

Association of Blood Pressure Elevation and Nocturnal Dipping With Brain Atrophy, Perfusion and Functional Measures in Stroke and Nonstroke Individuals

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BACKGROUND

Although both blood pressure elevation and lower nocturnal dipping increase vascular risk, it is not known whether either or both are also associated with brain atrophy, cerebral perfusion, and functional status.

METHODS

We investigated the association of elevated blood pressure and nocturnal dipping based on 24-h ambulatory recordings with brain atrophy and perfusion and functional status in 80 older adults with and without stroke (age 66.4 ± 0.8 years, 51% women, 16% nonwhite, 46% prior ischemic stroke, 55% hypertension). Anatomical and three-dimensional continuous arterial spin labeling (CASL) brain magnetic resonance imaging (MRI) measuring volumes and perfusion and 24-h ambulatory blood pressure readings were completed.

RESULTS

Nocturnal dipping of lesser magnitude in systolic (nonstroke: $P = 0.03$; stroke: $P = 0.005$) and pulse pressure (PP; nonstroke: $P = 0.002$;

stroke: $P = 0.01$) was associated with greater brain atrophy, affecting preferentially the fronto-parietal regions. Dipping of lesser magnitude in systolic blood pressure (SBP; nonstroke: $P = 0.01$; stroke: $P = 0.03$) and greater brain atrophy (nonstroke: $P = 0.04$; stroke: $P = 0.05$) were also associated with slower gait speed and worse functional outcome after stroke. Higher 24-h blood pressure averages were associated with lower cerebral perfusion but not atrophy in those with and without stroke.

CONCLUSIONS

In those with and without stroke, dipping of lesser magnitude in systolic and PP is associated with brain atrophy and worse functional status. Nocturnal dipping, in addition to elevated blood pressure, should be considered as an additional important target in the clinical evaluation of those at risk for cerebrovascular disease or functional loss.

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Elevated blood pressure is associated with lower cerebral blood flow and brain atrophy.¹⁻³ In addition, less night-time dipping in blood pressure, measured by ambulatory blood pressure monitoring (ABPM), is associated with greater risk of stroke⁴ and worse prognosis after a stroke.⁵ However, it is not clear whether dipping of lesser magnitude in blood pressure is also associated with brain atrophy and lower cerebral blood flow.

Elevated blood pressure may also affect cognitive and physical function. However, the evidence for this effect is conflicted.⁶⁻⁹ Limitations of early studies are partially related to their lack of consideration for circadian variability in blood pressure. Therefore, we hypothesized that nocturnal blood pressure changes can affect cerebral blood flow dynamics and possibly

cerebral atrophy, independent of age and other vascular factors. We further hypothesized that these changes are related to cognitive, especially executive function, and physical function.

Therefore, we investigated the relationship of both elevated blood pressure and nocturnal blood pressure dipping measured by ABPM with brain volumes and perfusion using high-resolution anatomical and three-dimensional continuous arterial spin labeling (CASL) perfusion magnetic resonance imaging (MRI) in older adults with and without history of stroke. In addition, we investigated the relationship between elevated blood pressure and nocturnal blood pressure dipping and these MRI measures with gait speed, cognitive function, and instrumental activities of daily living.

METHODS

Subjects. Potential subjects were invited to the study using local advertisement in the greater Boston area. All evaluations were conducted at the Beth Israel Deaconess Medical Center. As stroke is related to both our predictors and our outcomes, we included two groups—a stroke and a nonstroke group—and performed stratified analysis by the stroke group.

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Inclusion criteria for the nonstroke group included ≥ 50 years, able to perform study procedures including ABPM, brain MRI, and cognitive testing. The inclusion for the stroke group criteria were the same as the nonstroke group plus (i) having a large-vessel stroke by the Trial of Org 10172 in Acute Stroke Treatment criteria,¹⁰ (ii) at least ≥ 6 months from the stroke event, (iii) documented on MRI or computed tomography scan, (iv) affecting $< 1/3$ of middle cerebral artery territory, and (v) had a modified Rankin Scale score < 4 . The average time after stroke in our sample was 6.1 years. Due to the effect of antihypertensives on cerebral perfusion measurements, these medications were gradually tapered over 3 days and discontinued before the study for at least 2 days. Anticoagulation and antihyperlipidemic medications were allowed. Exclusion criteria included diabetes mellitus (history or hemoglobin A_{1c} levels > 7.0 mg/dl), dementia or Alzheimer's disease, congestive heart failure (identified by history, medications, or clinical examination), post-traumatic brain injury, severe active infections, chronic steroid use, human immunodeficiency virus-related brain complications or AIDS, homelessness, chronic renal and liver disease, transplantation, active cancer treatment or prior exposure to chemotherapy or radiation, major life threatening illness or clinically significant cardiac disease, arrhythmias, or cancer. All subjects provided written informed consent and the protocol was approved by the Beth Israel Deaconess Medical Center institutional review board.

We screened potential subjects with detailed medical history and physical and neurological examinations, electrocardiogram, and routine laboratory tests. A trained research nurse performed manual blood pressure measurements according to the American Heart Association guidelines. We measured blood pressure during the screening visit (pretaper measurement). If the participant was receiving antihypertensive medications, then he or she was given instructions to taper off the medication according to a standard protocol. Participants were then admitted for 2 days to the General Clinical Research Center. Two manual blood pressure and heart rate measurements were performed three times per day for 2 days. Cognitive assessment (the Trail Making Test-Part B,¹⁰ Mini Mental Status Examination¹¹), gait speed¹² (a 12-min hallway walking at usual speed), and assessment of the instrumental activity of daily living¹³ were also collected. In the stroke group, we used the National Institute of Health Stroke Scale¹⁴ to assess poststroke functional status with lower values indicating better functional status.

ABPM. ABPM was recorded from 8:00 AM on the first admission day to 8:00 AM the next day using a portable automatic monitor Dynapulse (Pulse Metric, Vista, CA). This monitor has been previously validated against intra-arterial blood pressure measurement with a correlation of 98% ($P < 0.001$).¹⁵ Systolic (SBP) and diastolic blood pressure (DBP) and heart rate were measured at 20-min intervals during the day and at 30-min intervals during the night. The subjects were asked to lie down at 10:00 PM and get up at 7:00 AM and to follow a regime resembling usual daily activities at home documented in a personal

diary. They were asked to avoid strenuous exercise and to follow the usual routine. All activities performed during the daytime and the sleep and wake times were confirmed using the diary and direct observations. Obtained blood pressure measurements were averaged over the 24-h period, the daytime (7:00 AM to 10:00 PM), and night-time period (10:00 PM to 7:00 AM). Pulse pressure (PP) calculated as the difference between SBP and DBP was also calculated.

Dipping and hypertension definition. Dipping was calculated according to the standard formula: (daytime blood pressure – night-time blood pressure)/daytime blood pressure $\times 100$ (extreme dippers if they drop $> 20\%$ in SBP or DBP, dippers 10–20% in SBP or DBP, risers if SBP or DBP increases at night).^{16–19} Participants were considered hypertensive if the average blood pressure was $\geq 135/85$ mm Hg (refs. 19,20). Those on antihypertensive treatment were also considered hypertensive independent of their ABPM.

MRI protocol and data analysis. Brain imaging was performed 3 h after completing the ABPM recording at the 3-Tesla MRI scanner. High-resolution anatomical image three-dimensional magnetization prepared rapid gradient echo were acquired to quantify volume of white matter, gray matter, and cerebrospinal fluid. A template of anatomical regions was applied to measure regional brain volume in frontal, occipital, parietal, and temporal lobes. Gray and white matter volumes in cm^3 were then divided by intracranial cavity in cm^3 and multiplied by 100 to account for variation due to intracranial size. In the stroke group, brain volumes were measured on the stroke and the opposite sides. Infarct areas were manually outlined and co-registered on a standard template. Infarcts were excluded from volume calculations for each lobe. Blood pressure was also measured during the MRI procedure. Perfusion was measured by CASL-MRI technology in $\text{ml}/100\text{g}/\text{min}$ (refs. 21–23). CASL images were acquired using a custom three-dimensional stack of interleaved spirals fast spin echo sequence. Labeled and unlabeled images were collected over 2-min periods during normal breathing (four scans). Quantitative cerebral perfusion data were reconstructed offline.^{4,6} Due to the concern that the antihypertensive effect on perfusion may have persisted due to the short taper period, we tested whether antihypertensive use was related to perfusion in our sample. (An expanded protocol is described in the **Supplementary Methods** online)

Statistical analysis. We conducted our analyses stratified by stroke group. Our predictor variables were nocturnal dipping (used as a continuous measure) and overall mean SBP, DBP, and PP (also used as continuous variables). We performed separate analyses for each. Our outcome variables were global and regional (frontal, occipital, parietal, and temporal lobes) gray and white matter volumes normalized to intracranial cavity volume then multiplied by 100. Global and regional cerebral perfusion were obtained from the CASL-MRI images and normalized to regional volumes. For the analysis of the functional outcomes,

Table 1 | Clinical and ABPM characteristics of the stroke and nonstroke participants (numbers are mean \pm s.e. unless noted)

	Nonstroke	Stroke	P value
N	43	37	
Age, years	68 \pm 1	64.5 \pm 1.4	0.04
Women, %	56	46	0.38
Nonwhite participants, %	19	14	0.47
Body mass index, kg/m ²	25 \pm 0.63	27.4 \pm 0.77	0.11
Stroke side (right), %		41	Na
Current smoking, %	2	24	<0.01
Past smokers, %	32	79	<0.001
Alcohol, weekly number of drinks	2.2 \pm 0.56	8.01 \pm 2.66	0.02
Hypertension by ABPM, %	37	46	0.55
Hypertension (by ABPM or treatment), %	51	77	0.02
HR, beats per minute	64 \pm 1	69 \pm 1	<0.01
ABPM measurements			0
SBP, mm Hg	129 \pm 2	133 \pm 2	0.11
DBP, mm Hg	66 \pm 1	67 \pm 1	0.59
PP, mm Hg	63 \pm 1	66 \pm 1	0.1
Daytime SBP mean, mm Hg	130 \pm 2	134 \pm 2	0.14
Daytime DBP mean, mm Hg	68 \pm 1	68 \pm 1	0.73
Daytime PP mean, mm Hg	63 \pm 1	66 \pm 2	0.12
Night-time SBP mean, mm Hg	124 \pm 2	132 \pm 3	0.04
Night-time DBP mean, mm Hg	61 \pm 1	64 \pm 1	0.18
Night-time PP mean, mm Hg	63 \pm 2	67 \pm 2	0.07
Extreme dippers, %	5	3	0.64
Dippers, %	44	32	0.28
Nondippers, %	37	46	0.43
Reverse dippers (risers), %	14	19	0.54
Medications			
Antihypertensive use, %	40	70	<0.01
Diuretics, %	21	24	0.13
Angiotensin converting enzyme inhibitors, %	16	32	0.09
β -Blockers, %	12	24	0.14
Calcium channel blockers, %	12	22	0.23
Statin use, %	23	68	<0.0001
Anticoagulation, %	0	8	0.11
Glucose, mg/dl	78.2 \pm 1.8	85.7 \pm 2.8	0.02
Cognitive function			
Mini Mental Status Exam	27.6 \pm 0.3	26.6 \pm 0.4	0.08
Trail Making Test-Part B, s	88 \pm 7	165 \pm 22	<0.01
Functional measures	\pm	\pm	0
Gait speed, m/s	1.16 \pm 0.02	0.92 \pm 0.05	<0.001
IADL	1 \pm 0.1	2 \pm 0.4	<0.01
NIHSS		2.4 \pm 0.4	NA

Table 1 | Continued

	Nonstroke	Stroke	P value
MRI measures			
Small vessel disease or white matter hyperintensities	0.005 \pm 0.001	0.01 \pm 0.002	<0.01
Global cerebral perfusion, ml/100 g/min	35.6 \pm 1.9	30.8 \pm 1.7	0.07
Gray matter volume, cm ³	630.5 \pm 13.6	632.2 \pm 11.7	0.9
White matter volume, cm ³	417.3 \pm 9.1	455.9 \pm 13.4	0.48
Extreme dippers if they drop >20% in SBP or DBP, dippers 10–20% in SBP or DBP, risers if SBP or DBP increases at night. ABPM, ambulatory blood pressure monitoring; DBP, diastolic blood pressure; HR, heart rate; hypertension by ABPM, if blood pressure average is \geq 135/85 mm Hg; hypertension by ABPM or treatment: if blood pressure average \geq 135/85 mm Hg or receiving antihypertensive medication; IADL, instrumental activities of daily living; MRI, magnetic resonance imaging; NIHSS, National Institute of Health Stroke Scale; PP, pulse pressure; SBP, systolic blood pressure.			

both MRI and ABPM variables were predictors and Trail Making Test-Part B in seconds, Mini Mental Status Examination, gait speed, instrumental activity of daily living, and National Institute of Health Stroke Scale were the outcome variables. Regression analyses were used for testing the association between the predictors and the outcomes. For the regional analyses, we used mixed models for correlated data. We used the best-fit test to assess the degree by which the model is robust to fit the observed data.²⁴ All models were adjusted for age, gender, race, body mass index, and prior use of antihypertensives. In the stroke group, we also adjusted for the infarct volume and performed separate analyses for the stroke and the nonstroke sides. To adjust for multiple comparisons, we used the method of Sidak adjusted for the high correlation between the various MRI-based measures and blood pressure measures ($\alpha = 0.03$) (refs. 25,26).

RESULTS

We assessed 80 participants (43 nonstroke and 37 with past stroke, mean age 66.4 \pm 0.8 years, 51% women and 16% non-white). **Table 1** describes main clinical and ABPM characteristics. After tapering antihypertensives, blood pressure did not change in those on antihypertensives in either group. There were no other differences in perfusion, gray matter, or white matter volumes between those receiving vs. those not receiving antihypertensives except marginally for perfusion in the nonstroke group (34.3 \pm 1.8 ml/100 g/min in those on no antihypertensives vs. 37.9 \pm 3.8 ml/100 g/min in those on antihypertensives, $P = 0.05$). Using the 24-h ABPM criterion (independent of treatment), hypertension prevalence was similar in both groups. However, use of antihypertensive therapy was higher in the stroke group ($P < 0.01$) and hence hypertension using the ABPM or treatment criterion was also higher ($P = 0.02$). The majority (>98%) of our participants did not dip by >20% in SBP or DBP but 49% of those in the nonstroke group and 35% in the stroke group dipped by \geq 10% in SBP or DBP.

Nocturnal dipping and MRI measures

In the nonstroke group, dipping of lesser magnitude in SBP and PP was associated with greater brain atrophy after adjusting for

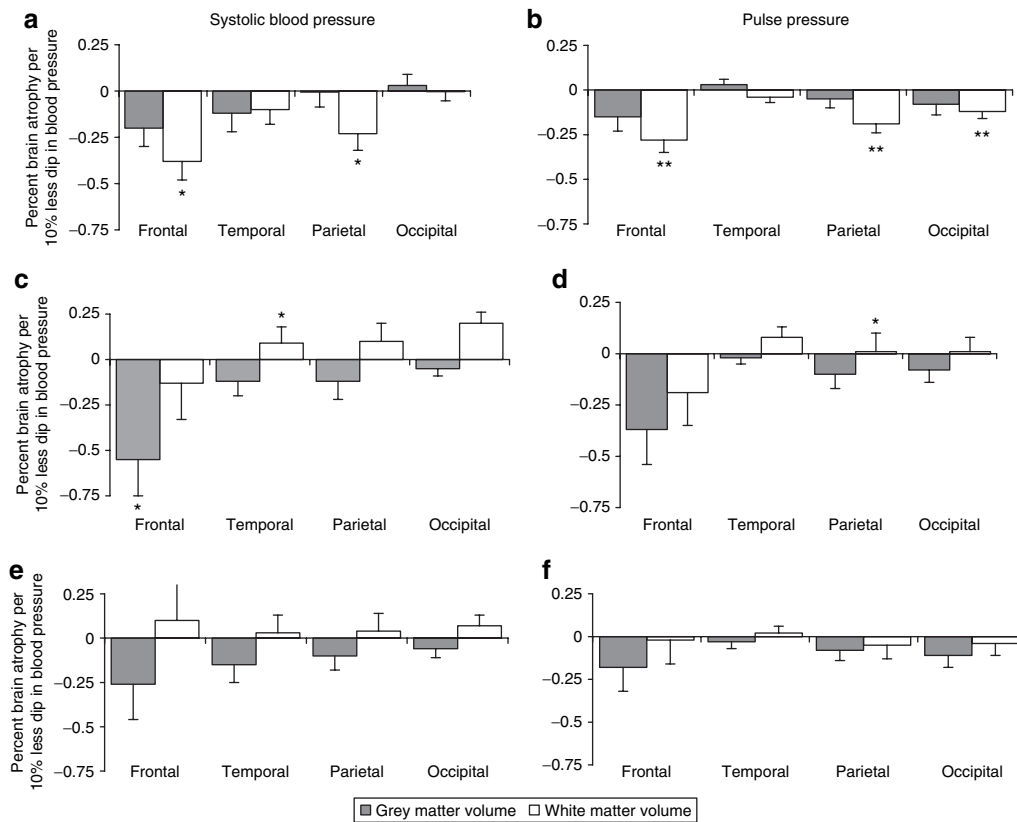


Figure 1 | Associations between regional brain volumes and percent dipping in systolic and pulse pressure in the (a, b) nonstroke, and the (c, d) stroke side and (e, f) the opposite side in the stroke group. * $P < 0.05$; ** $P < 0.01$. Values are the slope of the multivariate regression between dipping and brain volume (cm^3 brain volume/intracranial cavity cm^3 per 10% greater dip in blood pressure $\times 100$). P values are obtained from the multivariate models adjusted for age, gender, race, body mass index, and antihypertensives.

age, gender, race, BMI, and use of antihypertensives. This was predominantly related to loss in white matter volume (SBP: $R^2 = 21\%$, $P = 0.03$ and PP: $R^2 = 33\%$, $P < 0.01$). Regionally, it was predominantly related to frontal and parietal white matter volume loss. Figure 1a,b demonstrates the relation between nocturnal dipping and gray and white matter brain atrophy.

Similarly in the stroke group, dipping of lesser magnitude in SBP and PP was associated with greater brain atrophy after adjusting for age, gender, race, BMI, infarct size, and use of antihypertensives. This was predominantly related to loss in gray matter volume (SBP: $R^2 = 52\%$, $P < 0.01$ and PP: $R^2 = 50\%$, $P < 0.01$). Regionally, this was related to frontal region gray matter atrophy on the stroke side. Figure 1c,d shows the association between nocturnal dipping and gray and white matter atrophy in the four brain regions on the stroke side and Figure 1e,f on the contralateral side.

Dipping in DBP was not associated with brain atrophy except for the gray matter on the stroke side (see Supplementary Table S1 online). There was no relation between any blood pressure dipping and cerebral perfusion (see Supplementary Table S2 online).

Average blood pressure and MRI measures

Higher overall 24-h averages of SBP and PP were associated with lower cerebral perfusion in both the stroke and nonstroke

groups. Figure 2a,b shows the decline in regional perfusion per each 10 mm Hg increase in SBP or PP in the nonstroke group and Figure 2c,d in the stroke group. Although this association was similar in all four brain regions, in the stroke and nonstroke groups and with SBP and PP, it was consistently significant only in the frontal and parietal lobes. When analyzed separately, average SBP and PP during the day but not during the night were associated with cerebral perfusion. In addition, those with hypertension based on ABPM measurements without stroke had 10.4 ± 4.5 ml/100 g/min lower perfusion compared to normotensives ($P = 0.02$).

There was no relation among average, daytime or nighttime DBP, SBP, or PP, and global or regional brain atrophy (see Supplementary Table S3 online).

Functional measures

Lower dipping magnitude in SBP and greater brain atrophy were both associated with slower gait speed. Dipping of lesser magnitude PP was associated with higher instrumental activity of daily living score. In contrast, higher SBP average was associated with worse Trail Making Test-Part B. Table 2 provides the associations of ABPM and MRI with the functional measures. Dipping of lesser magnitude in SBP was associated with worse National Institute of Health Stroke Scale scores after stroke (SBP dipping $P = 0.04$). No association was

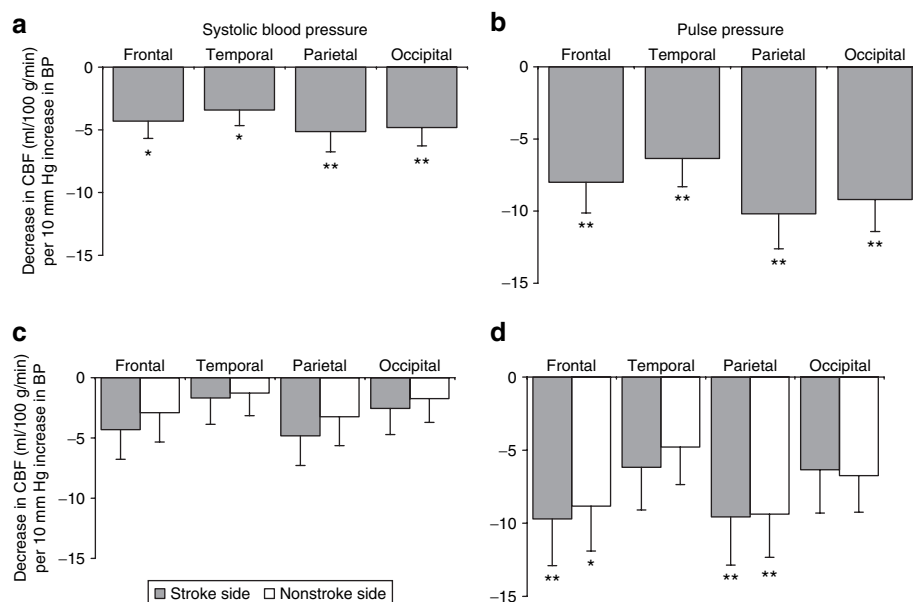


Figure 2 | Associations between cerebral blood flow (CBF) (and 24-h average systolic and pulse pressure mm Hg) in the brain regions in those without stroke (**a,b**) and with stroke (**c,d**). * $P < 0.05$; ** $P < 0.01$. Values are the slope of the multivariate regression between dipping and brain volume (ml/100 g/min cm^3 per 10 mm Hg increase in blood pressure). P values are obtained from the multivariate models adjusted for age, gender, race, body mass index, and antihypertensives. BP, blood pressure.

Table 2 | Association between ABPM and MRI measures with functional measures in the stroke and nonstroke groups

	Gait (m/s)		Trail making test-Part B (s)		IADL	
	Slope	P value	Slope	P value	Slope	P value
Nonstroke						
Average SBP (per each 10 mm Hg)	0.02 ± 0.04	0.53	16.00 ± 7.00	0.03	-0.28 ± 0.12	0.03
Average PP (per each 10 mm Hg)	0.02 ± 0.05	0.62	7.22 ± 9.90	0.48	-0.25 ± 0.17	0.16
SBP dipping (per each 10% increase in dipping)	0.10 ± 0.10	0.003	-14.79 ± 11.39	0.21	-0.07 ± 0.21	0.75
PP dipping (per each 10% increase in dipping)	0.04 ± 0.04	0.37	-9.24 ± 9.27	0.33	-0.03 ± 0.01	0.04
Cerebral perfusion (per each ml/100 g/min)	0.10 ± 0.10	0.36	-0.93 ± 0.77	0.25	0.10 ± 0.02	0.96
Gray matter (per each cm^3 /intracranial cavity)	0.27 ± 1.47	0.85	-129 ± 306	0.68	4 ± 5	0.42
White matter (per each cm^3 /intracranial cavity)	1.30 ± 0.60	0.03	-143 ± 313	0.65	-5 ± 5	0.36
Stroke						
Average SBP (per each 10 mm Hg)	-0.01 ± 0.05	0.92	7.07 ± 21.52	0.75	-0.44 ± 0.32	0.18
Average PP (per each 10 mm Hg)	-0.03 ± 0.07	0.63	26.25 ± 26.98	0.34	-0.36 ± 0.42	0.40
SBP dipping (per each 10% increase in dipping)	0.10 ± 0.40	0.03	40.93 ± 28.37	0.16	-0.30 ± 0.45	0.52
PP dipping (per each 10% increase in dipping)	0.08 ± 0.05	0.11	30.19 ± 19.54	0.14	-0.23 ± 0.31	0.48
Cerebral perfusion (per each ml/100 g/min)	0.01 ± 0.01	0.30	-2.97 ± 3.37	0.39	-0.04 ± 0.05	0.39
Gray matter (per each cm^3 /intracranial cavity)	3.20 ± 1.30	0.02	-142 ± 690	0.84	-15 ± 11	0.20
White matter (per each cm^3 /intracranial cavity)	2.63 ± 1.77	0.15	-301 ± 689	0.67	-19 ± 11	0.10

Slopes are coefficients obtained from the multiple regression models adjusted for age, gender, race, body mass index and antihypertensive use.

ABPM, ambulatory blood pressure monitoring; DBP, diastolic blood pressure; IADL, instrumental activities of daily living; MRI, magnetic resonance imaging; PP, pulse pressure; SBP, systolic blood pressure.

detected between MRI or ABPM measures and Mini Mental Status Examination.

DISCUSSION

This study demonstrates that a decrease in the magnitude of night-time dipping in systolic and PPs is associated with greater brain atrophy. This atrophy preferentially affects the fronto-parietal region and is independent of stroke. Both, dipping of lesser magnitude and brain atrophy are associated with slower gait speed, worse instrumental activity of daily living, and worse functional outcome after stroke. In contrast, higher blood pressure is associated with lower brain perfusion without affecting brain atrophy and with executive cognitive function.

Our study suggests that night-time dipping in blood pressure rather than the overall blood pressure averages is associated with brain atrophy. Similar to our finding, Nagai *et al.* has also shown that night-time dipping is correlated with overall brain atrophy in elderly hypertensives.²⁷ Goldstein *et al.* demonstrated that greater 24-h SBP variability is associated with greater brain atrophy independent of age.³ Although we have found that this association is significant in stroke and non-stroke individuals, prior stroke modulated this relationship in the affected hemisphere. In those with prior hemispheric stroke, the association was related to gray matter loss rather than white matter.

Prior evidence has suggested that casual elevation in blood pressure is associated with lower cerebral blood flow.²⁸ This study adds evidence that higher 24-h SBP and PP, but not DBP, averages are associated with lower brain perfusion measured by CASL-MRI. As no association was noted with brain volume, the observed association is more likely to be related to vascular changes in the cerebral circulation that lead to decreased brain perfusion.

Both hypertension and brain atrophy are associated with overall loss of physical and cognitive function.^{29–31} Our study suggests that blood pressure dipping of lesser magnitude is also associated with slower gait speed. Conceptually, night-time dipping, which is commonly seen in hypertensives,³² is associated with brain tissue atrophy, which leads to poor physical function. In contrast, the elevated blood pressure–poor executive function noted in our study and others^{31,33} could be related to lower cerebral perfusion. Because of the cross-sectional nature of our study, these pathways cannot be fully confirmed and warrant further exploration.

PP is closely correlated with arterial stiffness³⁴ and night-time PP is associated with increased stroke risk.³⁵ In this study, we provide new evidence that dipping of lesser magnitude in PP is associated with greater atrophy and elevated PP is associated with reduced perfusion. These PP associations are particularly significant in those with prior stroke. Hence, PP may be a particularly important factor to address in managing those with stroke.

The possible mechanisms of these associations are not clear. It is possible that, lack of adequate nocturnal dipping leads to pathological vascular changes that eventually lead to neuronal death and hence white matter atrophy. It is also

possible that in those with stroke, hormonal or structural changes predispose the gray matter to the lower nocturnal dipping in blood pressure.

The clinical implication of this study is that nocturnal dipping may be as important if not more important than the absolute elevation of blood pressure in the evaluation of high risk individuals. Circadian blood pressure changes may provide additional risk stratification for this population.

The advantage of this study is the simultaneous measurements of brain volumes and perfusion using CASL-MRI. Including both stroke and nonstroke participants allowed us to explore the role of stroke in the blood pressure–brain relation. One limitation of our study is its cross-sectional design. We cannot describe the temporal relationship between ABPM, brain atrophy, and perfusion and functional measures. The temporal lag between the 24-h ABPM and performing the MRI (3 h) may have affected our results. There were no significant differences between ABPM measurements and blood pressures during the MRI procedures. Another concern in this study, as in most studies that involve hypertensives, is the short- and long-term effects of hypertension treatment on the outcome measures. This may have also lead to a misclassification of participants with respect to their hypertension status. In our study, we attempted at addressing the short-term effect by stopping antihypertensives, albeit for a short time for safety reasons. We also did not see any association between use of antihypertensives and brain volume or perfusion, suggesting that this effect is not critical for our brain outcomes. Finally, our sample size might have precluded us from identifying existing associations among ABPM, MRI, and function measures.

Conclusion

Dipping of lesser magnitude in SBP and PP is associated with greater brain atrophy independent of stroke whereas blood pressure elevation is associated with lower cerebral perfusion without being related to brain volumes. These associations preferentially affect the fronto-parietal regions. Both nocturnal dipping and brain atrophy are linked to physical and cognitive function. These findings provide further insight into the brain–blood pressure relation: night-time dipping is related to brain atrophy and physical function whereas elevated blood pressure is related to perfusion and executive function. Dipping, in addition to elevated blood pressure, is an important target in the clinical evaluation of individuals at risk of physical and cognitive limitations.

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