.

Statistical Analyses

We initially evaluated our performance variables based on the designation of the more and less affected sides defined from the side of symptom onset. We compared spatial temporal gait performance, gait initiation performance, and leg strength between the 2 sides using a repeated-measures design. The statistical analyses failed to detect any statistically significant side-to-side differences in any of the outcome measures. Further, based on the small effect sizes (<0.2), we determined there were no clinically relevant differences. Thus, we averaged across sides on all relevant measures. The average values were used for the correlational analyses. The parametric correlations (knee extensor strength, functional reach, COP-COM moment arm, and 6-minute walk test) were evaluated using Pearson correlation coefficients. For nonparametric correlations (HY, UPDRS motor, UPDRS total), Spearman rho correlations were computed. Normal distribution of all measurements was confirmed, and a P value of .05 or less was considered to be significant.

RESULTS

Participants' characteristics and outcome scores are provided in table 1. Pearson correlations between knee strength, postural stability, and the 6-minute walk test are provided in table 2. Additionally, Spearman ρ correlation coefficients (HY, UPDRS motor, UPDRS total) are provided in table 3.

Knee extensor strength negatively correlated with disease severity as measured by the HY. Knee extensor strength positively correlated with dynamic postural stability as measured by the COP-COM moment arm. Interestingly, dynamic postural stability also demonstrated a positive correlation with the Functional Reach Test and the 6-minute walk test. Further, dynamic postural stability negatively correlated with the HY, UPDRS motor, and UPDRS total. Although correlations do not provide predictions, in general, decreased knee extensor strength and dynamic stability consistently and statistically related to increased disease severity and decreased function in this cohort of patients with PD.

DISCUSSION

This study investigated the associations between knee extensor strength, postural stability (both dynamic and static), functional ambulation, and disease severity in patients with PD. Consistent with our hypothesis, knee extensor strength is positively correlated with dynamic stability in patients with PD. Also in support of our hypothesis, this work suggests that knee extensor strength and dynamic stability are significantly negatively correlated with PD

disease severity. This work also suggests that dynamic stability, as measured by the COP-COM moment arm, may be related to the 6-minute walk test and disease severity. As such, these data are the first to demonstrate that knee extensor strength could be associated with impaired balance and increased disease progression as measured by the HY.

A primary aim of this study was to examine the relationship between knee extensor strength and dynamic postural stability. Studies^{29–31} have identified several distinguishing postural abnormalities in patients with PD including (1) abnormally sized automatic postural responses, particularly enlarged “medium latency” stretch responses in lower-leg muscles; (2) inability to modulate the response magnitude to different postural demands; (3) delayed initiation or reduced scaling of voluntary postural responses; and (4) abnormal execution of compensatory stepping movements. In PD, these abnormalities have been demonstrated in a variety of functional tasks (eg, gait initiation, rising from a chair, and gait termination), thus predisposing patients to falls. The results of our study suggest that these dynamic postural stability abnormalities are at least partially explained by knee extensor function. Sadeghi et al³² have shown that the major role of the knee during locomotion in older adults is to control balance during single-limb support. Thus, it is not surprising we observed a significant relationship between knee extensor strength and the maximum COP-COM moment arm obtained during the single-limb support phase of gait initiation.

The correlation between lower-extremity strength and dynamic postural stability in older adults without neurodegenerative disease has been previously demonstrated.^{7,9,11} For example, in older, neurologically normal adults, fall risk has been correlated with decreased muscular output and difficulty performing functional tasks.^{6,33} Although the muscles of the lower extremity are shown to be important contributors to postural and locomotor stability,³² the association between knee extensor strength and dynamic stability in PD has not been previously demonstrated. A previous study by Nallegowda et al³⁴ demonstrated that in patients with PD, a reduction of muscle strength in the spine, hip, and ankle was among the main causes of postural instability. Our results demonstrate that in addition to the spine, hip, and ankle musculature, the knee extensor complex is an important contributor to postural control. Collectively, these results emphasize the critical association between lower extremity strength and the observed deficits in postural control in persons with PD. Additionally, similar to research examining gait in healthy older adults, these results show that knee extensor strength may be a fundamental component of the neuromuscular processes required for maintaining dynamic postural control in patients with PD.

The data from this study represent a means by which clinicians may, in the future, attempt to improve balance and decrease the risk of falls seen in this population, although a carefully controlled study is needed. Previous literature has shown that exercise interventions in elderly populations are associated with increased performance in both static and dynamic stability tasks.^{4,5,35–38} Additionally, research has demonstrated that the decrements in muscle mass and strength production in the PD population are malleable.^{39–41} Therefore, knee extensor weakness encompasses a reversible component of postural instability. Thus, a strengthening treatment may potentially reduce the risk of falls exhibited in this population. Interestingly, in a recent systematic review on the effects of exercise on PD, Dibble et al⁴² reported that all studies examined demonstrated improvements in postural stability and balance task performance. It is therefore important for clinicians to recognize the importance of lower-extremity strength in not only the elderly but in patients with PD as well.

The correlation between knee extensor strength and dynamic stability is not surprising in a neurodegenerative process such as PD. Postural stability requires 3 processes: (1) sensory organization, in which one or more of the orientation senses (somatosensory, visual, vestibular) are involved and integrated with the central nervous system; (2) a motor

adjustment process involved with executing coordinated and properly scaled neuromuscular responses; and (3) adequate tone of muscles, through which adjustments in postural control are achieved.^{29,43} Because PD impacts multiple domains, deficiencies in 1 or more of the 3 sensory processes required for postural stability can be debilitating. Dennison et al⁴⁴ compared groups of PD fallers and PD nonfallers and found that fallers distinguish themselves from nonfallers with greater impairment on the UPDRS motor examination score and the UPDRS activities of daily living score, as well as on the disability and mobility subscale scores of the UPDRS. Our results parallel those of Dennison in that we demonstrated a significant relationship between dynamic postural stability and disease severity (as measured by the UPDRS “on” motor and UPDRS total, as well as the HY).

In addition to the statistical relationship demonstrated between dynamic postural stability and disease severity, we found a statistical relationship between knee strength and the HY. Collectively, these findings demonstrate that the UPDRS scores may be a good predictor of overall lower-extremity function. These results parallel the findings of Song and colleagues⁴⁵ in which they demonstrated that impaired UPDRS total and motor scores were linearly associated with greater time to perform functional tasks including walking, sit to stand, and stair climbing.

Interestingly, we found no statistical relationship between knee extensor strength and functional ambulation in this population of persons with PD. These results are in line with the work by Falvo and Earhart,⁴⁶ which demonstrated that the results of the 6-minute walk test in persons with PD is explained in part by disease-specific characteristics and perhaps to a greater extent by impaired balance and a predisposition to falling. In support of those findings, we observed a significant association between 6-minute walk performance and dynamic stability, and between 6-minute walk and disease severity.

The Functional Reach Test is a clinical tool that has been shown to be valid in older adults and persons with PD in the evaluation of balance.⁴⁷ Not surprisingly, our results confirmed that the Functional Reach Test correlated with dynamic postural stability as well as disease severity as measured by the UPDRS motor and UPDRS total. The functional reach test may therefore be an appealing tool for clinicians to identify postural stability because of its ease of administration. Interestingly, our results failed to demonstrate that functional reach performance was associated with strength, as previously demonstrated in healthy older adults.^{7,8,48}

Study Limitations

The limitations in this study include a small sample size and homogeneity of the cohort. Future studies need to examine these correlations along the spectrum of patients with PD (eg, disease duration, motor subtypes, and greater disease severity). Further, although knee extensor strength was shown to correlate with dynamic stability and disease progression, the relationship explains only a small portion of the variance. Thus, it is likely that knee extensor strength is only one piece of the multifactorial puzzle. Given the propensity of falls in this population, clinicians and researchers alike need to further identify factors that increase the risk of falls (eg, increased cognitive load and medications). Lastly, examining knee extensor strength at higher velocities may have had a greater effect on muscle performance. Indeed, previous studies have shown greater differences between persons with PD and controls at higher velocities. However, we chose a velocity that was in the middle range of tested velocities in the previous literature and more in line with the typical knee extension velocities observed during the stance phase of gait in disabled populations.

CONCLUSIONS

These findings may have important implications for both clinicians and researchers. If the findings are confirmed in larger studies, they will affirm the importance of muscular strength contributions to dynamic stability. The observed relationship between strength and dynamic stability, when coupled with the observed negative correlation between knee extensor strength and disease severity, supports the notion that strength training of the lower extremity may be beneficial in this population. Further, it appears that dynamic stability as measured by the COP-COM moment arm is significantly associated with not only postural control but also functional ambulation and disease processes. Thus, this method of evaluation could prove a useful quantitative index to examine the impact of interventions designed to improve ambulation, balance, and disease severity in PD. Similarly, the robustness of the associations between functional reach performance and the other indices suggests that it may represent an effective surrogate measure and thus may reduce the number of functional and clinical tools required to assess function in persons with PD.

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List of Abbreviations

COM	center of mass
COP	center of pressure
HY	Hoehn and Yahr
PD	Parkinson's disease
UPDRS	Unified Parkinson's Disease Rating Scale

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Fig 1. COP-COM moment arm relationship. When the distance between the COM and the COP projections (known as the COP-COM moment arm) increases, mechanical stability decreases and postural control must act to return the COM to a stable position.

Table 1

Participant Age, HY Score, UPDRS Scores, Functional Reach, Knee Strength, Dynamic Stability, and Walk Distance (N = 44)

Variables	Values
Age (y)	68.3 ± 4.24
UPDRS motor	21.4 ± 6.42
UPDRS total	38.92 ± 11.9
HY	2.26 ± 0.4
Functional reach (cm)	29.10 ± 7.0
Knee strength (Nm)	102.41 ± 40.77
COP-COM (cm)	3.19 ± 0.54
Six-minute walk (m)	479.23 ± 139.54

NOTE. Values are mean ± SD.

Table 2

Pearson Correlation Coefficients and *P*Values Between Functional Measures Including Functional Reach, Knee Strength, Dynamic Stability, and 6-Minute Walk

Functional Measures	Functional Reach	Knee Strength	Dynamic Stability	Six-Minute Walk Distance
Functional reach		.221	.367	-.017
<i>P</i>		.177	.018	.914
Knee strength	.221		.500	.248
<i>P</i>	.177		.001	.127
Dynamic stability	.367	.500		.529
<i>P</i>	.018	.001		.000
6-minute walk	-.017	.248	.529	
<i>P</i>	.914	.127	.000	

Table 3

Spearman Coefficients and *P* Values Between UPDRS Motor, UPDRS Total, HY and Functional Reach, Knee Strength, 6-Minute Walk, and Dynamic Stability

Functional Measures	UPDRS Motor	UPDRS Total	HY
Functional reach	-.266	-.275	-.248
<i>P</i>	.08	.07	0.1
Knee strength	-.246	-.116	-.484
<i>P</i>	.13	.48	.002
Dynamic stability	-.36	-.411	-.517
<i>P</i>	.021	.008	.001
6-minute walk	-.219	-.114	-.444
<i>P</i>	.15	.46	.003