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Novel Robotics-Treadmill Platform Application to Improve Walking in a Person with Parkinson's disease: A case report

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Abstract

Background: Parkinson's disease (PD) results in a distinct, slow, and less steady walking pattern due to changes in posture, poor balance control, reduced muscle strength, reduced endurance, slowed movement (bradykinesia). This case report describes a 6-week novel robotic treadmill system and training protocol focused on key neuromechanical elements required to improve walking performance in an older adult with PD.

Methods: An 82-year-old-female with a 3-year history of PD (Hoehn and Yahr stage 1) was referred to physical therapy (PT) to improve performance and safety of walking. She participated in twice-weekly PT sessions over 8 weeks using a robotic treadmill platform (KineAssist) that allows "self-driven"/intentional movement with body weight support and safety from falls, and the ability to provide resistive forces to improve strength, provide forward-aiding forces to improve speed, and balance perturbations to improve dynamic stability.

Results: Participant showed large-scale improvements across all outcomes assessed. The 6MWT distance improved 51% (318-481m); the TUG time improved 53% (10.3-5.5 sec); the TUG Carry, 50% faster (13.7- 6.8 sec); the TUG Cognitive, 50% faster (13.2- 6.5 sec), the Mini-Best Test improved 8 points (18/28-26/28). The self-selected 10MWT speed improved 196% (0.27- 0.8 m/s) and top walking speed by 120% (1.0-2.2 m/s).

Conclusions: An individualized robotic treadmill gait training protocol was successfully used with an older person with PD, and contributed to marked improvement in her endurance, strength, speed, and dynamic stability, exceeding available minimal clinically important distances for all outcome measures. Neuromechanical challenge via a robotic treadmill, may enable individuals to perform walking related training tasks with reduced fear of physical harm and to develop strategies for safe mobility in their environment.

Keywords: Parkinson's disease, Robotic treadmill, Gait, Rehabilitation

Introduction

Gait dysfunction is one of the most disabling motor consequences of Parkinson's disease (PD), usually associated with balance impairment, slow walking speed, poor strength and endurance, an increased risk of falling, loss of independence, and decreased quality of life [1]. Medications that boost dopamine levels in the brain only slightly improve gait and postural instability [2]. Physical rehabilitation is a well-recognized supplement to pharmacological and neurosurgical treatments for PD [3]. Various exercise technologies, such as specialized treadmills, have been used to treat gait impairments in PD as a restorative measure. Walking on a treadmill, which imposes a normal speed and serves as an external pacemaker, can improve one's gait characteristics [4]. It has also been shown that additional somatosensory cues, such as flashing lights, contrasting lines on the floor, rhythmical sounds, and Virtual Reality (VR), can be beneficial [5-8]. The recent use of treadmill gait training with robotic assistance is also a promising therapy [9-12].

One newly available robotics platform used for balance and mobility training operates within an challenge based training approach and allows participants to perform difficult walking and balance tasks beyond their threshold of confidence [13,14]. "Self-driven" or intentional movement on a treadmill supports the development of individualized speed walking and fall risk reduction strategies for safely moving within the training environment without fear of bodily harm. The training environment is more enriched, engaging, and stimulating than traditional balance and gait exercises, sustaining attention and encouraging motivation to perform tasks at a high level. It also provides immediate feedback about performance.

This approach to motor training has been shown to improve walking kinematics, speed, strength and endurance, and dynamic balance which are the principal limiting factors of Parkinsonian gait [15]. The purpose of this case study was to describe the use of an individualized gait training protocol, focused on the key elements of walking endurance, strength, speed and dynamic stability on a novel robotic treadmill platform in an outpatient rehabilitation clinic for an individual with PD referred to physical therapy for gait rehabilitation.

Case presentation

The individual was an 80-year-old female diagnosed with PD three years prior. Her symptoms started eight years earlier with left-hand tremors. She reported a gradual decline in mobility since that time, particularly with walking. She completed an LSVT BIG program two years prior but was unsure of any related improvements because she had a total knee replacement around the same time. Difficulty walking long distances was a primary concern. Other gait problems included those often seen with PD, i.e., overall unsteady gait, shuffling, and difficulty walking in tight spaces with obstacles. She was also prone to tripping, especially when changing directions or completing a side task. Past medical history included Basal Cell Carcinoma (BCC), elevated Fasting Blood Glucose (FBS), osteoarthritis, Hypertension (HTN), hypercholesteremia, and hypothyroidism.

At the time of the case report, she presented as overall Hoehn and Yahr stage 1. The Hoehn and Yahr is used to stage the functional disability associated with PD. (Hoehn and Yarn scale [16]) Her medication regimen consisted of Levodopa-Carbidopa 4 times daily, Acetaminophen 325mg as needed, Amlodipine 5 mg daily, Levothyroxine 50 mcg daily, Magnesium oxide 500 mg daily, Rivastigmine 9.5 mg/24 hour patch, and Cholecalciferol, Vit D3, 125 mcg daily. She presented with mild dyskinesias that began in the past year. She reported that her "on", and "off" phases had become more pronounced recently. Strength and range of motion were within normal limits throughout, and she was overall independent with basic transfers. There were no reported limitations in sensation or kinesthetic awareness.

Based on her initial clinical impression, it was decided that primary outcomes would measure walking balance, balance confidence, overall mobility while turning and multitasking, walking endurance, and lower extremity functioning. The primary outcome measures were the following.

Mini Balance Evaluation System (BEST) test

The 14-item Mini BESTest is designed to target and identify dynamic balance, and it covers 4 of the 6 sections found in the full BESTest. 1) Anticipatory postural correction 2) Postural control that is reactive 3) Sensory orientation 4) Dynamic gait. This test has a great correlation with BESTest (r=0.955) [17]. It has an excellent test retest reliability (ICC=0.92) [17] and inter-rater reliability (ICC=0.91) [17]. The minimal detectable change for this test is 17.1% or 5.52 points [17].

Activities Balance Confidence Scale

The ABC scale is a 16-item self-report measure of balance confidence in performing various activities without losing balance or experiencing a sense of unsteadiness. Each item is rated on a rating scale ranging from 0-100 that 0 representing no confidence and 100 representing complete confidence. The overall score was calculated by adding a number of scores and then dividing by the total number of items. The minimal detectable change for Parkinson's disease is 11.12. [18] The cut-off score predictive of recurrent falls is 69% (AUC=0.823, sensitivity 93%, specificity 69%). This test has an excellent test-retest reliability for Parkinson's disease (ICC=0.96) [19] and also has a perfect internal consistency (Cronbach's alpha=0.91) [20].

Timed Up & Go Test

The Timed Up and Go test (TUG) is a physical performance measure used to assess and track a patient's risk for falls and basic functional mobility [20]. The patient began sitting in a standard-height chair. Next, she was asked to walk to a mark three meters from the start, turn around, and return to the chair in the sitting position. Walking speed was described as a safe and comfortable speed. The time was recorded [20]. This measure has good test-retest reliability with an internal consistency coefficient of 0.75 (95% CI: 0.74, 0.94) [21]. The minimal detectable change of the TUG is 3.5 seconds [14].

TUG Manual & TUG Cognitive

The TUG Manual is a dual-task dynamic measure designed to identify individuals at risk for falls. She was asked to take the TUG test while holding a cup full of water. The greater than the 4.5-second difference between the TUG manual and TUG indicated an increased risk of falls for Parkinson's patients [22].

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the TUG Cognitive is a dual-task dynamic measure designed to identify individuals at risk for falls. She was asked to take the TUG test while counting backward by threes from a random number between 20 and 100. TUG cognitive has a 71% positive predictive value for falls in older adults, whereas TUG simple has a 42% positive predictive value [22].

Five-times-sit-to-stand
An aspect of transfer skill and lower function is measured by the Five Times Sit to Stand Test. The test measures functional lower extremity strength and/or identifies movement strategies used by a patient to complete transitional movements. She was asked to stand up and sit down for 5 times as quickly as possible. Cut off score of 16.0 seconds, discriminates patients at higher risk of falling from patients at lower risk [23]. This test has an excellent test retest reliability (ICC=0.91 (0.82-0.96)), [24] and also an excellent inter reliability value (ICC=0.99) [23].

Six-Minute Walk Test
The six-minute walk test (6MWT) is a performance measure that can assess fall risk, walking speed, and walking endurance [20]. She was instructed to walk as much distance as possible during the six minutes in an obstructed area in the clinic; breaks were allowed, if needed. The 6MWT has excellent test-retest reliability, with a minimal detectable change of 61.34 meters [20].

The KineAssist MX detects and follows human movement. The mobile base uses a forward-backward belt system that allows the device to be guided by the user's movements. The robot interface becomes virtually undetectable and allows for easy forward and turning motions while the machine moves in response to the patient's motion, this admission control methodology provides a haptic interface that compensates for the inertial effects of the robot. Pelvic harness forces are used to drive system motion. The patient can bend to the left and right, forward, and backward, and rotate about the forward axis with the help of the trunk and pelvis mechanism. Torso mechanisms are attached at chest level and can keep the trunk from collapsing forward. Trunk support has an adjustable, compliant constraint that can be used to catch patients if they lose their balance in a software-driven safety zone. Not only does this device prevent falls, but it can also provide body-weight support on their pelvis and apply backward forces to their pelvis for more intense resistance training (analogous to walking uphill) and apply forward-aiding forces for more intense speed training (analogous to walking downhill) [25]. Measures assessed on the KineAssist included:

- 6-minute walk test: the distance in meters walked on the treadmill platform in six minutes.
- Max resistance test: the maximum backward horizontal resistance applied at the hip level that she could overcome while walking at a >0.3 m/s speed
- Top walking speed: 1) top walking speed accomplished under conditions of forward-aiding forces with the successful completion of five complete strides in three successive trials without tripping, falling, or running; 2) comfortable walking speed during a 10-meter walk test (10MWT) on the robotic treadmill.
- Dynamic balance: assessed by instructing the patient to walk at her comfortable speed on the treadmill platform. A backward perturbation to the treadmill belt was applied by the device. "Passing" a trial constitutes an appropriate balance response and little to no interruption in walking. If she passed the trial, the trial was repeated, and the velocity of the perturbation increased. Trial was repeated until she lost her balance or failed to continue to move forward or did not wish to continue.

Intervention
Gait training was provided by the KineAssist, consisting of a mobile treadmill system and a harness system as the two primary components. The KineAssist system was well accepted by the client during a testing session. According to her, the trunk and pelvic supporting systems did not cause any discomfort.

A formal standardization procedure was used. Prior to testing, her weight, height, age, blood pressure, and resting heart rate were recorded, and the maximum safe heart rate was calculated for the participant. Each session took place over a 1-hour period. There were two evaluation sessions prior to the training sessions (one overground and one on the robotic treadmill) and 2 evaluation sessions at the end of the training sessions (one overground and one on the robotic treadmill).

The therapy course consisted of twelve sessions, scheduled 2 times a week for 6 weeks, distributed equally over each specific training approach (Endurance x 3, Strength x 3, Speed x 3, and Dynamic Balance x 3) (Figure 1). The robotic treadmill training sessions lasted approximately 50 minutes

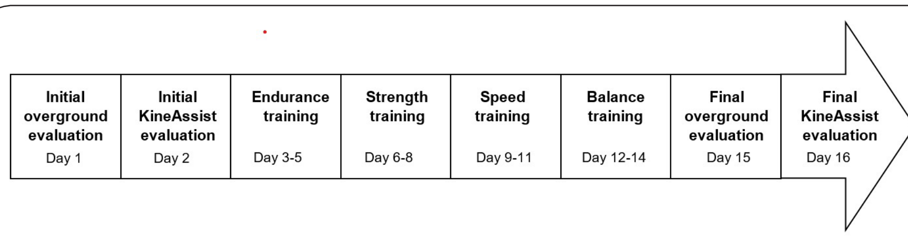

Figure 1. The chronology of evaluations and protocol training sessions.

and included a warmup phase (approximately 5 min) and cool down phase at the end (5 minutes). At the beginning of each session, her ideal level of body weight support (BWS) was identified by using 10-meter walk test (10 MWT) at 0%, 10%, 20%, and 30% BWS. We Chose the BWS that generates the fastest speed (+/0.08 m/s) at the lowest BWS value.

Endurance training consisted of 6 x five-minute bouts of walking on the self-driven mode (participant walks at self-determined speed) with comfortable walking speed (CWS) that targets 60-80% maximum heart rate (Max HR) reserve. Her heart rate was monitored for each minute. If her heart rate rose above 80% target heart rate (THR), we asked her to slow down or back off a until it is less than 80% THR.

Resisted-walking training consisted of 4 x five-minutes bouts of walking on the treadmill with backward directed resistance applied at the hip while walking at high effort. The backward horizontal resistance level was set to allow 12 continuous steps with <20% decrease in comfortable walking speed, and resistance was increased with each successful bout. If, due to fatigue, she was not able to sustain the speed after a few bouts, we would incrementally decrease the resistance until she could complete 12 continuous steps again.

Top walking s*peed training* consisted of 4 x five-minutes bouts of walking on the treadmill, with forward aiding forces applied at her hip. Beginning with her fastest 10 MWT speed, the treadmill speed was increased by 0.2 m/s each time until she could no longer succeed in keeping up with the speed of the treadmill and a subsequent loss of balance occurred (with safety catch engaged to prevent fall). The participant was asked to catch up to the speed and maintain for a total of 10 steps. Six total bouts of top walking speed were performed.

Dynamic balance training consisted of 3 x five-minutes bouts of walking on the treadmill with comfortable walking speed while experiencing intermittent backward perturbations at a set speed level. The treadmill belt would be programmed to accelerate to a new speed that was added to the current walking speed for a brief period (less than one second). 4 total bouts of maximum perturbation speed were performed, and for each successful trial, the clinician increased the belt's perturbation speed, until she could not recover from the disturbance and continue to walk in a forward direction without falling or tripping.

Outcomes

There was marked improvement across all gait measures (**Table 1**). Improvements exceeded Minimal Detectable Change (MDC), however, there was little change in the measure of lower extremity strength (5XSTS). After completing therapy, she subjectively reported that she was "extending her hips and knees more and moving her feet further forward". The ABC change reflected her statements about feeling more confident when walking over uneven terrain and obstacles and that she wasn't afraid of falling, which usually made her cautious when turning.

We also performed initial and discharge evaluation scores and percent change from the assessments performed on the robotic treadmill. Similar meaningful improvements were observed for those assessments (**Table 2**).

To depict change in performance across training sessions, we calculated a mean performance metric (e.g., distance walked, resistance applied, top walking speed, speed of perturbations) for each session based on the total number of exercise bouts within that session. For example, we reported the mean distance of 6, five-minute bouts of walking for the endurance training (See **Table 3**).

Discussion

The purpose of this case report was to describe a 6-week novel personalized gait and balance training for an 80-year-

Table 1. The initial and final overground evaluation outcomes.

	Initial Evaluation	Discharge Evaluation	Percent Change	MDC
6 MWT (m)	318	480.8	51%	61.34
Mini BESTest	18	26	44%	5.52
5TST (sec)	6.6	6.8	3%	2.3
TUG (sec)	10.3	5.5	46%	3.5
TUG manual (sec)	13.7	6.8	50%	2.49
TUG cognitive (sec)	13.3	6.5	51%	2.49
ABC score (%)	52	68	16%	11.12

m= meter; %= percentage; sec= seconds;
6MWT= 6-Minute Walk Test; ABC= the Activity-specific Balance Confidence Scale; 5TST= 5-Time Sit-to-Stand; TUG= Time Up and Go; TUG manual= Time Up and Go manual;
TUG cognitive= Time Up and Go cognitive.

Table 2. Initial and final evaluation of the participant's performance on the robotic treadmill (KineAssist).

	Initial Evaluation	Discharge Evaluation	Percent Change
10 MWT (m/s)	0.39	0.84	115%
Resistance test (lb.)	17	30	76%
Top speed test (m/s)	1.0	2.2	120%
6 MWT (m)	161	236	46%
Perturbation test (m/s)	0.6	0.9	50%

m/s= meter/second; lb.= pounds; m= meter; 10 MWT= 10-Meter Walk Test; 6 MWT= 6-Minute Walk Test
10 MWT= walking at a comfortable walking speed on the KineAssist on its self-driven mode for 10 meters. We repeated that for three times and calculated the mean speed; Resistance test: the maximum backward directed resistance applied at the hip while walking on the KineAssist at high effort with 12 continuous steps and <20% decrease in walking speed; Speed test: maximum walking speed accomplished with the successful completion of 10 steps in three successive trials without tripping, falling, or running; 6 MWT: the distance the client walked on the KineAssist on self-driven mode for 6 minutes; Perturbation test: the maximum backward perturbation speed that the client can overcome without tripping or falling.

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Table 3. Training session's performance on the robotic treadmill (KineAssist).

	First Session	Second Session	Third Session
Endurance Training, Mean 5 min Distance (m)	154	148.6	171.3
Resisted-Walking Training, Mean Backward Resistance (lb.)	21	20.6	23.8
Top Walking Speed Training, Mean Top Speed (m/s)	1.4	1.3	1.9
Dynamic Balance Training, Mean Top Perturbation Speed (m/s)	0.9	1.0	0.7

Performance scores represent the mean distance walked, resistance applied, top walking speed, and speed of perturbations for each session based on the total number of exercise bouts within that session; m/s= meter/second; lb.= pound; m= meter.

old woman with PD (Hoehn and Yahr stage 1) using a robotic treadmill system protocol that emphasized intense training and implicit learning of challenging tasks to improve walking safety, endurance, speed, strength, and dynamic balance. She demonstrated marked improvement in all walking measures, vastly exceeding available minimal detectable changes in most outcomes. A challenge-based approach combined with a robotic treadmill enabled the delivery of an intense level of challenging tasks without fear of physical harm and appeared to allow this client to develop her own strategies for more functional and safe mobility.

Both the KineAssist measures and overground outcome measures, demonstrated a meaningful improvement in outcome measures. The KineAssist device allows the selection of self-driven and push mode features. We used push mode for the top-speed training and used the self-driven mode for the endurance, strength, and dynamic balance training. In the self-driven mode, the KineAssist imposes some constraints at the speed and distance because of the small amount of deadband resistance (approx. 3 lbs) that the participant has to overcome to move the belt. This is a product safety feature that prevents the treadmill belt from unsteadiness during the stance phase. Patients may therefore walk for longer distance and faster overground, in comparison to the self-driven mode of the KineAssist. In push mode, the test administrator uses a joystick to control the speed of the treadmill belt. The treadmill belt accelerates regardless of the participant's generated force, like with any traditional treadmill and the participant can walk faster on the device compared with overground.

The marked improvement in 6MWT scores observed in this case suggests the moderate- to high-intensity walking training utilized was a key component. Achieving a training heart rate of 60-80% of maximum heart rate was a goal for each session and likely helped ensure a level of challenge needed to induce neurophysiologic change [26-28]. Several studies have shown that the potential mechanisms for high-intensity resistance and aerobic training induced neuromuscular remodeling and improved motor function may be related to the upregulation of genes that enhance muscle development [29-31]. These studies have also shown that central motor pathways exhibit altered neuroplasticity following intensive resistance and aerobic training even with advanced age and the neurological dysfunction associated with PD [29-33].

Meaningful improvements were also seen in measures of her overall mobility, dual task-cost performance, balance confidence, and walking speed. Robotic rehabilitation therapy can provide high-dosage, high-intensity training, making it beneficial for patients suffering from motor disorders caused by neurological diseases [34]. Safety concerns can be a limitation to the extent a clinician can effectively challenge a patient while training overground due to concern for falls or other injuries. Specialized treadmills, as was used in this case, can provide a more challenging training environment that is not easily accomplished with usual guarding practices overground.

It was noteworthy that improvements in her walking and balance occurred in the absence of change in overall lower extremity strength and function as measured by the 5TST. The 5TST is a well-validated test of lower extremity strength and assesses the ability to repeatedly rise from a chair [35]. Although our client progressed in the intensity of strength training sessions by overcoming greater backward resistance on the treadmill, her 5TST score was relatively unchanged. The underlying mechanism for this observation could be that by safely exposing this client to rigorous walking and balance challenges we were able to take advantage of the fundamental principal of specificity of training: [36-38] a person must perform the skill (e.g., faster gait, recovery from a loss of balance) in order to get better at it. This training protocol emphasized the development of the client's own walking strategies for safely moving within the environment as well. Improvements seen were likely more associated with motor learning and neurophysiologic changes than strength.

The evidence to date on the effective of robotic treadmills for gait rehabilitation has focused primarily on robotic assistants that emphasize producing more normal walking patterns by providing assisted movement [39]. This assisted movement, however, can reduce the patient's effort of walking and challenges to balance as well as minimize training intensity. The KineAssist does not emphasize mimicking normal gait. The technology is aimed at providing a safe walking environment (i.e., catching feature, full pelvic range of motion) to facilitate more intense training experiences, which is essential for gait rehabilitation. This is likely a distinguishing feature between the training approach used in this case and other robotic treadmills.

Although this case describes marked gait and balance improvement for a client with PD, there are limitations. While robotic treadmill-assisted therapy is a promising tool, it is still unclear through what mechanism of training this particular approach achieves its effects: i.e., via the endurance training, backward-resistance training, maximum speed training, perturbation training, or its body-weight support feature. The intensity and specificity of training within an implicit learning context is likely an underlying key feature allowed by this technology, however. Direct head-to-head comparisons between more conventional overground training and robotic treadmills that utilize, and implicit learning approach would also help in estimating magnitude of effect and efficiency over other locomotor training approaches.

Conclusion

In conclusion, this intervention incorporating a challenge-based approach with high intensity exposure on a robotic treadmill appeared to be effective in assisting this client with PD achieve meaningful gains in balance and walking. These are relatively early stages in the development of human-machine interactions, and future studies need to be designed to explore further potential benefits that this technology can bring to rehabilitation.

List of abbreviation

PD: Parkinson's Disease
BCC: Basal Cell Carcinoma
FBS: Fasting Blood Glucose
HTN: Hypertension
mini-BEST test: Mini Balance Evaluation System test
ABC scale: Activities Balance Confidence Scale
TUG: Timed Up & Go
6MWT: six-minute walk test
10MWT: 10 meter walk test
BWS: body weight support
CWS: comfortable walking speed
HR: Heart Rate
THR: Target Heart Rate
MDC: Minimal Detectable Change
5XSTS: 5 Times Sit to Stand

Competing interests

The authors declare that they have no competing interests.

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Authors have no relevant interest to disclose. David Brown is a co-inventor of the KineAssist device but does not receive any royalties. This study was funded by Moody Endowment grant.

Authors' contributions

Authors' contributions	NM	ST	CF	DAB
Research concept and design	--	√	--	√
Collection and/or assembly of data	√	--	√	--
Data analysis and interpretation	√	√	--	--
Writing the article	√	√	--	--
Critical revision of the article	√	√	--	√
Final approval of article	√	√	√	√
Statistical analysis	√	√	--	--

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