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Hemodynamics during Dialysis and Cognitive Performance

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Abstract

Background/Aims—Persons receiving hemodialysis (HD) are at increased risk of cognitive impairment (CI). Since blood pressure (BP) fluctuations during HD may affect cerebral perfusion – and subsequently cognitive function – we examined the relationship between dialytic BP fluctuation and cognitive outcomes.

Methods—We included HD patients without diagnosed dementia who were 50 years or older. Using established methods, we classified participants' in CI categories (none to mild and moderate to severe) based on results of a neurocognitive battery. We collected demographic and laboratory data from dialysis unit records, as well as all BP measurements from 12 dialysis sessions. We tested the association between CI and BP fluctuation, adjusting for demographic and laboratory variables.

Results—Our study enrolled 39 patients; 25 had moderate to severe CI. The normal to mild CI group and the moderate to severe patients had similar degrees of BP fluctuation (average minimum SBP: 107.6 ± 18.7 vs 110.2 ± 18.6 mmHg, maximum drop in SBP: 32.6 ± 10.2 vs 35.4 ± 15.0 mmHg; proportion of sessions with SBP < 90 mmHg: 0.2 ± 0.3 vs 0.2 ± 0.3 ; average change in SBP, pre to post HD: 10.2 ± 12.4 vs 11.8 ± 16.4 mmHg, all $p > 0.55$). There was no association between BP variables and performance on individual cognitive tests. Multivariable analysis showed that older age and non-Caucasian race were associated with a reduction in cognitive scores.

Conclusions—There was no cross-sectional association between dialytic BP changes and cognitive performance.

Keywords

hemodialysis; blood pressures; hypotension; cognitive impairment

Introduction

Over two thirds of persons receiving hemodialysis (HD) for end stage renal disease (ESRD) have moderate to severe cognitive impairment(CI).¹ Cognitive impairment in ESRD is associated with increased mortality and healthcare costs, and decreased quality of life.^{2, 3} Surprisingly, the factors causing the high prevalence of CI in this population are not clear.

Studies of patients with chronic kidney disease (CKD) indicate they commonly have multiple risk factors for CI, including such traditional risk factors as age, hypertension, and diabetes. Moreover, increasing severity of CKD, as measured by estimated glomerular filtration rate (eGFR), is also associated with CI, even after adjusting for traditional risk factors.⁴ However there suggestion that HD contributes directly to cognitive decline. Analysis of United States Renal Data System (USRDS) data reveals a significant increase in dementia prevalence within the two years immediately following initiation of hemodialysis (HD).⁵ Small longitudinal studies demonstrate that HD patients have more rapid decline in cognitive test scores than age matched controls.⁶

Since HD is often characterized by large fluctuations in blood pressure (BP), with 25% of sessions characterized by a drop of at least 20mmHg in systolic BP (SBP)⁷ and often times higher,⁸ it has been thought that these fluctuations lead to changes in cerebral perfusion which may cumulatively lead to ischemic injury, atrophy and subsequent cognitive decline.^{9, 10} Indeed, HD has been shown to reduce cerebral blood flow in studies using transcranial doppler monitoring.¹¹ Moreover, persons on HD undergoing brain imaging have more atrophy, silent infarcts, and white matter disease than do controls.^{12, 13} Therefore, we performed the present study to determine if persons on HD patients with significant CI have larger drops in BP or have lower trough BPs during dialysis compared to persons on HD without significant CI.

Methods

Study population

After approval from the Milwaukee VA Medical Center and Medical College of Wisconsin IRB, we recruited patients >50 years of age who were receiving thrice weekly chronic HD at one of three Milwaukee area dialysis centers. We excluded patients with diagnosed dementia, Parkinson's disease, intracranial tumor or bleed within the past 12 months, or traumatic brain injury. Additionally, we excluded patients who lacked stamina to undergo a one hour neuropsychological test battery. All participants provided written informed consent before beginning study procedures and research was carried out according to the principles of the Declaration of Helsinki.

Data collection procedure

Participants completed a written survey regarding sociodemographics (e.g. age, race, education, and employment status), duration of hemodialysis, and their personal history of hypertension, diabetes mellitus, congestive heart failure (CHF), coronary artery disease (CAD), peripheral vascular disease (PVD), cirrhosis and stroke. We reviewed the medical records of the dialysis unit and associated medical facilities to confirm the presence of comorbid conditions and the number of hospital admissions in the year prior to cognitive testing. We used the medical record to collect hemoglobin and albumin values, urea reduction ratio (URR), and a marker of dialysis adequacy (Kt/V). We collected the primary cause of renal disease from the ESRD Medical Evidence Report required for Medicare Registration.

We collected duration of dialysis, ultrafiltration (UF) volume and all sitting blood pressure measurements (pre-dialysis BP, dialytic BPs, and post-dialysis BP) for 12 consecutive treatment sessions over a one month period corresponding to the month during which the neurocognitive testing was conducted. Per our dialysis centers' protocols, BP is measured every 15 to 20 minutes during the dialysis session. For each session we calculated three measures of SBP and UF rate (see Table 1 for definitions). We also determined whether there was at least one hypotensive episode (SBP < 90 mmHg) during the session. We focused on SBP, since this has been shown to be a better predictor of clinical outcomes in persons over 50 years than diastolic blood pressure.¹⁴ For each participant we then calculated average UF rate and three measures of average SBP fluctuations across the 12 sessions. We also determined the proportion of dialysis sessions with at least one hypotensive episode.

Neurocognitive testing

Trained study team members administered a battery of neurocognitive tests to each participant using standardized procedures. The neurocognitive battery was administered following the dialysis session for the majority of patients (92%); however, in the case of scheduling conflicts testing was also conducted before a session or on an off day (8%). Testing was not conducted during dialysis as there would be too many distractions in the dialysis unit. The battery assessed 5 domains: executive function, memory, learning, language, and attention. The Montreal Cognitive Assessment (MoCA) assessed global cognitive function. The remainder of the neurocognitive battery included the Hopkin's Verbal Learning Test-Revised (HVLT-R), the Trail Making Test A and B, Controlled Oral Word Association Test (COWAT), Animal Naming, and the Wechsler Adult Intelligence Scale-Fourth Edition (WAIS-IV) Digits Span subtest. The Geriatric Depression Scale (GDS) was included to assess mood, as depression can influence cognitive performance. Published age, gender, education and ethnicity corrected norms were used to score the neuropsychological assessment.¹⁵⁻¹⁸ We classified each participant's level of CI using an algorithm developed by Murray et al, which has been used in the dialysis population and is based on the validated criteria for CI and dementia.¹⁹

Statistical Analysis

SAS V 9.2 was used for the statistical analysis. We compared baseline characteristics of participants with “normal to mild” CI to those with “moderate to severe” CI using t-tests, Fisher’s exact test or chi-squared tests as appropriate. Regression analysis evaluated the association between each of our measures of SBP fluctuation and scores on each cognitive test. We also compared the average value of each of our measures of SBP fluctuation among participants in the “normal or mild” CI group to the average among those with “moderate or severe” CI using a t-test. We then used logistic regression analysis to determine whether BP fluctuation affected cognitive status after adjusting for age, race, presence of diabetes, and duration of dialysis. We performed a series of linear regression analysis to determine if BP fluctuation was associated with scores on the MoCA, again adjusting for the clinical variables mentioned above.

Results

At our three dialysis units there were 121 patients who met inclusion criteria. Of these 105 were asked to participate, 16 were never asked as they were not present on recruiting days. Forty patients agreed to participate; one was excluded because development of Alzheimer’s disease was being considered by his primary care physician. The most common reason patients cited for declining participation was reluctance to remain at the dialysis unit for an additional hour to complete the neurocognitive battery. The mean age was 65.9 ± 9.0 years, and diabetes mellitus (DM) and hypertension (HTN) were present in 47% and 100% of participants, respectively.

Cognitive outcomes

Based on the neurocognitive battery, 66% of this cohort demonstrated moderate to severe CI, and 59% scored two standard deviations below the mean on MoCA. This cohort demonstrated greatest impairment on tests of memory and attention. See Table 2 for standardized means and percent performing below the population norms for each test. None of the persons in the cohort had severe depressive symptoms based on the GDS, thus it was not adjusted for in evaluating our cognitive outcomes.

Participant characteristics by cognitive level

Participants were initially categorized in four levels of CI, normal, mild, moderate and severe with 5, 8, 18, and 7 in each group, respectively. To improve statistical power, we then grouped participants in two levels 1) normal to mild CI and 2) moderate to severe CI. This grouping is clinically relevant since moderate to severe CI, as we have defined it, is likely equivalent to at least mild dementia, whereas mild CI may not correlate with dementia. Demographic, co-morbid and laboratory differences between groups are shown in Table 2. There were no significant differences in ethnicity, gender, duration of dialysis, and years of education between participants with normal to mild CI and moderate to severe CI. The age of the participants with normal to mild CI (mean = 68.7 ± 10.1) was older than participants with moderate to severe CI (mean 64.5 ± 8.2) but not significantly ($p = 0.2$). In general there were no significant differences in the presence or absence of comorbidities between groups. There were a higher proportion of participants with DM as primary cause of renal disease in

the moderate to severe CI group compared to the normal to mild CI group, and conversely a lower proportion with glomerulonephropathy. Laboratory findings demonstrated a difference in URR with $74.6\% \pm 4.5\%$ in the moderate to severe CI group vs $77.6\% \pm 3.2\%$ in the normal to mild CI group ($p = 0.04$). There was a trend to lower Kt/V in the moderate to severe group (1.5 ± 0.2) compared to the normal to mild group (1.6 ± 0.2), but this was not statistically significant ($p = 0.09$). There was no significant difference between CI groups in hemoglobin levels or serum albumin levels.

Dialytic blood pressure and cognitive scores

Overall the BP data varied across our cohort with the average dialytic BP ranging from a SBP of approximately 95mmHg to 170mmHg. Medically defined hypotension (SBP <90) occurred in 20% of dialysis sessions. There were no differences in frequency hypotension when comparing the two CI groups. The average minimum SBP, the average maximum drop in SBP and the average change in pre to post dialysis SBP were similar between the two cognitive groups (Table 3).

We performed univariate analysis to evaluate for associations between the average BP variables and cognitive test performance. We found no association between average minimum SBP during dialysis and primary outcome of MoCA score. Since our sample size of 39 was less than anticipated, we calculated our post-hoc power using observed values for standard deviation and sample size. We had 92% power to detect a decrease in MoCA score by 2 points for each 20 mmHg drop in average minimum SBP. There was also no association between MoCA score or any of the other measures of intradialytic hypotension. While the association between average maximum drop in SBP and the WAIS-IV Digit Span Sequencing was nominally significant ($p = 0.04$), this was not significant after adjusting for multiple hypothesis testing. No other significant associations between BP and scores on the neurocognitive battery were found.

Adjusted multivariate analysis for age, dialysis duration, race, and diabetes diagnosis showed no association between degree of CI and BP variables. The same multivariate model was done with MoCA score and the BP variables with no significant interaction. Specifically the model with average minimum SBP had a regression coefficient estimate of -0.02 for every 10mmHg (95% CI: $-0.7, 0.6$). However, for every 1 year increase in age, there was an associated 0.2 decrease in MoCa score (95% CI: $-0.3, -0.04$). In addition race was associated with a lower MoCA score by 2.8 points (95% CI, $-5.2, -0.4$) for race other than Caucasian (See Table 4).

Discussion

In our study we found no significant relationship between current dialytic BP fluctuations and performance on cognitive tests. This finding persisted when we examined multiple different measures of BP fluctuation and multiple measures of cognitive status, including global cognitive function (with classification of CI group and MoCA score) and domain specific cognitive function (with neurocognitive battery). It was also unaffected by adjusting for demographic and clinical characteristics. Our results did show that a lower MoCA score was associated with increasing age and also non-Caucasian race which is consistent with

findings in the general population. Although it is widely noted in the literature that hemodynamic fluctuations during dialysis may contribute to cognitive dysfunction,^{1, 9, 10, 20} ours is the first analysis to address the relationship between BP fluctuations during dialysis and cognitive status. Thus examination of our results is needed to determine future directions in investigating the mechanism of CI in the ESRD.

This study supports the present literature that demonstrates a high frequency of CI in the HD population. We classified two thirds of our cohort as exhibiting moderate to severe CI, consistent with previous studies.^{13, 19} The prevalence of CI in persons on dialysis is dramatically greater than the 22.2% prevalence of CI and 13.9% prevalence of dementia found in an elderly United States population based sample.^{21, 22} In contrast to our cohort, the afore-mentioned studies have lower rates of CI and dementia but an overall higher mean age (over 71 years), demonstrating the disproportionately higher burden of CI in persons on dialysis.

Our study attempted to investigate a mechanism for CI in persons with ESRD. Previous research has evaluated various etiologies including uremic clearance and contribution of traditional risk factors. The studies on uremic clearance have been conflicting. Murray et al showed that a higher Kt/V was associated with higher severity of CI.¹⁹ The Frequent Hemodialysis Network Trial showed that patients with frequent HD had a 40% higher weekly Kt/V but did not show any improvement in the primary outcome of executive function; however, there was some benefit in secondary outcomes of memory and verbal fluency.²³ Based on the difference in URR and Kt/V between the two CI groups, our data suggests that higher urea clearance is associated with improved CI and is more consistent with results from the Frequent Hemodialysis Trial. Thus far, research has indicated that the high prevalence of traditional risk factors such as ageing, diabetes mellitus, hypertension and vascular disease are contributors to CI.^{3, 24} However, this does not explain the significant increase in new dementia that occurs after the initiation of HD.⁵

Some studies speculate that HD may cause accelerated brain injury and atrophy due to small vessel cerebral ischemia during dialysis sessions.^{25, 26} Our data demonstrated an average maximum drop in SBP of 34.5 ± 13.5 mmHg. Systemic BP is a determinant of cerebral perfusion pressure, thus acute drops in systemic BP may lead to decreased cerebral perfusion causing brain ischemia.²⁷ Ischemic brain injury that occurs chronically overtime may lead to CI. In fact, Mizumasa et al were able to demonstrate that hypotension during dialysis was associated with progressive increase in frontal lobe atrophy over a three year period.²⁶ In contrast, our study examined the degree of BP fluctuations and cognitive test performance and found no association. It may be that cerebral imaging is a more sensitive indicator of ischemic damage. Alternatively, since the study of Mizumasa et al measured change in atrophy over 3 years, it may be that a longitudinal assessment of CI would find an association with dialytic BP fluctuations. In a recent study evaluating cognitive fluctuations in persons on dialysis, investigators found that a subset of HD patients had deterioration in attention and executive function test scores from pre to post dialysis, in contrast to a slight improvement in retest scores in the non-dialysis control cohort²⁸. This deterioration was associated with increased frequency of dialytic hypotensive episodes. However the primary goal of that study was to determine if cognitive performance varies around the dialysis

cycle, and thus they were not comprehensive in measuring dialytic BP changes, nor could they comment on the contribution of dialytic hypotension to the overall poor cognitive performance in the HD cohort.

Our study has certain limitations. First, small sample size ($N = 39$) limits interpreting our results. Post hoc power analysis did show we had the ability to detect an effect of 2 points in MoCA score/20mmHg in SBP, however if the true effect was smaller, then we may not have had adequate power based on our sample size. Although a standard for evaluating the clinical significance of a change in MoCA score has yet to be identified, a 2-point difference is considered a reliable change as it represents a difference of 1 standard deviation from the mean according to normative data.²⁹ Second, *as our population was voluntary we may have underestimated the true prevalence of CI, as those whom were most cognitively impaired are less likely to participate.* Third, the reason for the lack of association may be due to the use of prevalent patients in our study rather than incident patients. The effects of hemodynamic fluctuations may be more damaging in the early period of dialysis initiation and level out for persons who have been on dialysis for a number of years. In a recent study on incidence of stroke in persons initiating HD, the incidence of stroke peaked in the month after initiation, and then subsequently decreased at one year after initiation.³⁰ Likewise, small vessel ischemic changes may also occur more frequently during the months surrounding initiation of dialysis and then stabilize later on. The mean dialysis vintage for our population was over four years. It is possible that during previous years even persons who currently demonstrate hemodynamic stability on dialysis had periods of instability. Given changes in the medical record we do not have information on dialytic BPs from previous years for our participants. Lastly,, this was a cross-sectional study. A more sensitive measure of the effect of BP on cognitive function may be to evaluate changes in cognitive function longitudinally. The next step is to repeat cognitive assessment in our cohort one year after baseline assessment to evaluate the rate of decline. Blood pressure measurements over the course of the same one year period will be compared to changes in test scores to provide greater clarity on the role of dialytic BP on cognitive outcomes.

Conclusions

Our study reinforces the high frequency of CI in the dialysis population and highlights the importance of evaluating and monitoring cognitive function in this population. Our baseline data did not show an association between dialytic BP measurements and cognitive test performance; however this potential mechanism warrants further investigation due to the limitations of our cross-sectional data. Rigorous studies on the effects of dialysis on cerebral perfusion and the implications for cognitive status are needed in order to fully evaluate the mechanism for cognitive impairment in the dialysis population.

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References

1. Murray AM. Cognitive impairment in the aging dialysis and chronic kidney disease populations: an occult burden. *Adv Chronic Kidney Dis*. 2008; 15:123–32. [PubMed: 18334236]
2. U.S. Renal Data System, USRDS. 2005 Annual Data Report: Atlas of End-Stage Renal Disease in the United States. National Institutes of Health, National Institute of Diabetes and Digestive and Kidney Diseases; Bethesda, MD: 2005.
3. Kurella M, Mapes DL, Port FK, Chertow GM. Correlates and outcomes of dementia among dialysis patients: the Dialysis Outcomes and Practice Patterns Study. *Nephrol Dial Transplant*. 2006; 21:2543–8. [PubMed: 16751655]
4. Etgen T, Chonchol M, Forstl H, Sander D. Chronic kidney disease and cognitive impairment: a systematic review and meta-analysis. *American journal of nephrology*. 2012; 35:474–82. [PubMed: 22555151]
5. Murray AM, Li S, Collins A. Racial difference in the prevalence of dementia before and after hemodialysis initiation. *J Am Soc Nephrol*. 2001 Abstract ed.
6. Bossola M, Antocicco M, Di Stasio E, et al. Mini Mental State Examination over time in chronic hemodialysis patients. *Journal of psychosomatic research*. 2011; 71:50–4. [PubMed: 21665013]
7. National Kidney Foundation. K/DOQI Clinical Practice Guidelines for Cardiovascular Disease in Dialysis Patients. *Am J Kidney Dis*. 2005; 45(suppl 3):S1–S154.
8. Dubin R, Owens C, Gasper W, Ganz P, Johansen K. Associations of endothelial dysfunction and arterial stiffness with intradialytic hypotension and hypertension. *Hemodialysis international International Symposium on Home Hemodialysis*. 2011; 15:350–8. [PubMed: 21658174]
9. Madero M, Sarnak MJ. Does hemodialysis hurt the brain? *Seminars in dialysis*. 2011; 24:266–8. [PubMed: 21435001]
10. Davenport A. What are the causes of the ill effects of chronic hemodialysis? Balancing risks: blood pressure targets, intradialytic hypotension, and ischemic brain injury. *Seminars in dialysis*. 2014; 27:13–5. [PubMed: 24131204]
11. Stefanidis I, Bach R, Mertens PR, et al. Influence of hemodialysis on the mean blood flow velocity in the middle cerebral artery. *Clinical nephrology*. 2005; 64:129–37. [PubMed: 16114789]
12. Drew DA, Bhadelia R, Tighiouart H, et al. Anatomic brain disease in hemodialysis patients: a cross-sectional study. *Am J Kidney Dis*. 2013; 61:271–8. [PubMed: 23040011]
13. Fazekas G, Fazekas F, Schmidt R, Kapeller P, Offenbacher H, Krejs GJ. Brain MRI findings and cognitive impairment in patients undergoing chronic hemodialysis treatment. *Journal of the neurological sciences*. 1995; 134:83–8. [PubMed: 8747848]
14. Lewington S, Clarke R, Qizilbash N, Peto R, Collins R. Prospective Studies C. Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. *Lancet*. 2002; 360:1903–13. [PubMed: 12493255]
15. Wechsler, D. Wechsler Adult Intelligence Scale. 4. San Antonio, TX: Pearson; 2008.
16. Heaton, R.; SWM; MJT; IG. Revised Comprehensive Norms for an Expanded Halstead-Reitan Battery: Demographically Adjusted Neuropsychological Norms for African American and Caucasian Adults. Lutz, FL: Psychological Assessment Resources, Inc; 2004.
17. Brandt, J.; Benedict, R. Hopkins Verbal Learning Test-Revised. Lutz, FL: Psychological Assessment Resources, Inc; 2001.
18. Sheikh J, Yesavage J. Geriatric Depression Scale: Recent evidence and development of a shorter version. *Clinical Gerontologist*. 1986; 5:165–73.
19. Murray AM, Tupper DE, Knopman DS, et al. Cognitive impairment in hemodialysis patients is common. *Neurology*. 2006; 67:216–23. [PubMed: 16864811]
20. Prohovnik I, Post J, Uribarri J, Lee H, Sandu O, Langhoff E. Cerebrovascular effects of hemodialysis in chronic kidney disease. *Journal of cerebral blood flow and metabolism: official journal of the International Society of Cerebral Blood Flow and Metabolism*. 2007; 27:1861–9.
21. Plassman BL, Langa KM, Fisher GG, et al. Prevalence of cognitive impairment without dementia in the United States. *Ann Intern Med*. 2008; 148:427–34. [PubMed: 18347351]

22. Plassman BL, Langa KM, Fisher GG, et al. Prevalence of dementia in the United States: the aging, demographics, and memory study. *Neuroepidemiology*. 2007; 29:125–32. [PubMed: 17975326]
23. Kurella Tamura M, Unruh ML, Nissenson AR, et al. Effect of more frequent hemodialysis on cognitive function in the frequent hemodialysis network trials. *Am J Kidney Dis*. 2013; 61:228–37. [PubMed: 23149295]
24. Pereira AA, Weiner DE, Scott T, Sarnak MJ. Cognitive function in dialysis patients. *Am J Kidney Dis*. 2005; 45:448–62. [PubMed: 15754267]
25. Yoshimitsu T, Hirakata H, Fujii K, et al. Cerebral ischemia as a causative mechanism for rapid progression of brain atrophy in chronic hemodialysis patients. *Clinical nephrology*. 2000; 53:445–51. [PubMed: 10879664]
26. Mizumasa T, Hirakata H, Yoshimitsu T, et al. Dialysis-related hypotension as a cause of progressive frontal lobe atrophy in chronic hemodialysis patients: a 3-year prospective study. *Nephron Clinical practice*. 2004; 97:c23–30. [PubMed: 15153764]
27. Davenport A. Changing the hemodialysis prescription for hemodialysis patients with subdural and intracranial hemorrhage. *Hemodialysis international International Symposium on Home Hemodialysis*. 2013; 17 (Suppl 1):S22–7. [PubMed: 24134327]
28. Costa AS, Tiffin-Richards FE, Holschbach B, et al. Clinical Predictors of Individual Cognitive Fluctuations in Patients Undergoing Hemodialysis. *Am J Kidney Dis*. 2014
29. Nasreddine ZS, Phillips NA, Bedirian V, et al. The Montreal Cognitive Assessment, MoCA: a brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*. 2005; 53:695–9. [PubMed: 15817019]
30. Murray AM, Seliger S, Lakshminarayan K, Herzog CA, Solid CA. Incidence of stroke before and after dialysis initiation in older patients. *J Am Soc Nephrol*. 2013; 24:1166–73. [PubMed: 23620399]

Table 1

Definition of Predictor Variables

Average minimum SBP	Lowest SBP from any DP readings during dialysis, including pre and post measurements
Maximum decrease in SBP	The predialysis SBP minus the lowest SBP for each dialysis session
Change in pre to post SBP	Pre dialysis SBP minus the post dialysis SBP
Ultrafiltration rate	Net amount of fluid (ml) removed during the dialysis session divided by the duration of dialysis (hours) divided by the weight (kg)
Frequency of hypotension	Number of sessions with at least one SBP <90mmHg divided by the total number of sessions for that patient.

SBP = systolic blood pressure

Table 2

Hemodialysis cohort overall and by cognitive impairment classification

	Total N=38 (%)	Normal – Mild N = 13 (%)	Moderate-Severe N = 25 (%)	P Value
Age				
Mean ± SD	65.9 ± 9.0	68.7 ± 10.1	64.5 ± 8.2	0.18
Race				0.23*
American Indian/Alaskan Native	2 (5.3)	1 (7.7)	1 (4.0)	
African American	25 (65.8)	6 (46.2)	19 (76.0)	
White	11 (28.9)	6 (46.2)	5 (20.0)	
Gender				1.00*
Female	5 (13.2)	3 (15.4)	3 (12.0)	
Male	33 (86.8)	11 (84.6)	22 (88.0)	
Duration of Dialysis (years)				
Mean ± SD	4.6 ± 4.5	3.8 ± 5.0	5.0 ± 4.2	0.43
Years of Education				0.49*
No College	24 (63.1)	7 (55)	17 (68)	
College and beyond	14(36.8)	6 (46)	8 (32)	
Comorbidities				
(+) HTN	38 (100)	13 (100)	25 (100)	n/a
(+) DM	18 (47.4)	5 (38.5)	13 (52.0)	0.43**
(+) CHF	14 (36.8)	2 (15.4)	12 (48.0)	0.08*
(+) CAD	13 (34.2)	4 (30.8)	9 (36.0)	1.00*
(+) PVD	5 (13.2)	0 (0)	5 (20.0)	0.14*
(+) Cirrhosis	0 (0.0)	0 (0.0)	0 (0.0)	n/a
(+) Stroke	4 (10.5)	0 (0.0)	4 (16.0)	0.28*
Hospital Admissions	2.0±2.2	1.8±2.2	2.1±2.3	0.69
Cause of ESRD				0.01*
DM	14 (36.8)	2 (15.4)	12 (48.0)	
HTN	13 (34.2)	3 (23.1)	10 (40.0)	
GN	5 (13.2)	3 (23.1)	2 (8.0)	
Other	6 (15.8)	5 (38.4)	1 (4.0)	
Participants on ESA	26 (68.4)	10 (76.9)	16 (64.0)	0.49
Laboratory Data				
Hemoglobin (g/l) ± SD	109.2 ± 11.9	110.5 ± 16.0	108.4 ± 9.7	0.63
Albumin (g/l) ± SD	39.1 ± 3.9	39.7 ± 3.8	38.6± 4.1	0.48
URR (%)± SD	75.6 ± 4.3	77.6 ± 3.2	74.6 ± 4.5	0.04
Kt/V± SD	1.5 ± 0.2	1.6 ± 0.2	1.5 ± 0.2	0.09

T-test was used to compares groups except when marked by * for Fisher exact test and by ** when chi-squared test was used. HTN is hypertension, DM is Diabetes Mellitus, CHF is congestive heart failure, CAD is coronary artery disease, PVD is peripheral vascular disease, GN is glomerulonephropathy, ESA is erythropoietin stimulating agents (darbepoetin or epoetin). Hospital admissions refers to admission in the one year

prior to the date of the cognitive assessment. Laboratory data shown in mean $\pm$ SD. URR is the urea reduction ratio, and Kt/V, is a measure of dialysis adequacy.

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Table 3

Patterns of dialytic BP measurements in dialysis patients, by degree of cognitive impairment

BP Parameter	Cognitive Impairment Classification			
	Total N = 38	Normal-Mild N = 13	Moderate-Severe N = 25	* p-value
Proportion of sessions with hypotension (SBP<90mmHg) ± SD	0.2 ± 0.3	0.2 ± 0.3	0.2 ± 0.3	0.90
Average Minimum BP ± SD	109.3 ± 18.4	107.6 ± 18.7	110.2 ± 18.6	0.69
Average Maximum BP Drop ± SD	34.5 ± 13.5	32.6 ± 10.2	35.4 ± 15.0	0.55
Average Change in Pre-to-Post HD BP ± SD	-11.2 ± 17.1	-10.2 ± 12.4	-11.8 ± 16.4	0.76
Ultrafiltration rate (ml/h/kg) ± SD	9.6 ± 2.9	9.6 ± 2.8	9.6 ± 3.6	0.99

The mean blood pressure by variable for the entire cohort and the two cognitive impairment groups, normal to mild CI and moderate to severe CI. Values shown are the mean ± SD.

* T-test used to compare groups.

Table 4

Multivariate Model for MoCA score.

Variable	Coefficient estimate	95% CI
Age (per 1 year)	−0.2	−0.3, −0.04
Duration of dialysis (per 1 year)	−0.1	−0.4, 0.1
Race	−2.8	−5.2, −0.4
Diabetes	−1.4	−3.8, 1.0
Average min BP (per 10mmHg)	−0.06	−0.7, 0.6

For the continuous variables (age, duration of dialysis and average minimum BP) the coefficient estimate represents the difference in MoCA score for each unit change (noted in parenthesis) of the variable. For the categorical variables (race and diabetes) the change in MoCA is for a race other than Caucasian and for having diabetes mellitus.