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Article

Hemodialysis impact on motor function beyond aging and diabetes – Objectively assessing gait and balance by wearable technology

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Abstract: Motor functions are deteriorated by aging. Some conditions may magnify this deterioration. To examine whether hemodialysis (HD) process would negatively impact gait and balance beyond diabetes condition among mid-age adults (48-64 years) and older adults (65+ years). One hundred and ninety-six subjects (age=66.2±9.1 years, body-mass-index=30.1±6.4 kg/m^2, female=56%) in 5 groups were recruited: mid-age adults with diabetes undergoing HD (Mid-age HD+, n=38) and without HD (Mid-age HD-, n=40); older adults with diabetes undergoing HD (Older HD+, n=36) and without HD (Older HD-, n=37); and non-diabetic older adults (Older DM-, n=45). Gait parameters (stride velocity, stride length, gait cycle time, and double support) and balance parameters (ankle, hip, and center of mass sways) were quantified using validated wearable platforms. Groups with diabetes had overall poorer gait and balance compared to the non-diabetic group (p<0.050). Among people with diabetes, the HD+ had significantly worsened gait and balance when comparing to the HD- (Cohen's effect size d=0.63-2.32, p<0.050). Between-group difference was more pronounced among older adults with the largest effect size observed for stride length (d=2.32, p<0.001). Results suggested that deterioration in gait speed among the HD+ was correlated with age (r=-0.440, p<0.001), while this correlation was diminished among the HD-. Interestingly, results also suggested that poor gait in the Older HD- related to poor balance, while no correlation was observed between poor balance and poor gait among the Older HD+. Using objective assessments, results confirmed that the presence of diabetes can deteriorate gait and balance, and this deterioration can be magnified by HD process. Among non-HD people with diabetes, poor static balance described poor gait. However, among people with diabetes undergoing HD, age was a dominate factor describing poor gait irrespective of static balance. Results also suggested feasibility of using wearable platforms to quantify motor performance during routine dialysis clinic visits. These objective assessments may assist in identifying early deterioration in motor function, which in turn may promote timely intervention.

Keywords: hemodialysis; end stage renal disease; diabetes; motor performance; gait; balance; wearable; aging; frailty; diabetic peripheral neuropathy

1. Introduction

Motor function, such as gait and balance ability, is the major determinant of an independent and productive life [1]. Gait and balance are essential for predicting poor quality of life, morbidity, and

mortality [2, 3]. Aging causes deterioration in the sensory systems and changes the pattern of muscle activity, leading to degradation in gait and balance [4-6]. In addition, chronic disease, such as diabetes mellitus (DM) and end stage renal disease (ESRD), could accelerate this degradation. For people with diabetes and ESRD undergoing hemodialysis (HD) process, degradation in gait and balance may be even worse [7-9]. These patients are often required to visit dialysis clinic 3 time per week and spend 4 hours each time to receive HD process. After HD process, they are often exhausted, limiting their ability to be physical active. Long immobility may lead to muscle loss, which in turn may deteriorate motor function. Without timely intervention, motor function deterioration in HD patients may lead to serious adverse outcomes, including foot ulcer, amputation, early frailty, risk of falling and, loss of independency, which may further complicate their conditions. Together, with the increasing HD population [10], it imposes huge burden to the health care system [11].

Currently, it is still unclear why people with diabetes and ESRD undergoing HD process have poor gait and balance. Some researchers believe it is diabetes and diabetic peripheral neuropathy (DPN) causing the motor function impairment [12-14]. Petrofsky, J., et al. demonstrated that autonomic neuropathy, which is very common in HD population, can cause gait ability impairment [15]. Some studies show that through the HD process, certain blood particulates are not able to easily pass through the filter and can accumulate in the body and form amyloid deposits in the joints, causing movement disorders [16]. In addition, there are also studies reported immobility and sedentary behavior caused by post-dialysis fatigue can accelerate motor function degradation [17].

A few previous studies compared motor performance of HD patients with healthy controls [7-9], but these studies suffer from several shortcomings limiting the understanding of negative effect of HD on motor performance beyond diabetes and aging. Some of the limitations include self-reported bias, semi-subjective inaccuracies, focusing on only gait or only static balance, as well as lack of comparison between people with diabetes undergoing HD and without HD. Due to the prolonged HD process, post-dialysis exhaustion, limitation of transportation to research facilities, as well as immobility caused by HD, it is often impractical to bring HD patients, in particular older HD patients, to a dedicated gait laboratory for study [18]. Even a study could be conducted in the gait laboratory, the results may still be biased since the study sample is limited to non-cohort selected HD population (those with better condition who can visit a gait laboratory).

Recent advances in wearable technologies have opened new opportunities to objectively assess motor performance in place anytime and anywhere [19-24]. Using wearable sensors, no dedicated lab environment is required. As a result, motor function assessments, such as gait and balance tests, can be performed in any clinical setting, during patients' routine dialysis visits. In this study, we used wearable sensors and validated algorithms to objectively assess gait and balance performances of people with diabetes undergoing HD in the dialysis clinic. This approach may better replicate cohort HD population, who regularly visit dialysis clinics. We compared their gait and balance performances with non-HD people with diabetes, as well as with age-matched non-diabetic controls. The hypotheses of this study are: 1) compared to age-matched non-diabetic controls, people with diabetes have poorer gait and balance irrespective of HD process, 2) HD magnifies decline in gait and balance irrespective of aging; 3) HD caused motor function deterioration is more pronounced among older adults than mid-age adults; and 4) deteriorations of gait and balance in HD patients are associated with aging.

2. Methods

2.1. Study Population

One hundred and ninety-six eligible subjects were recruited in this study: 78 mid-age (48-64 years old) adults with diabetes ('Mid-age DM+'), 73 older (65-90 years old) adults with diabetes ('Older DM+'), and 45 older (65-88 years old) non-diabetic controls ('Older DM-'). Furthermore, based on ESRD/HD condition, the Mid-age DM+ group was further classified into 'Mid-age HD-' (n=40) and 'Mid-age HD+' (n=38) groups. Similarly, the Older DM+ groups was further classified into 'Older HD-' (n=37) and 'Older HD+' (n=36) groups. Subjects were excluded from the study if they were non-

ambulatory, had severe gait or balance problem (e.g., unable to walk a distance of 15 meters independently with or without assistive device or unable to stand still without moving feet), or were unwilling to participate. All subjects signed a consent form for this study. This study was approved by the local institutional review boards.

2.2. Demographic and Clinical Information

Subjects' demographics including age, gender, body-mass-index (BMI), and fall history were collected. All subjects underwent clinical assessments, including Fall Efficacy Scale - International (FES-I) [25], Center for Epidemiologic Studies Depression scale (CES-D) [26], and Physical Frailty Phenotype [27]. Subject with diabetes also underwent Vibration Perception Threshold test (VPT) [28], Ankle Brachial Index test (ABI) [29], and glycated hemoglobin test (HbA1c) [30]. The FES-I and its cutoff score, as suggested by Delbaere, K., et al. [31], were used to identify subjects with high concern about falling. The CES-D short-version scale was used to measure self-reported depression symptoms. A cutoff of CES-D score of 16 or greater was used to identify subjects with depression [32]. The Physical Frailty Phenotype, including unintentional weight loss, weakness (grip strength), slow gait speed (15-foot gait test), self-reported exhaustion, and self-reported low physical activity, was used to assess frailty [27]. Subjects with 1 or 2 positive criteria were considered pre-frail, and those with 3 or more positive criteria were considered frail. Subjects negative for all criteria were considered robust [27]. Plantar numbness was evaluated by the VPT measured on six plantar regions of interest, including the left and right great toes, 5th metatarsals, and heels. A subject was designated with Diabetic Peripheral Neuropathy (DPN) if his/her measured VPT value for any of the six plantar regions of interests reached 25 volts or greater [33]. The ABI was calculated as the ratio of the systolic blood pressure measured at the ankle to the systolic blood pressure measured in the upper arm. A subject was designated with Peripheral Artery Disease (PAD) if his/her ABI value was either greater than 1.2 or smaller than 0.8 [34].

2.3. Gait Test

For all subjects, two wearable sensors (LegSys™, BioSensics, MA, USA) were attached to left and right lower shins to quantify gait parameters of interest (Figure 1). Subjects were asked to walk with their habitual gait speed for 15 meters as suggested in previous studies [35, 36] without any distraction. Gait parameters, including stride velocity (unit: m/s), stride length (unit: m), gait cycle time (unit: s), and double support (unit: %), were calculated during steady state phase of walking using validated algorithms [35, 37]. The initiation of gait steady state was objectively estimated using a validated algorithm described elsewhere [38].

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Figure 1. An Illustration of gait test. Two wearable sensors were attached to left and right lower shins. The subject was asked to walk with habitual gait speed for 15 meters. Gait parameters, including stride velocity (unit: m/s), stride length (unit: m), gait cycle time (unit: s), and double support (unit: %), were calculated using validated algorithms.

2.4. Balance Test

Double-stance quiet standing balance test for 30 seconds under eyes-open condition was performed for all subjects. In addition, semi-tandem balance test was also performed for 20 seconds under eyes-open condition in the groups with diabetes. The same wearable sensors used in the gait test were attached to the lower back and lower dominant shin to measure balance performances by a two-link model (Figure 2). In the double-stance test, the subject stood in the upright position, keeping feet close together but not touching, with arms folded across the chest. In the semi-tandem test, the subject stood with the dominant foot a half-foot behind the other, keeping feet close together but not touching, with arms folded across the chest. Balance parameters, including ankle sway (unit: deg^2), hip sway (unit: deg^2), and center of mass sway (unit: cm^2) were calculated using validated algorithms [39].

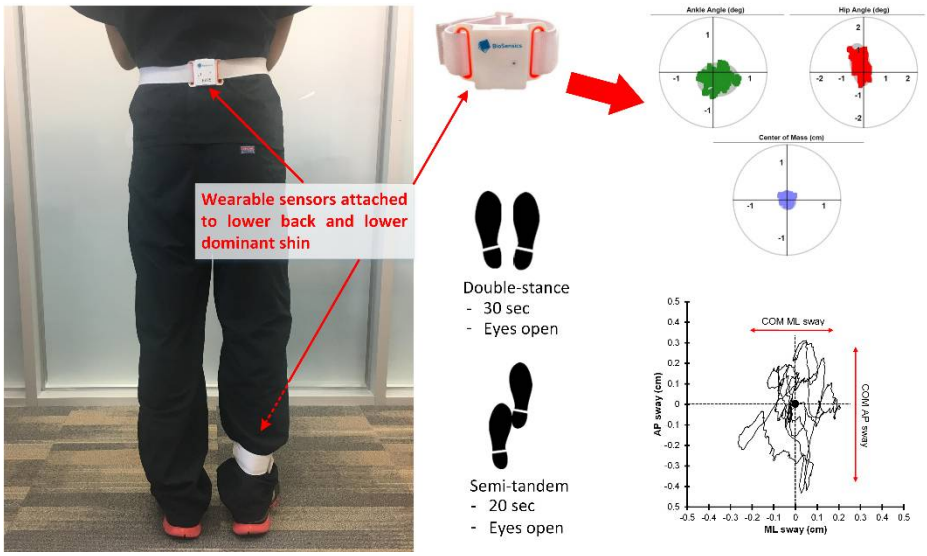

Figure 2. An Illustration of balance test. Two wearable sensors were attached to lower back and lower dominant shin. Double-stance for 30 seconds and semi-tandem for 20 seconds under eyes-open condition were performed. Balance parameters, including ankle sway (unit: deg^2), hip sway (unit: deg^2), and center of mass sway (unit: cm^2) were calculated using validated algorithms.

2.5. Statistical Analysis

All continuous data were presented as mean±standard deviation. All categorical data were expressed as count(percentage). The Shapiro-Wilk test was applied to test normality of data. Analysis of covariance (ANOVA) was used to compare between-group gait and balance performances, with adjustment for age, gender, and BMI. Fisher's least significant difference-based post-hoc test was performed for pairwise comparison to explore significant main effects and interactions. Cohen's d effect size was calculated to assess the magnitude of difference between each group. Values ranging from 0.20 to 0.49 indicated small, and values between 0.50 and 0.79 indicated medium. Values ranging from 0.80 to 1.29 indicated large, and values above 1.30 indicated very large effects. Values less than 0.20 were considered as having no noticeable effect [40]. The Pearson correlation coefficient was used to evaluate the degree of agreement between continuous variable. For all comparisons, significance was accepted at $p<0.050$. All statistical analyses were performed using IBM SPSS Statistics 24 (IBM, IL, USA).

3. Results

The analysis of demographic and clinical data were summarized in Table 1. Between the Mid-age DM+ and Older DM+ groups, no difference was observed for gender, BMI, fall history, plantar numbness, prevalence of DPN, prevalence of PAD, or HbA1C values. Older people with diabetes had increased prevalence of high concern about falling and depression, but the difference didn't reach statistical significance. The only clinical parameter reached statistical significance between the Mid-age DM+ and Older DM+ was frailty prevalence (22% vs. 40%, p=0.005). When comparing between the Older DM- and Older DM+ groups, several clinical parameters reached statistical significance, including prevalence of high concern about falling, depression, and frailty. Furthermore, Table 1 illustrated that the Mid-age HD+ group had higher prevalence of depression and frailty than the Mid-age HD- group (29% vs. 27% and 24% vs. 20%, respectively). These prevalence were more prominent when comparing between the Older HD+ and Older HD- (42% vs. 29% for depression and 58% vs. 23% for frailty).

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177 **Table 1.** General characteristics of the study groups.

Variable	Older Adults without Diabetes (DM-)	People with Diabetes (DM+)						*p*-value	
		Mid-age Adults			Older Adults			Older DM- vs. Older DM+	Mid-age DM+ vs. Older DM+ *
		Total	HD-	HD+	Total	HD-	HD+		
Subject Number, n	45	78	40	38	73	37	36	-	-
Age, years (mean±SD)	73.4±6.8	57.2±4.2	56.5±4.2	58.1±4.1	71.4±5.4	71.3±4.6	71.5±6.1	0.073	**<0.001**
Female, %	71%	51%	55%	47%	52%	49%	56%	**0.041**	0.924
BMI, kg/m² (mean±SD)	27.1±5.0	31.1±7.1	31.2±6.1	31.1±8.2	30.8±5.9	29.9±5.2	31.8±6.5	**<0.001**	0.780
Fall History, %	29%	36%	51%	21%	28%	36%	22%	0.951	0.307
High Concern about Falling, %	36%	65%	80%	50%	74%	78%	69%	**<0.001**	0.230
Depression, %	13%	28%	27%	29%	36%	29%	42%	**0.005**	0.246
Frailty, %	5%	22%	20%	24%	40%	23%	58%	**<0.001**	**0.005**
Plantar Numbness, VPT (mean±SD)	-	32.0±9.8	34.6±8.9	29.4±10.2	32.0±10.1	35.0±8.5	29.1±10.7	-	0.982
Diabetic Peripheral Neuropathy, %	-	76%	85%	66%	74%	88%	60%	-	0.845
Peripheral Artery Disease, %	-	59%	57%	61%	63%	64%	63%	-	0.650
HbA1c, % (mean±SD)	-	7.2±2.2	7.9±2.8	6.6±1.5	7.0±1.6	7.2±2.0	6.8±1.2	-	0.574

178 BMI: Body-mass-index. VPT: Vibration Perception Threshold. *: *p*-value calculated for Total Older DM+ and Total Mid-age DM+. Significant difference between groups were
179 indicated in bold
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Gait and balance performances for the Older DM-, Mid-age DM+, and Older DM+ groups were summarized in Table 2. For comparison between older groups with and without diabetes, results were adjusted by age, gender, and BMI. All gait parameters reached statistical significance. In particular, the Older DM+ group had significant lower stride velocity and shorter stride length, as well as significantly longer gait cycle time and higher double support, when compared with the Older DM- group (d=1.06-1.61, p<0.001). For balance performances, the Older DM+ group had significant larger ankle sway, hip sway, and center of mass sway than the Older DM- group in double-stance test (d=0.56-0.79, p<0.010). When examining the aging impact on gait and balance among people with diabetes, results were adjusted by BMI. Compared to the Mid-age DM+ group, deteriorations were observed for all gait and balance parameters in the Older DM+ group. Statistical significances were observed for the between-group difference of gait cycle time (d=0.34, p=0.036) and double support (d=0.46, p=0.005), but not for stride velocity or stride length. In addition, aging induced deteriorations were more pronounced in challenging balance test (semi-tandem test, d=0.38-0.45, p<0.050) than simple balance test (double-stance test, d=0.27-0.30, p>0.050).

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195 **Table 2.** Between-group comparison for gait and balance performance in Older DM-, Mid-age DM+, and Older DM+ groups.

		Older DM- n = 45	Mid-age DM+ n = 78	Older DM+ n = 73	Mid-age DM+ vs. Older DM-			Older DM+ vs. Older DM-			Older DM+ vs. Mid-age DM+		
					Diff (%)	*p*-value *	*d* *	Diff (%)	*p*-value †	*d* †	Diff (%)	*p*-value ‡	*d* ‡
Gait	**Stride Velocity, m/s (mean±SD)**	1.14±0.17	0.75±0.29	0.68±0.36	-34%	**<0.001**	1.55	-40%	**<0.001**	1.61	-10%	0.171	0.22
	Stride Length, m (mean±SD)	1.23±0.14	0.98±0.31	0.89±0.34	-20%	**<0.001**	1.02	-28%	**<0.001**	1.36	-10%	0.071	0.29
	Gait Cycle Time, s (mean±SD)	1.10±0.11	1.39±0.24	1.53±0.52	26%	**<0.001**	1.34	38%	**<0.001**	1.06	10%	**0.036**	0.34
	Double Support, % (mean±SD)	22.66±4.76	29.85±8.94	34.92±13.6	32%	**<0.001**	0.93	54%	**<0.001**	1.09	17%	**0.005**	0.46
Balance Double-Stance	**Ankle Sway, deg² (mean±SD)**	0.81±0.75	2.24±2.12	2.95±3.09	177%	**<0.001**	0.86	264%	**<0.001**	0.79	32%	0.105	0.27
	Hip Sway, deg² (mean±SD)	0.94±0.80	2.15±2.43	3.15±4.54	129%	**0.005**	0.57	235%	**0.008**	0.56	46%	0.098	0.27
	CoM Sway, cm² (mean±SD)	0.16±0.11	0.27±0.24	0.36±0.36	69%	**0.023**	0.47	125%	**0.002**	0.68	33%	0.076	0.30
Balance Semi-Tandem	**Ankle Sway, deg² (mean±SD)**	-	2.44±2.34	3.67±4.14	-	-	-	-	-	-	51%	**0.044**	0.38
	Hip Sway, deg² (mean±SD)	-	2.32±2.40	3.50±3.73	-	-	-	-	-	-	51%	**0.034**	0.40
	CoM Sway, cm² (mean±SD)	-	0.29±0.29	0.74±1.48	-	-	-	-	-	-	150%	**0.017**	0.45

196 CoM: Center of Mass. *: Results were adjusted by gender and BMI. †: Results were adjusted by age, gender, and BMI. ‡: Results were adjusted by BMI. Significant difference
197 between groups were indicated in bold. Effect sizes were calculated as Cohen's *d*
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Gait and balance performances for the Mid-age HD-, Mid-age HD+, Older HD-, and Older HD+ groups with adjustment by age, BMI, and maximum VPT value were summarized in Table 3. Among the mid-age adults with diabetes, subjects undergoing HD had significantly deteriorated gait and balance performances than non-HD subjects (d=0.63-1.68, p<0.050). HD induced motor function deteriorations were more pronounced among older adults with diabetes, with larger effect size for each gait and balance parameter (d=0.78-2.32, p<0.050).

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206 **Table 3.** Between-group comparison for gait and balance performance in Mid-age HD-, Mid-age HD+, Older HD-, and Older HD+ groups.

		Mid-age DM+					Older DM+				
		HD- n = 40	HD+ n = 38	Diff (%)	*p*-value *	*d* *	HD- n = 37	HD+ n = 36	Diff (%)	*p*-value *	*d* *
Gait	Stride Velocity, m/s (mean±SD)	0.93±0.22	0.55±0.22	-41%	**<0.001**	1.68	0.96±0.27	0.40±0.20	-58%	**<0.001**	2.31
	Stride Length, m (mean±SD)	1.18±0.20	0.78±0.26	-33%	**<0.001**	1.67	1.15±0.22	0.62±0.23	-46%	**<0.001**	2.32
	Gait Cycle Time, s (mean±SD)	1.29±0.20	1.49±0.24	15%	**0.001**	0.83	1.26±0.24	1.80±0.60	43%	**<0.001**	1.15
	Double Support, % (mean±SD)	26.30±6.37	33.75±9.67	28%	**<0.001**	0.87	26.34±5.50	43.74±14.22	66%	**<0.001**	1.42
Balance Double Stance	Ankle Sway, deg² (mean±SD)	1.48±0.90	3.03±2.68	105%	**0.002**	0.76	1.54±1.04	4.40±3.82	187%	**<0.001**	1.19
	Hip Sway, deg² (mean±SD)	1.29±1.02	3.03±3.09	134%	**0.003**	0.72	1.55±1.35	4.91±5.97	217%	**0.001**	0.90
	CoM Sway, cm² (mean±SD)	0.27±0.21	0.28±0.28	5%	0.743	0.08	0.35±0.26	0.37±0.44	6%	0.248	0.30
Balance Semi-Tandem	Ankle Sway, deg² (mean±SD)	1.66±1.13	2.99±2.78	80%	**0.025**	0.63	1.73±1.78	4.85±4.79	180%	**0.016**	0.78
	Hip Sway, deg² (mean±SD)	1.21±0.71	3.10±2.81	157%	**0.014**	0.70	1.65±1.63	4.63±4.27	181%	**0.002**	1.01
	CoM Sway, cm² (mean±SD)	0.31±0.19	0.29±0.35	-6%	0.709	0.11	0.37±0.33	0.37±0.37	0	0.483	0.23

207 CoM: Center of Mass. *: Results were adjusted by age, BMI, maximum VPT. Significant difference between groups were indicated in bold. Effect sizes were calculated as Cohen's *d*

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Figure 3 illustrated the correlation between age and gait performances for people with diabetes with and without HD. In Figure 3A, a significant correlation could be observed between age and stride velocity for subjects undergoing HD (r=-0.440, p<0.001). But the correlation in non-HD subject was weak (r=-0.007, p=0.953). Similarly, in Figure 3B, a significant correlation could be observed between age and double support for subjects undergoing HD (r=0.456, p<0.001). But the correlation in non-HD subjects was weak (r=0.012, p=0.917).

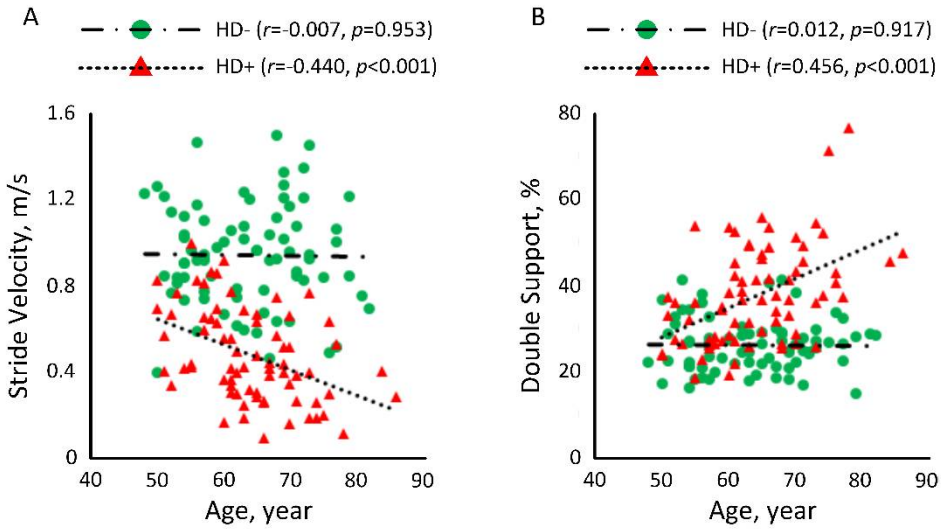

Figure 3. Correlation between age and A) stride velocity and B) double support for people with diabetes with and without HD.

In Figure 4A, a significant correlation was observed between double-stance ankle sway and stride velocity in non-HD older adults (r=-0.473, p=0.003). However, the correlation in older adults undergoing HD was weak (r=-0.092, p=0.604). Figure 4B also showed a significant correlation between double-stance ankle sway and gait cycle time in non-HD older adults (r=0.539, p=0.001). However, the correlation in older adults undergoing HD was weak (r=0.148, p=0.404).

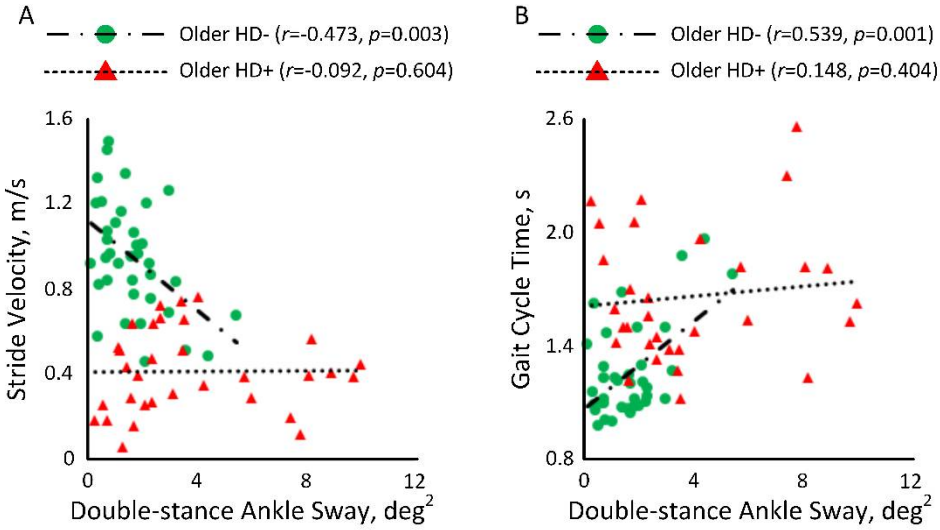

Figure 4. Correlation between double-stance ankle sway and A) stride velocity and B) gait cycle time for older adults with diabetes with and without HD.

4. Discussion

To our knowledge, this is the first study that objectively examined and quantified deteriorations in gait and balance among people with diabetes undergoing HD process, and compared with non-HD people with diabetes as well as non-diabetic individuals. We were able to confirm our hypothesis that due to the impact of HD, this population have significantly worsened gait and balance irrespective of age. In addition, motor function deterioration induced by HD is more pronounced in older adults than mid-age adults. A few previous studies have reported deteriorated gait and balance function of HD population when comparing with healthy controls [7-9], which is consistent with findings in this current study. However, none of previous studies compared HD population with cohorts with well-established model in motor function impairment, such as people with diabetes, as this current study did.

While gait and balance could be objectively quantify in a gait laboratory, such assessments are not practical for HD population. Many HD patients have limited mobility, suffer from post-dialysis fatigue, and thus can rarely visit a gait lab for the purpose of motor function assessment. Thus, most of previous researches about motor function in HD population was limited to semi-subjective inaccuracies (stopwatch-timed gait speed measurement) and unsafety (force platform balance measurement) [7-9]. To overcome these limitations, we used wearable sensors, which enabled us to quantify gait and balance in regular dialysis clinic prior the HD process. The whole process of sensor attachment and administration of gait and balance was less than 10 minutes, making such measurements more practical and acceptable for this vulnerable population.

Our results suggested significant correlations between age and gait performances in people with diabetes undergoing HD, while correlations in non-HD people with diabetes were weak. This demonstrated hemodialysis could magnify gait impairment caused by aging beyond diabetes. In addition, while hemodialysis could cause further deteriorations in gait and balance performances, our results also suggested that these deteriorations among older adults were more pronounced than mid-age adults. This was a novel discovery, demonstrating older patients are a higher vulnerable population of motor function impairment caused by hemodialysis process.

Another interesting finding in this current study was that significant correlations were observed between balance and gait in non-HD older adults, while the correlations were weak in older individuals undergoing HD. Lattanzio, F., et al have shown that balance impairment was significantly associated with decline of kidney function, but gait impairment was not [41]. We speculate that ESRD and HD may cause different scales of impacts on gait and balance functions, leading to imbalanced gait and balance performances. However this hypothesis needs to be validated in subsequent study.

In our study, we observed that Older HD+ group had a prevalence of frailty 53% higher than the Older DM- group and 34% higher than the Older HD- group. This demonstrated that ESRD and HD can magnify the likelihood of frailty, which can then lead to progression of adverse health outcomes, such as further motor function deterioration.

Limitations

A major limitation of this study is that the HD- groups were recruited from an outpatient podiatry clinic, and thus the majority had foot problems including DPN. The prevalence of DPN was higher in the HD- groups than the HD+ groups (87% in HD- vs. 64% in HD+). Therefore the HD- groups may not represent general DM+ population. In addition, it is well established the DPN negatively affects gait and balance [42]. We believe, however, that this imbalance in DPN prevalence did not affect the conclusion of the study, since the HD+ groups still had more deterioration than the HD- groups irrespective of age. In addition, with adjusting by VPT value (indicator of DPN severity), the between-group differences were still significant.

Our results also showed that the HD- groups had higher prevalence of fall history and concern about falling, when compared to the HD+ groups. This could be because of the high prevalence of DPN in the HD- groups. Studies have shown that DPN has a high contribution to falls and fear of falling [43, 44]. Another potential reason was that due to post-dialysis fatigue, subjects in the HD+

groups were highly sedentary. Low level of daily physical activity in individuals undergoing hemodialysis [45] may lead to low prevalence of fall history and concern about falling.

Finally, we noticed that the HD+ groups had significantly lower Hb1AC level than the HD- groups. In our previous study, we demonstrated that higher Hb1AC level is correlated with poorer balance [37]. Thus, we anticipate that lower HbA1C observed in the HD+ groups will not affect the significance of between-group difference observed in this study. On the other hand, it is debated whether HbA1C is a reliable metric to determine glucose level among HD patients [46]. In other words, Hb1Ac level is calculated by measuring hemoglobin to which glucose is bound in red blood cells (RBCs). While the longer an individual's RBCs are in circulation the greater chance they will be glycosylated. The average lifespan of RBCs is about 120 days in healthy individuals [47]. However, the RBCs lifespan in patients with ESRD can reduce by 30% to 70% [48]. Therefore, the Hb1Ac level could be systematically lower in patients with ESRD. In addition, study has shown that sevelamer carbonate, which is often used in individuals undergoing hemodialysis to control their phosphorus levels [49], can significantly reduce HbA1c level [50]. Because of these limitations of Hb1A1C measurement among HD patients, we didn't adjust the results by Hb1A1C level.

5. Conclusions

In conclusion, while diabetes deteriorates gait and balance, HD magnifies the deterioration beyond diabetes condition irrespective of age. In addition, progression in age significantly affects the magnitude of gait and balance deterioration in HD patients, when compared with non-HD individuals. Results revealed that poor static balance is correlated with poor gait in the Older HD- group. However, interestingly, no correlation was observed between poor balance and poor gait among the HD+ group and the deterioration of gait is highly depends on age. This study demonstrated the feasibility of using wearable sensors to quantify gait and balance as a part routine patient visit for HD population. Such assessment may assist early detection of motor function decline and thus promote early intervention.

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