

Postural control in hemodialysis patients



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ARTICLE INFO

Article history:

Received 26 June 2013

Received in revised form 12 September 2013

Accepted 8 October 2013

Keywords:

Standing balance

Kidney disease

Rehabilitation

ABSTRACT

The current investigation examined whether patients undergoing hemodialysis (HD) have reduced standing postural control performance during simultaneous cognitive task performance (i.e. dual task cost (DTC)) compared to age–gender matched controls. 19 persons undergoing HD and 19 age, gender, and body mass index (BMI) matched controls participated in the investigation. All participants performed 2 trials of quiet standing balance and 2 postural trials in which they performed a cognitive task. Postural control was indexed with various measures of the center of pressure (COP) trajectory. The change in postural control with a cognitive task (e.g. dual task cost DTC) was quantified as a change in the center of COP parameters of postural control from quiet standing to the cognitive condition.

The primary observations were that (1) HD patients had significantly greater postural sway than age, gender, BMI matched controls (p 's < 0.05); (2) HD patients had a greater DTC than the controls during quiet standing (p 's < 0.05). The observations highlight that HD participants have poor postural control that is further exacerbated by a simultaneous performance of a cognitive task. It is possible that this impaired postural control places HD participants at elevated fall risk. Further study is necessary to determine contributing factors to an increased DTC in this population and whether targeted interventions such as exercise can reduce DTC.

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1. Introduction

Chronic kidney disease (CKD) is a progressive disorder typically characterized by chronic inflammation that affects over one in ten adults in the U.S. [1]. The prevalence of patients with advanced CKD requiring maintenance hemodialysis (HD) therapy is increasing rapidly [1]. This patient group has significantly reduced physical function and activity levels due to a number of comorbidities which are mechanistically linked including cardiovascular disease, bone–mineral abnormalities, and muscle catabolism [2,3]. Given these comorbidities, it is not surprising that persons undergoing HD therapy have impaired mobility and balance [4], which is linked to elevated fall risk [5–7].

Traditionally, these impairments in mobility and balance and elevated fall-risk have been exclusively related to muscle atrophy and weakness [8]. In contrast to this traditional view, there is considerable evidence that mobility and balance performance are

influenced by cognitive processing [9–11]. Often the simultaneous performance of a cognitive task while walking or maintaining a static posture results in a decline in motor performance [11,12]. This is referred to as a dual task cost (DTC). Elevated DTC is consistently observed in groups with impaired balance such as persons with Parkinson's disease [13] multiple sclerosis [14], and stroke patients [15]. Although it has been observed that persons undergoing HD have greater DTC during walking than healthy controls [16], it is not clear if they have greater DTC during static balance tasks.

Examinations of DTC during static balance tasks in HD patients are important for theoretical as well as clinical reasons. From a theoretical standpoint identification of DTC in HD patients would provide further evidence of the generalizability of this motor control phenomenon [11]. Clinically, evidence of DTC of postural control may provide a novel approach to detect subtle postural dysfunction in this patient population. Additionally, it might also suggest new rehabilitation approaches to maximize postural control and reduce associated fall risk in HD patients.

Therefore, the purpose of the present study was to compare DTC in HD patients and healthy controls during a static balance task. It was hypothesized that persons undergoing HD would have elevated DTC during a static balance task.

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2. Methods

2.1. Participants

Nineteen (15 male and 4 female, age 47.6 ± 7.8 years) community dwelling ambulatory maintenance HD patients who were receiving thrice weekly HD and 19 age, BMI matched controls (12 male and 7 female age 48.7 ± 9.5 years) who were free of chronic disease participated in this investigation. Inclusion criteria for HD patients included: (1) receiving HD 3 days per week and (2) ability to walk independently. The inclusion criteria for the controls included: (1) absence of chronic disease; (2) functional impairment; and (3) ability to walk independently. Exclusion criteria in the healthy control group included: (1) a fall in the previous year, and (2) any neurological or musculoskeletal disorder which affected postural control.

2.2. Procedures

Height and weight were measured using a scale and stadiometer, respectively. Age, disease status, and diabetes status were determined through health history questionnaire. To quantify postural control, participants stood on a force platform (AMTI, Inc.) with arms by their side for 4 trials. During the first 2 trials participants stood quietly; however, during the last 2 trials participants stood on the force plate while performing a cognitive task. The first dual task trial consisted of a semantic word generation task (i.e. participants were instructed to list as many fruit and vegetables as possible) while the second dual task trials utilized a phonetic word generation task (i.e. participants were asked to name as many words beginning with the letter “H” as possible). The use of both semantic and phonetic task minimized any potential for a learning effect. The number of words uttered in each trial was recorded.

The force platform recorded six components of postural dynamics including three force components: mediolateral force (Fx), anteroposterior force (Fy), and vertical force (Fz); and three moment components taken about the respective axes: Mx, My, Mz. The signals were amplified using a six-channel AMTI-Model SGA6-4 amplifier. A gain of 4000 was used. The bridge excitation was set to 5 V and data were collected at 100 Hz. Signals from the force plate were filtered with a 4th order low pass Butterworth filter with a cutoff of 10 Hz. The center of pressure, a reflection of the system's neuromuscular response to the imbalances of the body's center of gravity, were separately calculated along with AP and ML axis utilizing standard procedures [17].

95% confidence ellipse area is a statistical estimate of amount of postural sway in a confidence ellipse that encloses approximately 95% of the data points of the COP trajectory. Root mean square (RMS) of COP is equivalent to the standard deviation (SD) of the zero-mean normalized COP. Mean velocity (MV) was calculated by the sum of the COP of each component divided by total time period.

Range of COP was the maximum displacement between any two points of the COP path. These variables were indexed since they have been found to be reliable and valid [18].

DTC was calculated for each variable based on the procedures of Shin et al. [16]. It was defined as the percent change between single task and dual task.

$$DTC = \frac{S - D}{S} \times 100$$

where *S* is a performance for the single task, and *D* is for the dual task. A negative DTC indicates decreased performance during the dual task condition for each parameter.

2.3. Statistical analysis

Descriptive analyses were conducted in SPSS version 18.0. To determine differences between HD and control groups in demographic variables, a χ^2 test was conducted for the categorical variables (i.e. gender) and an independent sampled *t*-test was performed for continuous variables. To determine differences in postural control between the HD group and the control group in each specific condition (baseline vs. dual task), an independent *t*-test was conducted on each outcome variable. Additionally, an independent *t*-test was conducted on DTC for each variable to determine if there were group differences in postural DTC. Significance was defined as $P \leq .01$. We opted for a study-wise adjustment of alpha given the number of analyses. Cohen's *d* was calculated as the effect size. For Cohen's *d*, an effect size of 0.2 was a “small” effect, around 0.5 a “moderate” effect, and 0.8 a “larger” effect were also suggested [19].

3. Results

The primary cause of participants receiving HD was hypertension ($n = 9$), followed by type 2 diabetes ($n = 5$), type 1 diabetes ($n = 2$), nephritis ($n = 1$), polycystic kidney disease ($n = 1$) and unknown ($n = 1$). There were no significant differences in age, height, weight, body mass index, or gender between the HD and healthy control groups (Table 1). HD patients had a reduced number of word utterances during the DTC compared to healthy controls.

Fig. 1 illustrates a representative healthy control (upper panel) and HD (lower panel) participants' COP trajectory in both the baseline and dual task condition. It is clear in the figure that overall the HD participant has a greater amount of postural sway than the control and that there is an increase in the amount of sway in the dual task condition.

Statistical analysis of group data confirmed these observations. Specifically, in the baseline condition the HD group had larger sway area, faster mean velocity in both AP and ML directions, and larger RMS in both AP and ML directions compared to the control group

Table 1
Participant demographics.

Variables	Controls ($n = 19$)	HD patients ($n = 19$)	Non-diabetic HD patients ($n = 8$)	Diabetic HD patients ($n = 11$)
Age [years], mean (SD)	51.2 (9.5)	51.3 (9.9)	49.0 (11.2)	51.0 (9.7)
Height [cm], mean (SD)	172.8 (8.2)	171.5 (8.1)	171.4 (1.0)	172.4 (0.9)
Weight [kg], mean (SD)	92.9 (14.7)	100.2 (25.1)	84.5 (17.2)	98.3 (25.5)
BMI	31.3 (5.9)	34.1 (8.4)	28.8 (6.6)	33.0 (7.6)
Gender (F/M)	5/14	5/14	3/5	2/9
No. of words	12.42 (3.38)*	9.97 (2.97)*	10.31 (3.03)	9.67 (3.05)
Months on dialysis	NA	55.78 (38.6)	82.37 (30.44)*	36.09 (31.96)*

Note: values are mean (SD).

* Significance determined by an independent sampled *t*-test between controls and HD group or non-diabetic and diabetic patients ($P < 0.05$).

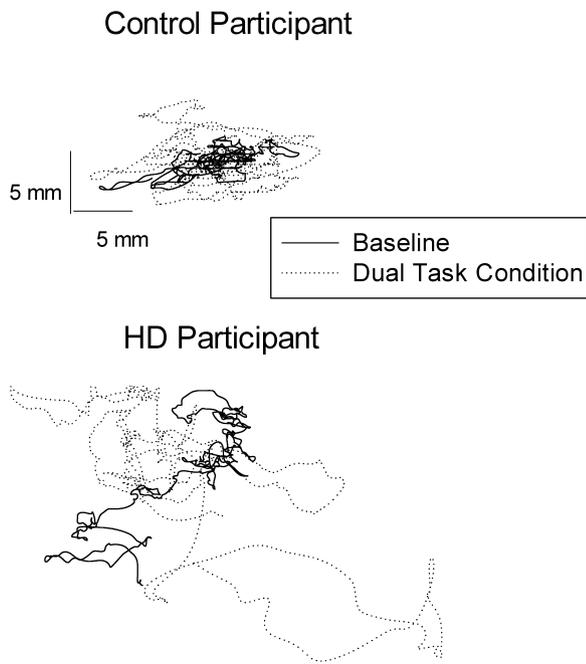


Fig. 1. Center of pressure trajectory of a representative control (upper panel) and HD (bottom panel) participant during quiet stance (solid line) and dual task condition (dotted line).

(P values <0.05 , Table 2). Overall, effect sizes of these differences were large in magnitude ranging from 0.98 to 1.65.

In the dual task condition, the HD group also had larger sway area, faster mean velocity in both AP and ML directions, and larger RMS in both AP and ML directions compared to the control group (P values <0.01 , Table 2). Overall effect sizes of these group differences were large in magnitude ranging from 0.97 to 1.27.

The control group was only found to have a significantly different DTC than 0 in the RMS along the ML axis. In contrast, the HD group had DTC's different than 0 in sway area and median velocity in along the AP and ML axis (see Table 3). Moreover, the DTC for 95% ellipse area, RMS and sway range was significantly larger in HD patients compared to healthy controls ($P < 0.01$; see Table 3). The overall effect sizes of these differences were moderate to large in magnitude ranging from 0.69 to 0.93.

4. Discussion

The current study compared the effect of simultaneous performance of a cognitive task on postural control (e.g. DTC) in HD patients compared to healthy controls. The primary findings of the current investigation were that (1) HD patients had greater postural sway than age, gender, BMI matched controls and (2) HD

patients had a greater DTC than the control group during quiet standing. To our knowledge, this is the first experimental report concerning cognitive-motor interference in postural control of HD patients. Our findings imply that cognitive factors may play a role in postural impairment of HD patients.

Maintenance of an upright stance (e.g. postural control) results from a complex interplay of the sensory information processing (i.e. visual, vestibular and proprioceptive) and appropriate motor output. Impairment in any of these processes can lead to decreases in the control of posture. The observation that HD patients have greater postural sway than healthy controls in the baseline condition is consistent with previous reports [4]. Blake and colleagues [4] reported that patients with end-stage-renal disease have reduced postural stability with nearly 32% larger body sway than age and sex-matched healthy controls. The authors proposed that elevated postural sway resulted from proprioceptive sensory dysfunction. Unfortunately, no data pertaining to proprioceptive function was recorded in the current investigation to test this possibility.

In addition to proprioceptive sensory dysfunction, it is well established that HD patients suffer from muscle weakness and atrophy [3]. It is possible that declines in postural control observed in the HD patients stem in part from muscle weakness. Further research examining this possibility is warranted.

Although elevated DTC in standing balance tasks have been observed in numerous clinical populations [11,14], to our knowledge this is the first documentation of elevated DTC in HD patients compared to age, gender and BMI matched controls. Since the HD group had greater postural sway in the baseline condition, this elevated DTC indicates a greater proportional increase in sway with a simultaneous cognitive task. It is possible that the use of a DTC paradigm would allow for the detection of subtle postural control deficits as has been found in other clinical populations [10].

There could be several potential reasons why the HD group had a larger DTC in postural control than healthy controls. There are two main theoretical models used to explain DTC, namely the capacity model and bottleneck model [11]. The capacity model maintains that there are finite cognitive resources available and decrements in performance occur once demands outpace the cognitive capacity available. The bottleneck model maintains that there is a reduction in performance when similar cognitive/neural pathways are utilized simultaneously. The use of a verbal fluency test as the cognitive task in the dual task condition in the current investigation seemingly minimizes our ability to test the predictions of the bottleneck theory. Although it is logical to assume that the neural pathway(s) required for word generation do not overlap with that of maintenance of upright posture, it has been suggested that verbal fluency tasks, such as the task used here, share complex neural pathways connecting different brain regions which are interlinked with those controlling postural

Table 2
COP parameters as a function of condition and group (control vs. HD patients: mean \pm SD).

Variables	Control		HD patients		P value		Cohen's d	
	Baseline	Dual	Baseline	Dual	Baseline	Dual	Baseline	Dual
95% Ellipse area (mm ²)	106.5 \pm 43.8	103.9 \pm 78.5	273.2 \pm 152.5	465.8 \pm 420.7	<0.01	<0.01	-1.48	-1.00
MV _{AP} (mm/s)	8.5 \pm 1.8	9.5 \pm 3.0	10.9 \pm 4.3	13.8 \pm 5.3	0.04	<0.01	-0.98	-1.00
MV _{ML} (mm/s)	4.0 \pm 0.7	4.5 \pm 1.8	5.3 \pm 1.5	7.4 \pm 3.5	<0.01	<0.01	-1.09	-1.02
RMS _{AP} (mm)	3.8 \pm 0.8	3.8 \pm 0.8	5.6 \pm 1.3	7.1 \pm 3.8	<0.01	<0.01	-1.65	-1.18
RMS _{ML} (mm)	1.5 \pm 0.4	1.2 \pm 0.4	2.6 \pm 1.1	3.5 \pm 3.2	<0.01	<0.01	-1.33	-0.97
Range _{AP} (mm)	17.9 \pm 3.4	18.9 \pm 3.8	27.0 \pm 7.8	32.3 \pm 14.4	<0.01	<0.01	-1.51	-1.27
Range _{ML} (mm)	7.5 \pm 1.6	7.1 \pm 3.6	13.1 \pm 5.8	17.1 \pm 14.2	<0.01	<0.01	-1.31	-0.97

Note: values are mean \pm SD or as otherwise indicated. P value and Cohen's d relate to group difference ($P < 0.01$).

Table 3
Dual task cost of postural control as a function of group (mean \pm SD).

Variables	Control	HD patients	P value	Cohen's <i>d</i>
95% Ellipse area	-0.6 \pm 52.0	-82.3 \pm 125.6*	0.01	0.89
MV _{AP}	-8.9 \pm 22.9	-25.3 \pm 30.3*	0.12	0.52
MV _{ML}	-11.9 \pm 46.5	-33.6 \pm 45.7*	0.18	0.43
RMS _{AP}	-6.2 \pm 27.4	-17.0 \pm 40.7	0.22	0.41
RMS _{ML}	16.7 \pm 17.6*	-37.1 \pm 79.6	<0.01	0.93
Range _{AP}	-11.1 \pm 24.6	-15.4 \pm 38.3	0.46	0.24
Range _{ML}	5.2 \pm 45.7	-35.9 \pm 69.8	0.04	0.69

Note: values are mean \pm SD or as otherwise indicated. P value and Cohen's *d* relate to group differences.

* Indicates DTC significantly different than 0 within each group ($P < 0.01$).

stability [20]. Consistent with the capacity model of DTC, cognitive impairment is very common in HD patients with $\sim 75\%$ of HD patients having some impairment [21]. The reduced number of word utterances during the DTC in HD patients observed may be further evidence of cognitive impairments in this current sample. Regardless of the theoretical framework, it is proposed that the performance of the simultaneous cognitive task further disrupts sensorimotor processing underlying postural control in HD patients.

Interestingly, elevated DTCs in HD were more prevalent along the ML axis (e.g. MV and RMS in ML direction) than the AP direction. Larger side to side sway has been associated with increased falls in elderly [22] and greater side to side sway during dual task conditions was found to be an indicator of injurious falls in older adults [23]. Indeed there is growing evidence that dual task effects during walking and balance performance are predictive of falls in various clinical populations [24,25]. Consequently, the current observations may imply the possibility of increased fall risk in persons undergoing HD. This proposition is congruent with the growing evidence that HD patients are at significant fall risk [5,6].

There is growing evidence that exercise based rehabilitation can improve physical function in HD patients [26,27]. However it is not clear if improvements in physical function result in improved DTC performance. There is data that DTC can be improved with training in older adults [28,29]. For instance, older adults with balance impairments who received 4 weeks of progressive exercise training focusing on body stability exercises while simultaneously engaged in a cognitive task improved their DTC of walking [28]. It remains to be seen if this type of treatment will lead to an improvement in DTC in persons undergoing HD.

Despite the novel observations of this investigation it was not without limitations. A significant limitation was the lack of information pertaining to cognitive function that was collected. It is possible that the increase DTC in persons undergoing HD results from a reduced cognitive capacity and not postural control dysfunction. Further work is necessary to test these opposing hypotheses. Another limitation was that the order of experimental conditions was not counter-balanced. Consequently, it is possible that the greater DTC observed in the HD group resulted from fatigue – since the dual task conditions were completed after the baseline conditions. We note that participants were offered rest throughout the testing and that no participants reported fatigue, thus making the effect of fatigue limited.

5. Conclusion

Overall, HD patients had impaired balance control with a larger magnitude of sway, faster mean velocity, and greater RMS in both AP and ML directions. The greater DTC in HD patients, especially in the ML direction, implies that they are at a higher fall risk. Further work is necessary to determine other factors contributing to elevated DTC in HD patients, and whether DTC can be reduced with targeted interventions.

Acknowledgements

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

Conflict of interest

This investigation was supported in part from funding from the NIH (1R01DK084016). The authors have no conflict of interest to declare. Moreover, we certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated.

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