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Correlation between intradialytic blood pressure variability and cognitive impairment in patients on maintenance hemodialysis

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Abstract

Background The relationship between intradialytic blood pressure variability (BPV) and mild cognitive impairment (MCI) in maintenance hemodialysis (MHD) patients is currently unclear. Our present study aimed to illustrate the correlation between intra-dialysis BPV and CI in MHD patients.

Methods Intradialytic SBP within 3 months before cognitive assessment of the patients were collected as baseline data and averaged as final data. The intradialytic SBP was converted to the following 4 candidate short-term BPV indices: standard deviation (SD), coefficient of variation (CV), average real variability (ARV), RANGE. Overall cognitive function was assessed by the Montreal Cognitive Assessment (MoCA) scale.

Results The study finally enrolled 170 patients with 6662 dialysis records and 26,580 SBP measurements. The mean age of the patients was 57.99 years, the MCI prevalence was 78.24%. Intradialytic SBP ARV (average real variability) was notably higher in patients with MCI than in the non-MCI (NMCI) group (8.91 vs. 7.60, $P=0.042$), but there was no statistical difference in the mean SBP and other BPV indices between the two groups. There was a non-linear relationship between SBP ARV and MCI, and the inflection point of SBP ARV was 7.52.

Conclusion Our study found that high SBP ARV was closely associated with MCI, indicating that high SBP ARV may act as an indicator of MCI in MHD patients.

Keywords Blood pressure variability, Cognitive impairment, Hemodialysis

Background

Blood pressure variability (BPV) reflects dynamic changes in blood pressure (BP), and increased BPV leads to endothelial dysfunction [1], arterial stiffness [2], cerebral ischemic changes, and impaired blood-brain barrier [3], which may be potential mechanisms of mild cognitive impairment (MCI) [4]. A growing number of studies have identified BPV as an independent risk factor for CI and dementia, independent of mean BP [3, 5].

End-stage renal disease (ESRD) is a vital public health problem worldwide. Maintenance hemodialysis (MHD) is the main renal replacement therapy for ESRD patients. There are about 749,000 MHD patients in China, and the

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number is increasing at a rate of more than 100,000 per year [6–8]. The prevalence of CI among MHD patients is up to 58% or higher [9, 10]. After initiation of hemodialysis, approximately 50% of patients develop MCI within 2 years [11], and MCI is also a risk factor for death and poor prognosis in MHD patients [12].

Intradialytic hemodynamic instability may provoke repetitive cerebral ischemia and neurological damage, thus leading to MCI [13]. MHD patients are more likely to have fluctuating BP during dialysis, with a relatively higher incidence of dialysis hypotension or hypertension [14], which may have a greater impact on MCI. However, the relationship between intradialytic BPV and MCI in MHD patients is currently unclear. Therefore, our present study aimed to illustrate the correlation between intra-dialysis BPV and MCI in MHD patients.

Methods

Study population enrollment

Clinical data of patients receiving MHD at the Specialty Medical Center of the Ground Force, People's Liberation Army (Daping Hospital) from 1 January 2023 to 31 May 2023 were retrospectively analyzed. Inclusion criteria included: (1) MHD patients with ≥ 3 months of hemodialysis; (2) age ≥ 18 years, no restriction on gender; (3) complete data on blood pressure during dialysis (data for > 3 months). Patients were excluded for (1) missing the Montreal Cognitive Assessment (MoCA-B) scores; (2) requirement of medication intervention for bp during HD; (3) an acute systemic infection, acute cardiovascular events, active hepatitis, or cancer; (4) a history of medication use that may affect cognition or sleep (e.g., donepezil, antihistamines, tricyclic antidepressants, benzodiazepines, and citicoline). This study was approved by the Medical Ethics Committee of the Daping Hospital (YYLS2022-210) before the commencement of this study. The requirement for informed consent was waived, as the utilization of anonymized retrospective data does not require patient consent under the local legislation.

Cognitive function evaluation

All cognitive function assessments were performed by researchers who were trained and certified by a neuropsychologist before the study. To avoid the effects of hemodynamic changes on the day of dialysis, neuropsychological assessment was performed individually in a separate room on the day before or the day after dialysis. It took about 30 min on average. Overall cognitive function was assessed by the Beijing version of the Montreal Cognitive Assessment (MoCA) scale, including executive function, naming, memory, language, abstraction, orientation, and attention domains, with a total score of 30. If the subject was illiterate, an additional 1 point was given to the final total score, regardless of the number of years of education. A total score of ≥ 26 was classified as normal cognitive function. Based on the MoCA score, the patients were assigned to the MCI group (MoCA score < 26) and the non-MCI group (MoCA score ≥ 26).

Data collection

Demographic data of patients were collected at enrolment, including age, year of hemodialysis, gender, history of diabetes mellitus, and history of stroke. The single-pool Kt/V (spKt/V) was chosen as an indicator of dialysis adequacy. spKt/V was determined based on the following formula: spKt/V =-In (R- 0.008t) + (4-3.5R) x $^{\triangle}$BW/BW [15, 16], where R represents post-dialysis/pre-dialysis urea nitrogen, t represents treatment time, $^{\triangle}$BW represents ultrafiltration volume, and BW represents post-filtration body weight. a two-point urea kinetic model of urea reduction and weight loss during dialysis. Laboratory data including hemoglobin, albumin, C reactive protein, triglycerides, and cholesterol were also obtained.

BPV-related indicators and calculation formulas

Dialysis data (intradialytic SBP, dry weight, ultrafiltration rate) within the 3 months before cognitive assessment of the patients were collected as baseline data and averaged as final data. Intradialytic SBP was measured using an automated oscillometric device (Omron, HEM-7121) as recommended by the NKF K/DOQI guidelines [17]. The patient was placed in the supine position, with the cuff at the same level as the heart and rested for 5 min before SBP measurement. Normally, SBP was measured before and after each dialysis session, and upper extremity SBP on the non-HD access side was measured every 1 h after the start of dialysis. If discomforts (sweating, muscle cramps) occurred during dialysis, additional SBP monitoring was performed, and the patient's SBP was converted to the following 4 candidate short-term BPV indices:

Standard deviation (SD).

SD is the most used index of BPV and is correlated with mean BP, independent of measurement order.

$$SD = \sqrt{\frac{\sum_{i=1}^{n} \left(SBP_i - \overline{SBP}\right)^2}{(n-1)}}$$

Coefficient of variation (CV).

CV indicates the difference in BP fluctuations at different stages. CV is commonly used for correction because absolute SD values may be positively correlated with mean BP.

$$CV = 100 \times SD/mean$$

Average real variability (ARV).

ARV is the average of absolute differences between successive BP and is sensitive to the measurement order of individual BP, with the advantage of considering the temporal nature of BP changes.

$$ARV = \frac{1}{n-1}\sum_{i=1}^{n-1}|SBP_{i+1} - SBP_i|$$

RANGE is influenced by extreme SBP values and is therefore highly variable and highly correlated with SD and CV.

REAGE = Maximum-minimum BP values.

Statistical analysis

Categorical variables were depicted as percentage, and normally distributed continuous variables as mean ± SD. Non-normally distributed continuous variables were exhibited as median and interquartile range. Univariate and multivariate logistic regression analyses were adopted to appraise the association between BPV and study outcomes. If non-linearity was detected, we first calculated the inflection point using a recursive algorithm and then constructed a two-piecewise logistic regression model on both sides of the inflection point. All statistical tests were two-tailed and $P < 0.05$ was considered statistically significant. EmpowerStats (www.empowerstats.com, X&Y solutions, Inc. Boston, MA) and R software version 3.6.1 (http://www.r-project.org) were applied for statistical analyses and graphic plotting, respectively.

Results

Basic characteristics

According to the inclusion criteria, 201 patients were eligible for enrolment, finally, 170 patients were enrolled, with a total of 6,662 dialysis recordings and 26,580 SBP measurement recordings (Fig. 1). The mean age of the patients was 57.99 years. The proportion of males was 58.24%, and MCI prevalence was 78.24%. Patients in the

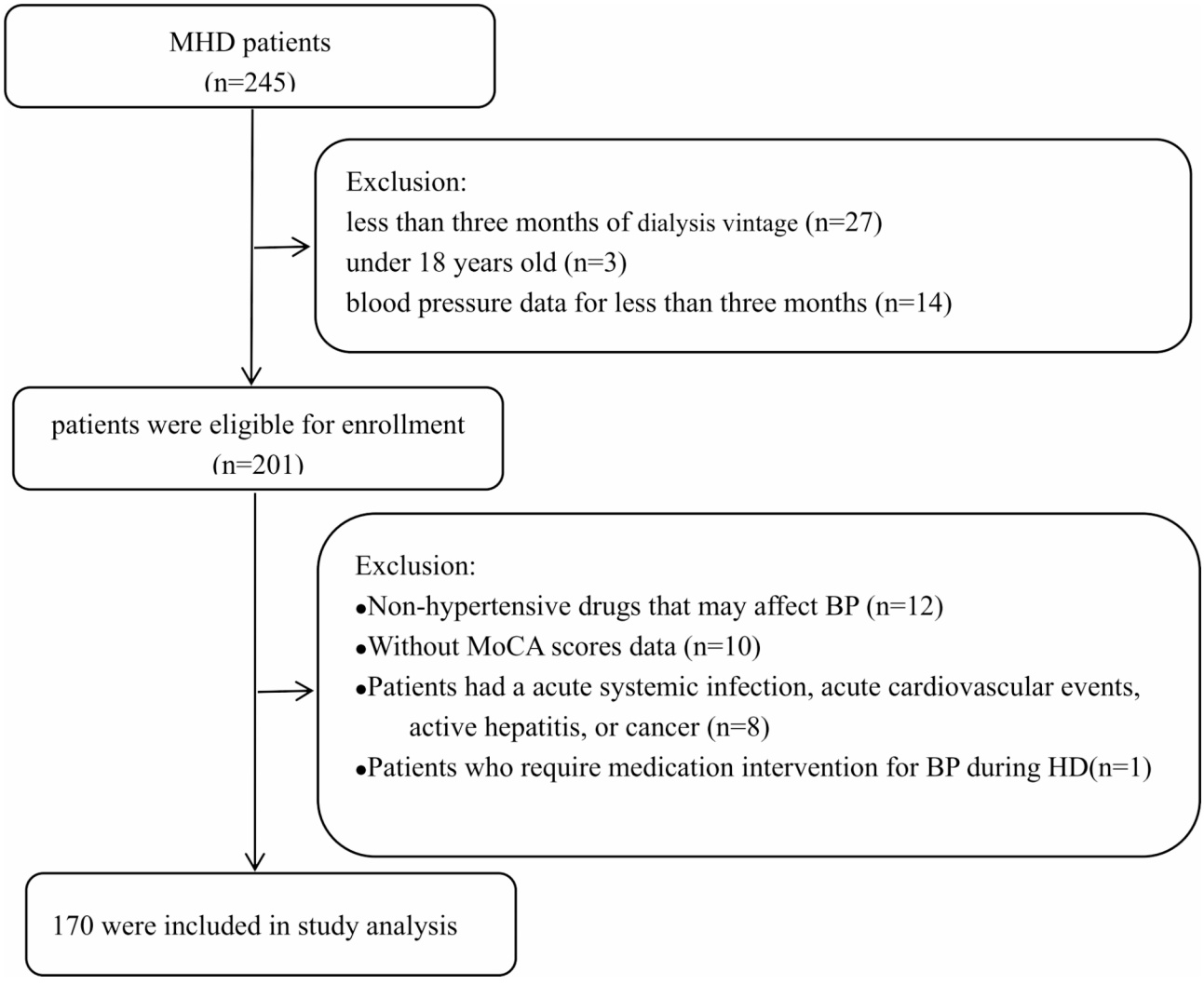

Fig. 1 Flow chart of study population

Table 1 Demographic and clinical characteristics of the patients at baseline

Categories	Total (*n* = 170)	NMCI (*n* = 37)	MCI (*n* = 133)	*P*
Age (year)	57.99 ± 13.43	46.89 ± 13.06	61.08 ± 11.85	<0.001
Dialysis vintage (year)	6.29(5.75, 10.35)	6.24(2.00, 8.00)	6.31(1.00, 10.00)	0.948
MoCA scores	21(15.00, 25.00)	27(26.00, 28.00)	19(14.50, 22.00)	<0.001
Male *n* (%)	99(58.24%)	22(59.50%)	77(57.89%)	0.864
History of diabetes mellitus, *n* (%)	37(21.76%)	2(5.41%)	35(26.32%)	0.006
History of stroke, *n* (%)	23(13.53%)	3(8.11%)	20(15.04%)	0.276
Dry weight (kg)	58.68 ± 10.59	59.83 ± 13.16	58.36 ± 9.79	0.458
Ultrafiltration volume (l/4 h)	2.10 ± 0.65	2.17 ± 0.67	2.08 ± 0.65	0.483
spKt/v	1.34 ± 0.25	1.37 ± 0.26	1.33 ± 0.25	0.351
Hemoglobin (g/l)	112.58 ± 16.86	109.51 ± 16.43	113.44 ± 16.94	0.212
Albumin (g/l)	37.95 ± 4.53	38.72 ± 4.71	37.73 ± 4.47	0.241
C reactive protein (mg/l)	9.41(0.50,9.41)	10.81 (0.66,9.41)	9.01(0.50,9.41)	0.641
Triglyceride (mmol/l)	1.74 ± 1.30	1.86 ± 1.07	1.71 ± 1.37	0.555
Total cholesterol (mmol/l)	3.74 ± 0.86	3.73 ± 0.96	3.74 ± 0.84	0.954
SBP SD (mmHg)	8.86(7.49, 10.41)	8.04 (6.92, 9.56)	9.12 (7.66, 10.67)	0.1
SBP CV (mmHg)	7.19 ± 1.93	6.65 ± 1.35	7.34 ± 2.04	0.086
SBP ARV (mmHg)	8.71(7.40, 9.77)	7.60 (7.07, 8.73)	8.91 (7.59, 9.99)	0.042
SBP RANGE (mmHg)	24.11(18.26, 25.73)	21.35(17.33, 23.60)	24.87(18.77, 26.46)	0.087
SBP MEAN (mmHg)	130.79 ± 14.72	128.19 ± 13.68	131.51 ± 14.96	0.225

MCI: Mild cognitive impairment, SBP: Systolic blood pressure, SD: Standard deviation, CV: Coefficient of variation, ARV: Average real variability

Table 2 The results of mutivariate analysis between SBP ARV and MCI

Parameters	Non-adjusted			Model I			Model II		
	OR	95%CI	*P* value	OR	95%CI	*P* value	OR	95%CI	*P* value
SBP ARV (mmHg)	1.24	1.01–1.51	0.041	1.17	0.97–1.42	0.1	1.16	0.95–1.43	0.14
SBP ARV (mmHg) tertile									
Low <7.75	Reference			Reference			Reference		
Middle 7.75–9.23	3.5	1.39–8.80	0.008	3.29	1.28–8.45	0.014	3.44	1.31–9.03	0.012
High >9.23	3.57	1.42–8.97	0.007	2.86	1.10–7.41	0.031	2.73	1.02–7.28	0.046

Outcome variable: MCI; Non-adjusted model adjust for: None; Model I adjust for: Age, gender; Model II adjust for: Age, gender, spKt/v, history of diabetes, history of stroke, total cholesterol, triglyceride, ultrafiltration; MCI: Mild cognitive impairment, SBP: Systolic blood pressure, ARV: Average real variability

MCI group were older and had a higher percentage of diabetes mellitus. Intradialytic SBP ARV was markedly higher in the MCI group than in the non-MCI group (8.91 vs. 7.60), but there was no notable difference in mean SBP, SBP SD, SBP CV, and SBP RANGE (Table 1).

Univariate and multivariate logistic analysis

The univariate logistic analysis showed that higher intradialytic SBP ARV was significantly associated with MCI (OR: 1.24, 95% CI: 1.01–1.51, $p = 0.041$) (Supplementary Table 1), when analyzed as a continuous variable. SBP MEAN and other BPV indicators were not found to be associated with MCI. Clinical indicators that were significant in the univariate analyses and related to MCI included age (OR: 1.1, 95% CI: 1.06–1.14, $P < 0.001$), history of diabetes mellitus (OR: 6.25, 95% CI: 1.43–27.35, $P = 0.015$) (Supplementary Table 1).

The significant indicators from the univariate analysis and those clinically considered to be potentially related to cognitive impairment were ultimately included in the multivariable logistic analysis (Table 2). When SBP ARV was considered a continuous variable, after adjusting for covariates in model I and model II, the association remained but became less significant (OR 1.17, 95% CI: 0.97–1.42, $p = 0.100$; OR 1.16, 95% CI: 0.95–1.42, $p = 0.146$, respectively). When tertiles of SBP ARV were considered a categorical variable, both middle (OR 3.47, 95% CI: 1.33–9.08, $p = 0.011$) and high tertiles of SBP ARV (OR 2.71, 95% CI: 1.02–7.25, $p = 0.047$) showed significantly increased odds of MCI compared to the low tertile in all models. These findings suggest that patients with higher SBP ARV are likely to have MCI, even after adjusting for relevant factors.

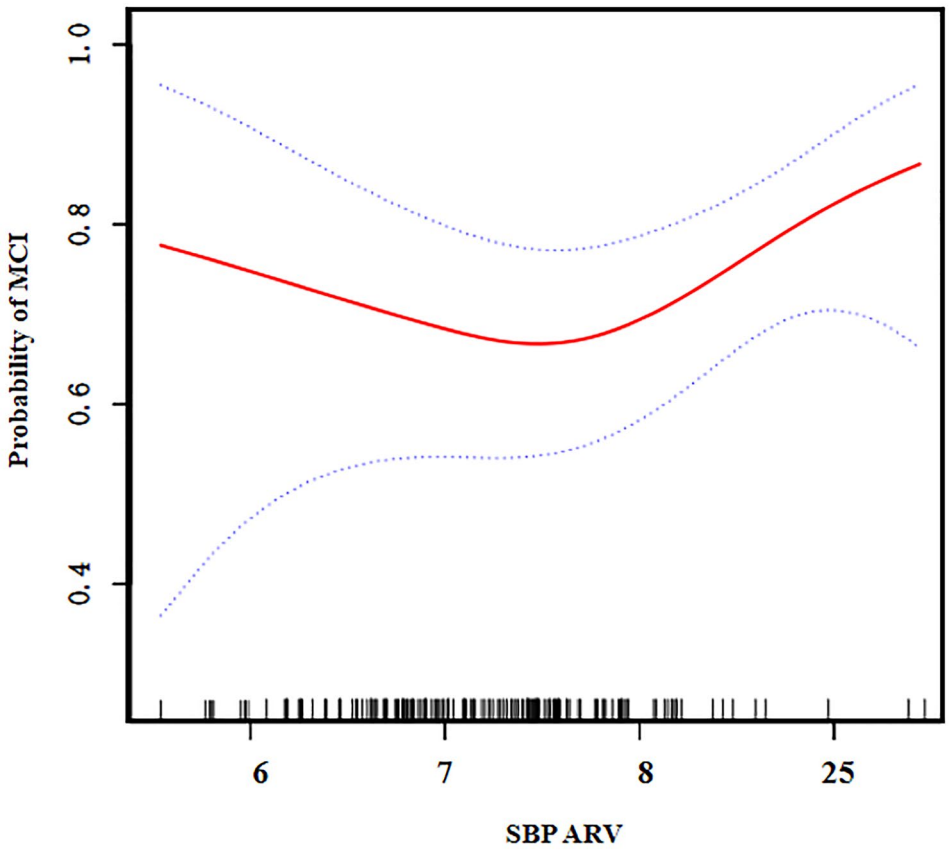

Fig. 2 Curve fitting between SBP ARV and MCI. Adjusted for Age; gender, spKt/v, history of diabetes, history of stroke, total cholesterol, triglyceride, ultrafiltration. SBP: Systolic blood pressure, ARV: Average real variability, MCI: Mild cognitive impairment

Table 3 The result of the two-piecewise linear regression model

Outcome	OR (95% CI)	*P*-value
Fitting model by stand linear regression	1.49 (0.96, 2.30)	0.075
Fitting model by two-piecewise linear regression		
Inflection point		
< 7.52	0.43 (0.15, 1.26)	0.125
≥ 7.52	4.10 (1.61, 10.46)	0.003
P for log-likelihood ratio test		0.008

Curve fitting and analysis of threshold effect

After adjusting for the risk factors, we observed a non-linear relationship between SBP ARV and MCI (Fig. 2). Two fitting models were compared to explore the curved associations (Table 3). The *p*-value of the log-likelihood ratio test was 0.008, which was the result of the two-piecewise linear fitting model. The inflection point of SBP ARV was 7.52, which suggested that when SBP ARV ≥ 7.52, SBP ARV was associated with MCI (OR: 4.10, 95% CI: 1.61–10.46, $P = 0.003$) (Table 3), and when SBP ARV < 7.52, there was no significant correlation between SBP ARV and MCI (OR = 0.43, 95% CI: 0.15–1.26, $p = 0.125$) (Table 3).

Discussion

Main findings

To the best of our knowledge, this is the first study on the association between intradialytic BRV and MCI in MHD patients. Our study found that patients with higher SBP ARV were closely associated with MCI, but mean SBP and other blood pressure variability indices (CV, SD, and RANGE) were not associated with MCI. A non-linear relationship was revealed between SBP ARV and CI. When SBP ARV ≥ 7.52, SBP ARV was associated with CI (OR: 4.10, 95% CI: 1.61–10.46, $P = 0.003$), while when SBP ARV < 7.52, there was no significant correlation between SBP ARV and CI (OR = 0.43, 95% CI: 0.15–1.26, $p = 0.125$).

Potential mechanisms of BPV in MCI

There is growing evidence that BPV is associated with MCI and dementia [5, 18]. The underlying mechanism involves hemodynamic instability that induces inadequate cerebral perfusion, endothelial damage, and chronic inflammation, and eventually leads to vascular thickening, arterial stiffness, amyloid-β deposition, cerebral small vessel diseases, and brain atrophy [19, 20]. In the context of chronic renal failure, MHD patients

present with premature vascular stiffness and increased pulse wave velocity [21, 22]. Based on the diseased vessels, hemodynamic alterations caused by hemodialysis trigger faster blood flow to the central nerve, increase central SBP in the short term, and induce intracranial inflammation [20], which damages the central nervous system. This may explain why the incidence of MCI in MHD patients has not been improved with dialysis [11]. Our study displayed that patients in the MCI group were older and had a higher proportion of diabetes mellitus, similar to the findings of other studies [10, 11, 23].

Association between BPV candidates and MCI

BPV is categorized into long-term and short-term indices based on the time interval of measurement. Short-term BPV is usually measured by BP monitoring over 24 h or at specified short intervals. In dialysis patients, intradialytic BPV can be quantified by short-term BPV [24]. The four most used short-term BPV indexes: SD, CV, ARV, and RANGE were selected for our study. However, there is currently a lack of comparison between commonly used short-term BPV indicators in patients with MCI. Our results suggested that SBP ARV was greatly higher in the MCI group than in the non-MCI group (8.91 vs. 7.60). Patients with higher SBP ARV were likely to have MCI, but mean SBP, SBP SD, and SBP RANGE were not, consistent with the results of other studies [3, 5].

ARV is one of the most used BPV indices, which is the mean of the absolute differences of consecutive measurements and considers the temporal nature of BP changes. Since SBP changes from time to time during dialysis, ARV better reflects the changes in BP. ARV was found to be an independent risk factor for stroke [25], cardiovascular events [26], and death [27] in MHD patients. Our results illustrated that if SBR ARV is considered as a continuous variable, we did not find any association with MCI, when considering tertiles of SBP ARV, both middle (OR 3.47, 95% CI: 1.33–9.08, $p = 0.011$) and high tertiles (OR 2.71, 95% CI: 1.02–7.25, $p = 0.047$) showed significantly increased odds of the outcome compared to the Low tertile in all models.

After adjusting for the risk factors, we observed a non-linear relationship between SBP ARV and MCI. The inflection point of SBP ARV was 7.52. Similarly, a previous study has found a non-linear relationship between BPV and cognitive decline [28], suggesting that it is necessary to identify MHD patients with excessive BP instability during hemodialysis and take measures to prevent cognitive decline. This highlights the importance of early recognition and intervention in MHD patients with unstable BP during hemodialysis to prevent MCI [28]. Current clinical guidelines fail to offer a definitive definition of blood pressure stability [29]. In the context of MCI prevention, our work further demonstrates the importance of maintaining stable blood pressure during dialysis and provides valuable references for establishing optimal targets to control BPV during hemodialysis.

Limitations

There are also some limitations. First, MCI and BPV were measured only during the survey, but the long-term impact of BPV on MCI was not assessed. Second, there may be confounders that we did not include, such as antihypertensive medications class, the relationship between different classes of antihypertensive medications and cognitive impairment is controversial [30–33], and more research is needed to explore the underlying mechanisms between them. Third, we did not include home SBP because it has not been yet routinely monitored in the clinical practice. Fourth, our conclusions on BPV were based on a 3-month exposure period, and different measurement timings may also affect the results.

Conclusion

Our study found that high SBP ARV was closely associated with MCI, indicating that high SBP ARV may act as an indicator of MCI in MHD patients. Further prospective cohort studies are needed to clarify the potential mechanisms between BPV and MCI in MHD patients.

Abbreviations

BPV	Blood pressure variability
CI	Cognitive impairment
MHD	Maintenance hemodialysis
MoCA	Montreal cognitive assessment
MoCA-B	Beijing version of the MoCA
SBP	Systolic blood pressure
SD	Standard deviation
CV	Coefficient of variation
ARV	Average real variability
OR	Odd ratio
CI	Confidence internal

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12882-024-03908-0.

Supplementary Material 1

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Author contributions

All authors contributed to the study conception and design. Writing - original draft preparation: [Jingfang Wan]; Writing - review and editing: [Jingfang Wan, Jun Liu, Yani He, Kehong Chen]; Conceptualization: [Yani He, Kehong Chen]; Methodology: [Jingfang Wan, Jing Pan]; Formal analysis and investigation: [Jingfang Wan, Jun Liu, Jing Pan, Lili Fu, Dandan He]; Funding acquisition: [Yani He, Kehong Chen]; Resources: [Jingfang Wan, Jun Liu, Lili Fu, Dandan He, Yaru Yao]; Supervision: [Yani He, Kehong Chen], and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethical approval and consent to participate
This study was approved by the Medical Ethics Committee of the Daping Hospital (YYLS2022-210) before the commencement of this study. The requirement for informed consent was waived, as the utilization of anonymized retrospective data does not require patient consent under the local legislation.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Diaz KM, Veerabhadrappa P, Kashem MA, Feairheller DL, Sturgeon KM, Williamson ST, Crabbe DL, Brown MD. Relationship of visit-to-visit and ambulatory blood pressure variability to vascular function in African Americans. Hypertens Res. 2012;35(1):55–61.
2. Nagai M, Hoshide S, Ishikawa J, Shimada K, Kario K. Visit-to-visit blood pressure variations: new independent determinants for carotid artery measures in the elderly at high risk of cardiovascular disease. J Am Soc Hypertens. 2011;5(3):184–92.
3. Ma Y, Blacker D, Viswanathan A, van Veluw SJ, Bos D, Vernooij MW, Hyman BT, Tzourio C, Das S, Hofman A. Visit-to-Visit Blood Pressure Variability, Neuropathology, and Cognitive Decline. Neurology. 2021;96(23):e2812–23.
4. Webb AJS, Werring DJ. New Insights Into Cerebrovascular Pathophysiology and Hypertension. Stroke. 2022;53(4):1054–64.
5. Guimarães Cunha P, Stolarz-Skrzypek K, Persu A. Increased Blood Pressure Variability May Herald Cognitive Decline and Dementia. Hypertension. 2020;76(4):1076–8.
6. Obrador GT, Levin A. CKD Hotspots: Challenges and Areas of Opportunity. Semin Nephrol. 2019;39(3):308–14.
7. Yang C, Wang H, Zhao X, Matsushita K, Coresh J, Zhang L, Zhao MH. CKD in China: Evolving Spectrum and Public Health Implications. Am J Kidney Dis. 2020;76(2):258–64.
8. M. QCKD: Chinese National Renal Data System[Z]. 2022.
9. van Zwieten A, Wong G, Ruospo M, Palmer SC, Barulli MR, Iurillo A, Saglimbene V, Natale P, Gargano L, Murgo M, et al. Prevalence and patterns of cognitive impairment in adult hemodialysis patients: the COGNITIVE-HD study. Nephrol Dial Transpl. 2018;33(7):1197–206.
10. Hidaka S, Nishimiura A, Hirata M, Ishioka K, Ohtake T, Oka M, Tamura T, Shibata K, Nishihara M, Kuji T, et al. Prevalence of mild cognitive impairment and its association with handgrip strength in patients on hemodialysis. Sci Rep. 2022;12(1):3850.
11. Chien CW, Lin YC, Huang SK, Chen PE, Tung TH. A population-based study of the association between hemodialysis and cognitive impairment. Asia Pac Psychiatry. 2020;12(4):e12404.
12. Song YH, Cai GY, Xiao YF, Chen XM. Risk factors for mortality in elderly haemodialysis patients: a systematic review and meta-analysis. BMC Nephrol. 2020;21(1):377.
13. MacEwen C, Watkinson P, Tarassenko L, Pugh C. Cerebral ischemia during hemodialysis-finding the signal in the noise. Semin Dial. 2018;31(3):199–203.
14. Alostaz M, Correa S, Lundy GS, Waikar SS, Mc Causland FR. Time of hemodialysis and risk of intradialytic hypotension and intradialytic hypertension in maintenance hemodialysis. J Hum Hypertens. 2023;37(10):880–90.
15. Daugirdas JT. Second generation logarithmic estimates of single-pool variable volume Kt/V: an analysis of error. J Am Soc Nephrol. 1993;4(5):1205–13.
16. KDOQI Clinical Practice Guideline for Hemodialysis Adequacy. 2015 update. Am J Kidney Dis. 2015;66(5):884–930.
17. K/DOQI clinical practice guidelines on. hypertension and antihypertensive agents in chronic kidney disease. Am J Kidney Dis. 2004;43(5 Suppl 1):S1–290.
18. Xiao H, Li H, Dong L, Song X, Wu Y, Wei H, Shang W, Tian M, Dong J. Correlation between home systolic blood pressure variability and cognitive impairment in maintenance hemodialysis patients. Semin Dial. 2022;35(2):129–37.
19. Sun F. The impact of blood pressure variability on cognition: current limitations and new advances. J Hypertens. 2023;41(6):888–905.
20. Turana Y, Shen R, Nathaniel M, Chia YC, Li Y, Kario K. Neurodegenerative diseases and blood pressure variability: A comprehensive review from HOPE Asia. J Clin Hypertens (Greenwich). 2022;24(9):1204–17.
21. Lioufas N, Hawley CM, Cameron JD, Toussaint ND. Chronic Kidney Disease and Pulse Wave Velocity: A Narrative Review. *Int J Hypertens* 2019, 2019;9189362.
22. Cabrera-Fischer E, Zocalo Y, Wray S, Bia D. Arterial Stiffness in Haemodialyzed Patients: Findings and Controversies. Curr Hypertens Rev. 2018;14(2):100–6.
23. Zhao Y, Song P, Zhu C, Zhang L, Chen X, Zhang H, Han P, Ding W, Niu J, Zhao J, et al. Relationship between physical performance and mild cognitive impairment in elderly hemodialysis patients is modified by the presence of diabetes: A multicenter cross-sectional study. Front Endocrinol (Lausanne). 2022;13:897728.
24. Flythe JE, Brunelli SM. Blood pressure variability among chronic dialysis patients: recent advances in knowledge. Curr Opin Nephrol Hypertens. 2015;24(2):163–9.
25. Cheng Y, Li Y, Zhang F, Zhu J, Wang T, Wei M, Mo L, Li Y. Interdialytic blood pressure variability and the risk of stroke in maintenance hemodialysis patients. Med (Baltim). 2020;99(29):e21232.
26. Liu Q, Wang W, Wu X, Lv J, Cai S, Li Y. Intra-dialytic blood pressure variability is a greater predictor of cardiovascular events in hemodialysis patients. BMC Nephrol. 2023;24(1):113.
27. Feng Y, Li Z, Liu J, Sun F, Ma L, Shen Y, Zhou Y. Association of short-term blood pressure variability with cardiovascular mortality among incident hemodialysis patients. Ren Fail. 2018;40(1):259–64.
28. Li C, Ma Y, Hua R, Yang Z, Zhong B, Wang H, Xie W. Dose-Response Relationship Between Long-Term Blood Pressure Variability and Cognitive Decline. Stroke. 2021;52(10):3249–57.
29. Williams B, Mancia G, Spiering W, Agabiti Rosei E, Azizi M, Burnier M, Clement DL, Coca A, de Simone G, Dominiczak A, et al. 2018 ESC/ESH Guidelines for the management of arterial hypertension. Eur Heart J. 2018;39(33):3021–104.
30. Peters R, Yasar S, Anderson CS, Andrews S, Antikainen R, Arima H, Beckett N, Beer JC, Bertens AS, Booth A, et al. Investigation of antihypertensive class, dementia, and cognitive decline: A meta-analysis. Neurology. 2020;94(3):e267–81.
31. Trompet S, Westendorp RG, Kamper AM, de Craen AJ. Use of calcium antagonists and cognitive decline in old age. The Leiden 85-plus study. Neurobiol Aging. 2008;29(2):306–8.
32. de Oliveira FF, Chen ES, Smith MC, Bertolucci PHF. Pharmacogenetics of Angiotensin-Converting Enzyme Inhibitors in Patients with Alzheimer's Disease Dementia. Curr Alzheimer Res. 2018;15(4):386–98.
33. Hanyu H, Hirao K, Shimizu S, Iwamoto T, Koizumi K, Abe K. Favourable effects of nilvadipine on cognitive function and regional cerebral blood flow on SPECT in hypertensive patients with mild cognitive impairment. Nucl Med Commun. 2007;28(4):281–7.

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