Effect of muscle strength on gait in hemodialysis patients with and without diabetes

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There is minimal data on the gait of hemodialysis (HD) patients with and without diabetes. This investigation examined spatiotemporal parameters of gait in HD patients with and without diabetes compared with age-matched, sex-matched, and BMI-matched controls. The effect of muscle weakness on gait in HD patients was also examined. Eighteen HD patients and 18 age-matched, sex-matched, and BMI-matched controls completed two walking trials along a 7.9 m long pressure sensitive pathway. The HD participants were divided into groups based on their diabetic status (eight patients without diabetes and 10 with diabetes). Spatiotemporal markers of gait, including variability metrics, were determined. Knee strength was quantified only in the HD groups. Overall HD patients had a worse gait compared with controls ($P<0.01$). Furthermore, HD patients with diabetes had an elevated gait variability compared with those without diabetes, even after controlling for muscle strength ($P<0.05$). Further research is warranted to explore whether increases in lower extremity strength lead to improvements in gait in this population. ***International Journal of Rehabilitation Research*** **37:29–33 © 2014 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

International Journal of Rehabilitation Research 2014, **37**:29–33

Keywords: fall risk, renal function, variability, walking

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Received 2 April 2013 **Accepted** 12 June 2013

Introduction

Patients with renal failure undergoing maintenance hemodialysis (HD) have a variety of metabolic disturbances that increase morbidity and mortality. Protein malnutrition, muscle wasting, bone disorders, and cardiovascular complications are especially common, and these comorbidities greatly reduce physical function. In addition to muscle atrophy, reductions in physical function are exacerbated by a reduction in the capacity of the central nervous system and abnormalities in neuromuscular function (Johansen *et al.*, 2005).

Not surprisingly, HD patients also have an impaired walking performance (Bohannon *et al.*, 1995; Shin *et al.*, 2013). The majority of research examining walking impairment in HD patients focuses on ordinal scales or timed performance tests (Bohannon *et al.*, 1995; Blake and O'Meara, 2004) and demonstrates that individuals with HD walk slower. Although, this approach is helpful in determining changes in the walking speed, it provides minimal information on the organization of walking. To quantify the organization of walking, the spatiotemporal parameters of walking such as stride length, cadence, and stride width as well as the variability of these parameters must be assessed. Moreover, the assessment of spatiotemporal parameters informs rehabilitation. In addition, there is growing evidence that investigations of spatiotemporal parameters of walking are more sensitive to walking impairment in clinical populations compared with timed walking tests (Lockhart *et al.*, 2010; Spain *et al.*, 2012).

In addition to not providing any information on the spatiotemporal organization of gait, timed walking tests do not quantify variability in walking. There is growing evidence that variability in physiological output provides unique information on the control of movement (Brach *et al.*, 2001; Hausdorff, 2007). Increases in gait variability, defined as fluctuations in the gait, have been found to be related to impaired mobility and functional disability in various clinical populations, including older adults (Brach *et al.*, 2007) and patients with multiple sclerosis (Sosnoff *et al.*, 2012) and Parkinson's disease (Hausdorff *et al.*, 2003). Moreover, gait variability is an independent predictor of future falls and incident mobility disabilities (Brach *et al.*, 2005).

Lower extremity muscular weakness and the adverse effects of diabetes have been suggested to be contributing factors to a walking impairment in individuals undergoing HD (Bohannon *et al.*, 1995; Blake and O'Meara, 2004). However, the majority of these reports used timed performance tests and did not quantify the spatiotemporal organization of walking. Consequently, it is not clear what spatiotemporal properties of gait are related to lower extremity muscular strength or diabetes in individuals undergoing HD.

Quantifying spatiotemporal parameters of walking and exploring factors related to walking impairment in this clinical population will inform rehabilitation approaches aimed at maintaining mobility. Therefore, the purpose of

0342-5282 © 2014 Wolters Kluwer Health | Lippincott Williams & Wilkins DOI: 10.1097/MRR.0b013e3283643d76

this preliminary study was to (a) examine spatiotemporal parameters of walking in HD patients with and without diabetes compared with age-matched and sex-matched controls; and (b) investigate whether muscle strength is related to gait in HD patients with and without diabetes.

Materials and methods

Participants

Eighteen (13 male and five female, mean age 51.9 ± 11.0 years) HD patients and 18 (13 male and five female, mean age 51.2 ± 10.2 years) age-matched healthy controls participated in this investigation. The HD group was further divided into diabetic ($n = 8$) and nondiabetic ($n = 10$) subgroups. The inclusion criteria for HD patients were as follows: HD administration for 3 days/week, ability to walk independently, and ability to comprehend written and spoken English. The inclusion criteria for the controls were as follows: absence of chronic disease or functional impairment and the ability to walk independently. The exclusion criteria in the healthy control group were as follows: falls during the past year, diagnosis of diabetes, or any neurological or musculoskeletal disorder, which affected gait performance. The procedures were approved by the local Institutional Review Board, and all participants provided written informed consent before testing.

Procedures

The participants completed two walking trials along a 7.9 m GAITRite (CIR systems Inc., Sparta, New Jersey, USA) mat at a comfortable, self-selected pace. The following validated measures provided by the GAITRite were recorded: velocity (cm/s), cadence (steps/min), stride length (cm), base of support (cm), stride width, swing time (s), stance time (s), and the double-support phase (Cutlip *et al.*, 2000). The intraindividual variability based on the coefficient of variability [CV = (SD/mean) × 100] of step length, step time, base of support, swing time, stance time, and double-support time was also determined. The average of the two trials for each variable was used in the analysis for improved reliability of the measures.

Quadriceps and hamstring muscular strength was assessed using an isokinetic dynamometer (Biodex System 3 Dynamometer; Cybex, Shirley, New York, USA). Unilateral maximal isokinetic contractions were performed at 60°/s. Strength was assessed in both legs. Participants performed two sets of six repetitions per leg with a 3-min rest between sets. The highest peak torque achieved was recorded and used for analysis. Verbal encouragement was provided throughout each trial to maximize participant effort.

Statistical analysis

Descriptive analyses were performed using SPSS version 17.0 (SPSS Inc., IBM, Chicago, Illinois, USA). To determine the differences between HD-non-diabetic, HD-diabetic, and control groups, the χ^2-test was used for categorical variables (i.e. sex) and one-way analysis of variance was used for continuous variables. Significance was defined as a P value of 0.05 or less. To determine the effect size of group differences of each spatiotemporal parameter, η^2 was calculated. For η_P^2, an effect size of 0.01 or less was considered a 'small' effect, between 0.01 and 0.13 a 'moderate' effect, and of at least 0.13 a 'large' effect (Cohen, 1988). To determine whether the differences in gait between the HD groups were due to muscle strength, one-way analysis of covariance was used with group (diabetic vs. nondiabetic) as the between-group subject factor and muscle strength as the covariate.

Results

Overall, there were no significant differences in age, height, weight, BMI, or sex between the control and HD groups. Dialysis vintage and knee flexion strength were greater in the nondiabetic group than the diabetic group ($P \leq 0.05$; Table 1).

As expected, both HD groups walked slower with shorter strides than the control group (Table 2). In addition, the HD-diabetic group took fewer, wider strides and spent a greater portion of the gait cycle in the double-support phase than controls. The HD-diabetic group also had a more variable gait than the control group (Table 2). Overall, the HD-diabetic group had greater variability in stride length, stride time, swing time, and stance time than the healthy control group ($P < 0.01$ for all). The

Table 1 Participant demographics (mean±SD)

Variables	Controls ($n=18$)	Nondiabetic ($n=8$)	Diabetic ($n=10$)	F/χ^2	P
Age (years)	51.2 (10.2)	47.5 (10.0)	55.5 (10.9)	1.35	0.27
Height (cm)	174.2 (7.6)	172.0 (9.1)	171.3 (7.5)	0.51	0.60
Weight (kg)	87.6 (13.4)	97.6 (29.0)	97.53 (19.0)	1.22	0.30
BMI	29.0 (5.3)	33.0 (9.5)	33.3 (6.6)	1.72	0.20
Sex (F/M)	5/13	3/5	2/8	0.68	0.71
Months on dialysis	NA	70.75 (35.6)[a]	28.4 (21.2)[a]	9.12	<0.01
Knee ext MVC (N m)	NA	192.5 (58.9)	146.3 (70.2)	2.21	0.16
Knee flex MVC (N m)	NA	107.5 (39.4)	68.4 (38.3)	4.52	0.05

Knee ext MVC and knee flex MVC, mean linear sum of left and right extension and flexion maximal voluntary contraction, respectively.
[a]Significant group difference between nondiabetic and diabetic groups ($P \leq 0.01$).

Table 2 Spatiotemporal gait parameters as a function of group (mean±SD)

Variables	Controls	Nondiabetic HD	Diabetic HD	*F*	*P*	η^2
Average gait parameters						
Speed (cm/s)	136.50±15.11	102.44±12.60*	90.38±29.67*	19.93	<0.01	0.55
Cadence (steps/min)	112.96±10.36	96.92±8.53	94.89±18.10*	8.05	<0.01	0.33
Stride length (cm)	147.69±13.24	123.56±17.49*	112.78±23.97*	13.92	<0.01	0.46
Support base (cm)	10.44±2.37	11.06±4.23	13.04±3.69	2.12	0.13	0.11
Stride width (cm)	12.67±2.55	15.04±4.33	17.06±3.41*	6.10	<0.01	0.27
Stride time (s)	1.08±0.10	1.23±0.13	1.31±0.26*	7.06	<0.01	0.30
Swing time (s)	0.39±0.04	0.42±0.05	0.42±0.07	1.40	0.26	0.08
Stance time (s)	0.69±0.07	0.81±0.09	0.90±0.21*	9.10	<0.01	0.36
Double-support(% gait cycle)	27.59±4.09	30.73±4.03	36.40±6.08*	11.35	<0.01	0.41
Intraindividual gait variability						
Stride length (% CV)	1.86±0.60	2.37±0.66	3.04±1.01*	8.18	<0.01	0.33
Support base (% CV)	17.48±8.01	18.78±9.53	18.10±11.06	0.06	0.95	0.00
Stride width (% CV)	13.63±5.91	12.21±3.68	12.06±5.03	0.37	0.70	0.02
Stride time (% CV)	1.60±0.53	1.80±0.79	2.98±0.82*§	13.78	<0.01	0.46
Swing time (% CV)	3.27±0.77	4.25±1.86	5.61±2.10*	7.84	<0.01	0.32
Stance time (% CV)	2.21±0.76	2.47±0.79	4.00±1.15*§	13.55	<0.01	0.45
Double-support time (% CV)	4.59±2.22	4.45±0.96	6.14±2.77	1.91	0.16	0.10

CV, coefficient of variation; HD, hemodialysis.
*$P \leq 0.01$ indicates significant difference between controls and nondiabetic and diabetic-HD groups.
§$P \leq 0.01$ indicates significant difference between nondiabetic and diabetic-HD groups.

HD-diabetic group had greater double-support time variability than the HD-non-diabetic group ($P = 0.04$).

As there was a difference in muscle strength between the diabetic and nondiabetic HD groups, it was of interest to determine whether muscle strength contributed to the gait differences. After controlling for muscle strength, it was found that the diabetic-HD group had a greater double-support phase than the nondiabetic group (36.43±6.08% vs. 30.72±4.03%; $P < 0.05$). The diabetic group was also found to be more variable in their stride (2.98±0.82% vs. 1.80±0.79%) and stance time (4.00±1.15% vs. 2.47±0.79%) when controlled for muscle strength compared with the nondiabetic group (P's < 0.05). Overall, these analyses suggest that the effect of diabetes is different from that of muscle strength on walking impairment in individuals undergoing HD.

Discussion

The present investigation examined the spatiotemporal parameters of gait in HD patients with and without diabetes compared with healthy age-matched controls. Similar to our previous findings (Shin *et al.*, 2013), the HD groups walked slower with shorter strides than the healthy control group. The HD-diabetic group also had elevated variability in their gait than healthy controls. When taking into account the muscle strength, patients with diabetes had greater impairment in walking than did nondiabetic patients. To our knowledge, this is the first detailed examination of gait in individuals undergoing HD with and without diabetes as a function of muscle strength.

Although gait speed itself is an important marker of physiological function, it does not provide information on the organization of gait. The observed differences in spatiotemporal parameters suggest that not only does the HD group walk slower but they also have a different organization of gait. For instance, one of the few investigations to examine spatiotemporal parameters of gait in HD patients (Blake and O'Meara, 2004) found a 14% longer duration of the gait cycle in HD patients compared with healthy controls. Overall, the decreased gait speed observed in this study was characterized by a 26% shorter stride length, a 22% wider stride width, and a 16% longer double-support phase. This pattern of gait suggests that individuals undergoing HD walk cautiously (Nutt, 2001), possibly to minimize their risk of falls.

There are numerous factors that contribute to gait impairment in individuals undergoing HD. In a large sample ($n = 110$) of renal transplant candidates, it was found that knee extension strength was related to a comfortable and maximal walking speed (Bohannon *et al.*, 1995). Similarly, in the present study sample, knee strength was positively associated with gait speed and stride length and negatively associated with a support base and a double-support phase.

Although the association between lower extremity strength and walking function was strong, unexplained variance in the spatiotemporal parameters of walking still existed, indicating that there are other factors contributing to impaired walking. An analysis of the effect of diabetes on gait function in the HD group revealed that individuals with diabetes had a greater double-support phase and elevated temporal variability compared with those without diabetes. As this analysis controlled for strength differences between groups, it potentially indicated that the adverse effect of diabetes on walking is different from that of muscle weakness. Deficits in walking due to diabetes are believed to stem from

declines in proprioception caused by neuropathy and neurological impairment (Menz *et al.*, 2004; Petrofsky *et al.*, 2005).

Gait variability and hemodialysis patients

A novel observation of the present investigation is that individuals undergoing HD have a gait variability 33–35% larger than that of healthy age-matched and sex-matched controls. This elevated gait variability is similar to that reported in previous studies examining other clinical populations (Brach *et al.*, 2001; Hausdorff, 2007; Sosnoff *et al.*, 2012). For instance, Montero-Odasso *et al.* (2011) reported that frail elderly individuals have a gait variability ~60% greater than that of age-matched and sex-matched nonfrail older adults. Increases in gait variability are indicative of a decrease in the control of a basic physiological function (Lipsitz, 2002; Sosnoff and Newell, 2006).

Gait variability has been associated with mobility disability and falls in various clinical populations (Brach *et al.*, 2005; Brach *et al.*, 2007; Hausdorff, 2007; Nakamura *et al.*, 2009; Socie and Sosnoff, 2013). The greater variability of the HD group in general and the increased temporal gait variability among individuals undergoing HD with diabetes specifically suggest that these groups are at greater risk of falls. The greater gait variability in the diabetic subgroup indicates that they are at the greatest risk for falls. This notion is congruent with reports that both individuals with diabetes (Cavanagh *et al.*, 1992) and those undergoing HD (Desmet *et al.*, 2005; Abdel-Rahman *et al.*, 2011) are at higher risk of falls compared with healthy age-matched and sex-matched controls.

There are numerous mechanisms that contribute to gait variability. For instance, muscle quality has been found to be related to gait variability in healthy older adults (Shin *et al.*, 2012). Congruent with this notion, muscle strength was associated with swing time and support base variability in the present investigation. This raises the possibility that interventions increasing lower limb muscle strength would decrease the fall risk in individuals undergoing HD.

Regardless of the mechanisms underlying walking impairment in individuals undergoing HD, there is growing evidence that walking impairment can be improved with targeted interventions (Heiwe and Jacobson, 2011). For instance, it has been documented that a 4-month intradialytic exercise program improves shuttle walk performance in individuals undergoing HD (Wilund *et al.*, 2010). The current observation that gait impairment varied with muscle strength suggests that interventions targeting lower limb strength have the potential to yield improvements in walking function and minimize the risk of falls in this population. Future research should investigate whether exercises that increase lower body strength can improve gait.

Despite the novel observations, there were some limitations in the present investigation. The small sample size makes generalization to all HD patients uncertain. We also did not quantify strength in healthy controls. In addition, the results cannot be generalized to all individuals with chronic kidney disease. The participants in the present study were patients with stage 5 chronic kidney disease undergoing maintenance HD and a more severe impairment in renal function compared with patients with lower stages of chronic kidney disease. Therefore, future studies are needed to examine how less severe deficits in renal function influence gait performance.

Conclusion

HD patients are found to walk slower with shorter wider strides when compared with healthy age-matched and sex-matched participants. In addition, they are also found to display more variation in stride length and the stance time. Among individuals undergoing HD, gait dysfunction varies with muscle strength. Furthermore, HD patients with diabetes are found to have elevated gait variability compared with those without diabetes, even after controlling for muscle strength. Further research is needed to determine whether increases in lower extremity muscle strength lead to an improved gait function and a decreased risk of falls in HD patients.

Acknowledgements

The authors thank the staff of the Champaign-Urbana Dialysis clinic for their extensive help and support with all research efforts.

Source of funding/support: 1R01DK084016.

Conflicts of interest

There are no conflicts of interest.

References

Abdel-Rahman EM, Turgut F, Turkmen K, Balogun R (2011). Falls in elderly hemodialysis patients. *QJM* **104**:829–838.

Blake C, O'Meara YM (2004). Subjective and objective physical limitations in high-functioning renal dialysis patients. *Nephrol Dial Transplant* **19**:3124–3129.

Bohannon RW, Smith J, Hull D, Palmeri D, Barnhard R (1995). Deficits in lower extremity muscle and gait performance among renal transplant candidates. *Arch Phys Med Rehabil* **76**:547–551.

Brach JS, Berthold R, Craik R, VanSwearingen JM, Newman AB (2001). Gait variability in community-dwelling older adults. *J Am Geriatr Soc* **49**:1646–1650.

Brach J, Berlin J, VanSwearingen J, Newman A, Studenski S (2005). Too much or too little step width variability is associated with a fall history in older persons who walk at or near normal gait speed. *J Neuroeng Rehabil* **2**:21–29.

Brach JS, Studenski SA, Perera S, VanSwearingen JM, Newman AB (2007). Gait variability and the risk of incident mobility disability in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* **62**:983–988.

Cavanagh P, Derr J, Ulbrecht J, Maser R, Orchard T (1992). Problems with gait and posture in neuropathic patients with insulin-dependent diabetes mellitus. *Diabet Med* **9**:469–474.

Cohen J (1988). *Statistical power analysis for the behavioral sciences*. 3rd ed. New York: Academic Press.

Cutlip RG, Mancinelli C, Huber F, DiPasquale J (2000). Evaluation of an instrumented walkway for measurement of the kinematic parameters of gait. *Gait Posture* **12**:134–138.

Desmet C, Beguin C, Swine C, Jadoul M (2005). Falls in hemodialysis patients: prospective study of incidence, risk factors, and complications. *Am J Kidney Dis* **45**:148–153.

Hausdorff J, Schaafsma J, Balash Y, Bartels A, Gurevich T, Giladi N (2003). Impaired regulation of stride variability in Parkinson's disease subjects with freezing of gait. *Exp Brain Res* **149**:187–194.

Hausdorff JM (2007). Gait dynamics, fractals and falls: finding meaning in the stride-to-stride fluctuations of human walking. *Hum Mov Sci* **26**:555–589.

Heiwe S, Jacobson SH (2011). Exercise training for adults with chronic kidney disease. *Cochrane Database Syst Rev* **10**:CD003236.

Johansen KL, Doyle J, Sakkas GK, Kent-Braun JA (2005). Neural and metabolic mechanisms of excessive muscle fatigue in maintenance hemodialysis patients. *Am J Physiol Regul Integr Comp Physiol* **289**:R805–R813.

Lipsitz LA (2002). Dynamics of stability: the physiologic basis of functional health and frailty. *J Gerontol A Biol Sci Med Sci* **57**:B115–B125.

Lockhart TE, Barth AT, Zhang X, Songra R, Abdel-Rahman E, Lach J (2010). Portable, non-invasive fall risk assessment in end stage renal disease patients on hemodialysis. *ACM Trans Comput Hum Interact* 84–93.

Menz HB, Lord SR, St George R, Fitzpatrick RC (2004). Walking stability and sensorimotor function in older people with diabetic peripheral neuropathy. *Arch Phys Med Rehabil* **85**:245–252.

Montero-Odasso M, Muir SW, Hall M, Doherty TJ, Kloseck M, Beauchet O, Speechley M (2011). Gait variability is associated with frailty in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* **66**:568–576.

Nakamura T, Meguro K, Sasaki H (2009). Relationship between falls and stride length variability in senile dementia of the Alzheimer type. *Gerontology* **42**:108–113.

Nutt JG (2001). Classification of gait and balance disorders. *Adv Neurol* **87**:135–145.

Petrofsky J, Lee S, Bweir S (2005). Gait characteristics in people with type 2 diabetes mellitus. *Eur J Appl Physiol* **93**:640–647.

Shin S, Valentine RJ, Evans EM, Sosnoff JJ (2012). Lower extremity muscle quality and gait variability in older adults. *Age Ageing* **41**:595–599.

Shin S, Chung HR, Kistler BM, Fitschen PJ, Wilund KR, Sosnoff JJ (2013). Walking and talking in maintenance hemodialysis patients. *Arch Phys Med Rehabil* **94**:127–131.

Socie MJ, Sosnoff JJ (2013). Gait variability and multiple sclerosis. *Mult Scler Int* **2013**:645197.

Sosnoff JJ, Newell KM (2006). The generalization of perceptual-motor intra-individual variability in young and old adults. *J Gerontol B Psychol Sci Soc Sci* **61**:304–310.

Sosnoff JJ, Sandroff BM, Motl RW (2012). Quantifying gait abnormalities in persons with multiple sclerosis with minimal disability. *Gait Posture* **36**:154–156.

Spain R, St George R, Salarian A, Mancini M, Wagner J, Horak F, Bourdette D (2012). Body-worn motion sensors detect balance and gait deficits in people with multiple sclerosis who have normal walking speed. *Gait Posture* **35**:573–578.

Wilund KR, Tomayko EJ, Wu PT, Chung HR, Vallurupalli S, Lakshminarayanan B, Fernhall B (2010). Intradialytic exercise training reduces oxidative stress and epicardial fat: a pilot study. *Nephrol Dial Transplant* **25**:2695–2701.