Blood pressure variability and outcomes after mechanical thrombectomy based on the recanalization and collateral status

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Abstract

Background: Blood pressure (BP), recanalization status, and collateral circulation are important factors for cerebral autoregulation after stroke. We aimed to investigate the association of various BP variability (BPV) parameters with clinical outcomes after mechanical thrombectomy (MT) according to recanalization and collateral status.

Methods: We included 502 consecutive patients who underwent MT due to anterior circulation large vessel occlusion stroke at three comprehensive stroke centers. BPV parameters were standard deviation (SD), maximum/minimum BP, coefficient of variation (CV) and successive variation (SV). The clinical outcomes included 90-day functional outcome assessed by modified Rankin Scale score and symptomatic intracranial hemorrhage (sICH).

Results: Among the included patients, 219 (43.6%) achieved good functional outcomes and 59 (11.8%) developed sICH. After adjusting for confounders, higher systolic BP (SBP) variability [CV (odds ratio (OR), 1.089, $p = 0.035$), SV (OR, 1.082, $p = 0.004$). and SD (OR, 1.074, $p = 0.027$)] was associated with a lower likelihood of a favorable outcome. In addition, higher SBP [CV (OR, 1.156, $p = 0.001$) and SD (OR, 1.118, $p = 0.001$)] were significantly associated with increased odds of sICH. Moreover, the relationship between BPV and the outcomes depended on recanalization status. However, regardless of collateral status, a higher BPV after MT was associated with worse outcomes.

Conclusions: Higher SBP SD and CV during the first 24 h after MT was a powerful predictor of worse clinical outcomes, regardless of the collateral status. However, the effects of BPV on outcomes were more substantial among patients with successful reperfusion.

Keywords: blood pressure, mechanical thrombectomy, prognosis, stroke, variability

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Introduction

Mechanical thrombectomy (MT) has become the current standard of care for patients with large vessel occlusion stroke (LVOS) of the anterior circulation.[1] Nevertheless, in the real world, nearly half of patients with successful MT still may not achieve functional improvement.[2,3] Several confounders affecting the outcome of stroke have been recognized. Of the confounders, postprocedural blood pressure (BP) may be a relevant factor regarding the outcome.[4] Moreover, BP is a readily modifiable parameter with the potential to improve outcomes in patients with MT.[5,6] Unfortunately, the optimal BP management after the endovascular procedure is currently unknown.[7]

For patients with LVOS, cerebral autoregulation is impaired.[8] The fate of the ischemic penumbra mainly depends on the maintenance of proper cerebral perfusion. In this process, BP, recanalization status, and collateral circulation are three

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largely important interrelated factors.[9] Although findings from prior studies suggested that either a decrease or an increase in BP during the MT perioperative period may lead to adverse outcomes,[10,11] the substantial association of BP with outcomes based on recanalization and collateral status in patients treated with MT remains to be unestablished. Accordingly, the existing guidelines still recommend maintaining a BP level of <180/105 for 24 h after MT,[1] which is based on intravenous thrombolysis (IVT).

BP variability (BPV) could fully reflect the real BP status of acute stroke. Moreover, BPV has been considered to be an emerging risk factor for poor outcome after stroke.[12] Although several studies have shown the association of BPV and outcomes after MT,[13–15] most studies are limited by retrospective single-center design, inclusion of anterior and posterior circulation, and few using the modern thrombectomy device. In addition, based on recanalization and collateral status, the effect of BPV after thrombectomy on outcomes is still unclear.

In view of these considerations, we performed a multicenter cohort study of Chinese patients by a prospective registry. We aimed to investigate the association of various BPV parameters with clinical outcomes according to recanalization and collateral status.

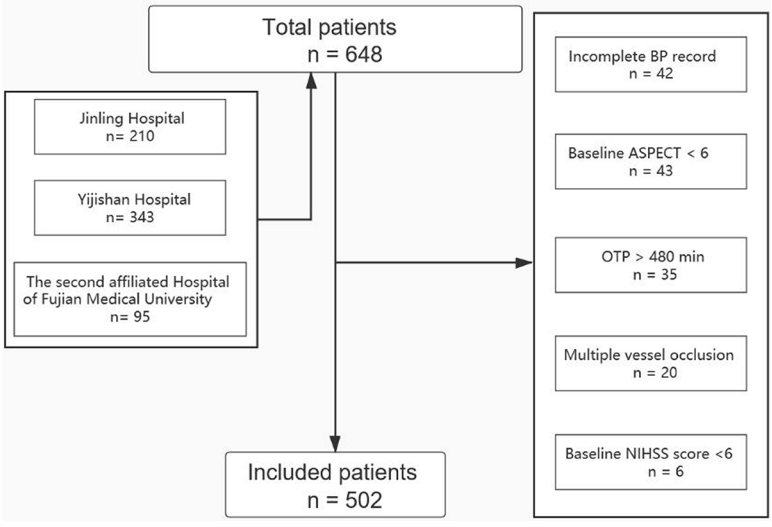

Figure 1. Flow chart of the inclusion of the study population.
ASPECT, Alberta Stroke Program Early computed tomography; BP, blood pressure; NIHSS, National Institutes of Health Stroke Scale; OTP, symptoms onset to groin puncture time.

Methods

Study population

This study was a retrospective analysis of a prospective registry from three comprehensive stroke centers (Jinling Hospital between January 2014 and December 2018, Yijishan Hospital between July 2015 and December 2019 and the Second Affiliated Hospital of Fujian Medical University between January 2016 and December 2019). We enrolled patients with anterior circulation LVOS who underwent MT. The study was approved by the local ethics committee (No.2019-039).

Patients were registered if they met the following inclusion criteria: (a) age ⩾ 18 years; (b) time from stroke onset to puncture (OTP) ⩽ 8 h; (c) baseline National Institutes of Health Stroke Scale (NIHSS) score ⩾ 6, baseline Alberta Stroke Program Early computed tomography (ASPECT) score ⩾ 6, and pre-stroke modified Rankin Scale (mRS) score <2; and (d) occlusion of the internal carotid artery, proximal segment (M1/M2 or A1/A2) of the middle cerebral artery or the anterior cerebral artery confirmed by preoperative imaging. In addition, we excluded patients with multiple vessel occlusion (MVO). The treatment protocol and methods have been published before.[16] The flow chart of the inclusion of the study population is displayed in Figure 1.

Data collection

All baseline clinical data were prospectively recorded, including demographics, medical history, baseline NIHSS and ASPECT score, and the Trial of ORG 10172 in Acute Stroke Treatment (TOAST) classification.

BP data were consecutively recorded by noninvasive BP monitoring devices each hour during the first 24 h after MT. We calculated BPV for both systolic BP (SBP) and diastolic BP (DBP) using five statistical methodologies (details are provided in the Supplemental methods): standard deviation (SD), maximum (max), minimum (min) BP, coefficient of variation (CV), and successive variation (SV).

The procedural parameters were recorded by operators, including OTP, time from stroke onset to reperfusion (OTR), occlusion site, the MT approach (stent retriever first/aspiration first/angioplasty or stent first), bridging and rescue treatment,

and collateral circulation. Recanalization status was evaluated based on the modified Thrombolysis in Cerebral Infarction (mTICI) grading system. Successful recanalization was defined as an mTICI score of 2b or 3. Collateral circulation was assessed according to retrograde contrast opacification of vessels within the occluded area on delayed pre-treatment digital substraction angiography images. The collateral score was classified as follows:[17] grade 0 was assigned if there was little or no significant reconstitution in the territory of the occluded vessel or if the collaterals reached less than one-third of the occluded territory, grade 1 was assigned if the collaterals reached less than two-thirds of the occluded territory, and grade 2 was assigned if the collateralization reached more than two-thirds of the territory or the proximal main stem. Good collateral circulation was defined as grade 2, and poor collateral circulation was defined as grade 0–1.

Outcome measures

The primary endpoint was patients' functional outcome at 90 days assessed by the mRS. mRS score 0–2 was defined as the good functional outcome, and mRS score ≥ 3 was defined as the poor functional outcome. The secondary endpoint was the incidence of symptomatic intracranial hemorrhage (sICH). sICH was defined as any hemorrhage within 24 h after MT confirmed on imaging associated with a $\geq$4-point increase in NIHSS score according to the European Cooperative Acute Stroke Study (ECASS) criteria.[18]

Statistical analysis

Continuous variables are presented as the mean $\pm$ SD or as the median (interquartile range). Categorical variables are presented as percentages. Continuous variables were analyzed using the Mann–Whitney U test. Categorical variables were analyzed using the Chi-square test or Fisher's exact test as appropriate. Multivariate logistic regression models were computed for the prediction of odds of good outcome and sICH. In the entire cohort, the variables with $p < 0.1$ from the univariate analysis were entered into the logistic regression.

To explore the effect of BPV on all outcome parameters based on different subgroups, we used a logistic regression model to assess the probability of a 90-day functional outcome based on the recanalization status or collateral status after adjusting for age, baseline NIHSS score, baseline ASPECT score, and mean BP. Considering the small sample size and multiple comparisons, in subgroup analysis we performed multivariable logistic regression adjusting for the following prespecified confounders: age, sex, mean BP, baseline NIHSS and ASPECT scores, OTR, TOAST classification, occlusion site, collateral circulation status and mTICI score. The models' goodness of fit was assessed by the Hosmer–Lemeshow (HL) test. Regression coefficients and odds ratios (OR) with two-sided 95% confidence intervals (CIs) for each of the variables included in the model were finally calculated. All statistical analyses were computed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) and SPSS 25 (IBM Corp., Armonk, NY, USA).

Results

General characteristics

A total of 648 anterior circulation LVOS patients undergoing MT were registered in the three centers during the study period. Of those patients, 502 patients [age 66.9 $\pm$ 11.7 years, male 58%, baseline NIHSS scores (16 (13–20)), baseline ASPECT scores (9 (8–10)), OTP 262 $\pm$ 79.7 min] were analyzed in the present study. In total, 146 patients were excluded from the analysis for the following reasons (Figure 1): incomplete BP record ($n = 42$), baseline ASPECT score < 6 ($n = 43$), OTP > 8 h ($n = 35$), patients with MVO ($n = 20$), and baseline NIHSS score < 6 ($n = 6$). The baseline characteristics of the patients are shown in Table 1.

The baseline SBP was significantly lower in patients with the good functional outcome at 3 months than in those with the poor outcome (140 mmHg *versus* 150 mmHg, $p = 0.014$). A similar difference was seen with DBP (80 mmHg *versus* 82 mmHg, $p = 0.023$). However, according to the sICH group, we did not find the differences in baseline BP (Supplemental Table 1).

BPV parameters and clinical outcomes in the entire cohort

The good functional outcome at 90 days (mRS score 0–2) were achieved in 219 (43.6%) patients, and sICH occurred in 59 (11.8%) patients. Patients with the good functional outcome had significantly lower mean SBP (122 mmHg *versus* 126 mmHg), maximum SBP (147 mmHg *versus* 156 mmHg), SBP CV (9.15 *versus* 10.79), SV

Table 1. Demographics and baseline characteristics stratified by outcome.

	All patients ($n=502$)	Good outcome ($n=219$)	Poor outcome ($n=283$)	p
Age, mean (SD), years	66.9 (11.7)	63.9 (11.3)	69.3 (11.4)	<0.001
Male, *n* (%)	291 (58)	145 (66.2)	146 (51.6)	0.001
Medical history, *n* (%)				
Hypertension	339 (67.5)	139 (63.5)	200 (70.7)	0.088
Diabetes mellitus	101 (20.1)	29 (13.2)	72 (25.4)	0.001
AF	239 (47.6)	79 (36.1)	160 (56.5)	<0.001
Clinical characteristics, median (IQR)				
Baseline SBP, mmHg	146 (128–160)	140 (126–159)	150 (130–160)	0.014
Baseline DBP, mmHg	80 (72–91)	80 (72–90)	82 (72–94)	0.023
Baseline NIHSS score	16 (13–20)	14 (12–18)	18 (14–20)	<0.001
Baseline ASPECT score	9 (8–10)	9 (8–10)	8 (8–10)	<0.001
Mean SBP (24 h)	124 (117–132)	122 (115–129)	126 (118–134)	<0.001
Mean DBP (24 h)	71 (65–77)	70 (65–75)	72 (65–78)	0.115
TOAST classification, *n* (%)				0.001
LAA	170 (33.9)	91 (41.6)	79 (27.9)	
Cardioembolic	280 (55.8)	101 (46.1)	179 (63.3)	
Undetermined or others	52 (10.3)	27 (12.3)	25 (8.8)	
Occlusion site, *n* (%)				<0.001
ICA	213 (42.4)	64 (29.2)	149 (52.7)	
MCA/ACA (M1/A1)	254 (50.6)	137 (62.6)	117 (41.3)	
MCA/ACA (M2/A2)	35 (7)	18 (8.2)	17 (6)	
OTP, mean (SD), min	262 (79.7)	270 (82)	257 (77.5)	0.082
OTR, mean (SD), min	353 (93.4)	345 (89.8)	360 (95.7)	0.130
Tandem occlusion, *n* (%)	68 (13.5)	37 (16.9)	31 (11)	0.054
Collateral circulation, *n* (%)				<0.001
Grade 0	94 (18.7)	13 (6)	81 (28.6)	
Grade 1	198 (39.5)	78 (35.6)	120 (42.4)	
Grade 2	210 (41.8)	128 (58.4)	82 (29)	
Continuous intravenous antihypertensive agents, *n* (%)	307 (61.2)	138 (63)	169 (59.7)	0.452
Bridging treatment, *n* (%)	119 (23.7)	56 (25.6)	63 (22.3)	0.387

(Continued)

Table 1. (Continued)

	All patients ($n=502$)	Good outcome ($n=219$)	Poor outcome ($n=283$)	p
Type of procedure, *n* (%)				0.272
Stent retriever first	392 (78)	171 (78.1)	221 (78.1)	
Aspiration first	60 (12)	22 (10)	38 (13.4)	
Angioplasty or stent first	50 (10)	26 (11.9)	24 (8.5)	
Rescue treatment, *n* (%)	103 (20.5)	32 (14.6)	71 (25.1)	0.004
mTICI, 2b/3, *n* (%)	364 (72.5)	193 (88.1)	171 (60.4)	<0.001

ACA, anterior cerebral artery; AF, atrial fibrillation; ASPECT, Alberta Stroke Program Early CT; DBP, diastolic blood pressure; ICA, internal carotid artery; LAA, large-artery atherosclerosis; MCA, middle cerebral artery; mTICI, modified Thrombolysis in Cerebral Infarction; NIHSS, National Institutes of Health Stroke Scale; OTP, symptoms onset to groin puncture time; OTR, symptoms onset to reperfusion; SBP, systolic blood pressure; TOAST, the Trial of ORG 10172 in Acute Stroke Treatment.

(12.18 *versus* 15.25), and SD (11.19 *versus* 13.70) than those with the poor outcome. In addition, compared with patients without sICH, higher SBP max (160 mmHg *versus* 151 mmHg), SBP CV (12.69 *versus* 9.73), SV (16.93 *versus* 13.49), and SD (16.11 *versus* 12.13) were found in patients with sICH. Similar results were observed in DBP parameters.

In the multivariate logistic regression models, increases in SBP CV (OR, 1.089, 95% CI: 1.006–1.179, $p=0.035$; p for HL test = 0.606), SV (OR, 1.082, 95% CI: 1.025–1.143, $p=0.004$; p for HL test = 0.540) and SD (OR, 1.074, 95% CI: 1.008–1.145, $p=0.027$; p for HL test = 0.315) were associated with a lower likelihood of favorable outcome at 3 months. In addition, a similar result was seen with DBP max (OR, 1.039, 95% CI: 1.006–1.072, $p=0.019$; p for HL test = 0.351) and CV (OR, 1.079, 95% CI: 1.005–1.158, $p=0.035$; p for HL test = 0.606). We also evaluated the association of BPV with 3 months mRS in multivariable ordinal regression models. The similar results were found (Table S2).

As expected, higher SBP CV (OR, 1.156, 95% CI: 1.064–1.257, $p=0.001$; p for HL test = 0.110) and SD (OR, 1.118, 95% CI: 1.049–1.192, $p=0.001$; p for HL test = 0.229) were significantly associated with increased odds of sICH. However, there was no association of any DBP parameters with the outcome parameters in the multivariate logistic models. Associations of BPV parameters with different outcomes are shown in Tables 2 and 3.

BPV parameters and clinical outcomes according to recanalization status

After stratification by mTICI after MT, there were 138 (27.5%) patients with mTICI 0–2a and 364 (72.5%) patients with mTICI 2b–3. The changes in the probability of the adverse outcome (90-day mRS score 3–6) and sICH associated with SBP SD based on recanalization status are shown in Figure 2 (a/b). We found that the association between BPV and dichotomized mRS or sICH was different between the 2 subgroups of mTICI 0–2a and 2b–3.

In the multivariate logistic regression models, for patients with successful recanalization, increases in SBP SV (OR, 1.092, 95% CI: 1.027–1.160, $p=0.005$), DBP SD (OR, 1.124, 95% CI: 1.006–1.257, $p=0.040$), DBP CV (OR, 1.092, 95% CI: 1.011–1.181; $p=0.026$), and DBP max (OR, 1.045, 95% CI: 1.009–1.083, $p=0.014$) were associated with a lower likelihood of favorable outcome at 3 months. In addition, higher SBP CV (OR, 1.177, 95% CI: 1.045–1.324, $p=0.007$) and SD (OR, 1.141, 95% CI: 1.040–1.250, $p=0.005$) were significantly associated with increased odds of sICH in patients with successful recanalization. Associations of BPV parameters with different outcomes in patients with successful reperfusion are shown in Figure 3. However, we did not find an association between any BPV parameters and outcomes, including 90-day functional outcome and sICH in patients with unsuccessful recanalization (Supplemental Table 3). For all multivariate logistic regression models, the p for HL test $\geqslant 0.05$.

Table 2. Blood pressure variability parameters of the study population according to functional outcome.

	Unadjusted			Adjusted		
	Good outcome	Poor outcome	*p*	OR (95% CI)	*p*	*p* for HL test
SBP						
Max	147 (17.8)	156 (20.8)	<0.001	1.013 (0.994–1.033)	0.177	0.351
Min	103 (10.9)	103 (13.7)	0.654	0.969 (0.938–1)	0.052	0.596
CV	9.15 (2.92)	10.79 (4.57)	<0.001	1.089 (1.006–1.179)	0.035	0.606
SV	12.18 (4.01)	15.25 (8.09)	<0.001	1.082 (1.025–1.143)	0.004	0.540
SD	11.19 (3.87)	13.70 (6.02)	<0.001	1.074 (1.008–1.145)	0.027	0.315
DBP						
Max	88 (11.2)	92 (13.6)	<0.001	1.039 (1.006–1.072)	0.019	0.351
Min	56 (7.9)	55 (10.8)	0.332	0.972 (0.928–1.019)	0.238	0.596
CV	11.81 (3.39)	13.52 (4.50)	<0.001	1.079 (1.005–1.158)	0.035	0.606
SV	9.52 (2.76)	11.03 (4.01)	<0.001	1.066 (0.985–1.155)	0.113	0.540
SD	8.29 (2.49)	9.56 (3.11)	<0.001	1.099 (0.995–1.214)	0.063	0.315

Adjusted for: age, sex, baseline National Institutes of Health Stroke Scale and Alberta Stroke Program Early CT score, onset to puncture, mean blood pressure, hypertension, diabetes mellitus, Trial of ORG 10172 in Acute Stroke Treatment classification, tandem occlusion, occlusion site, rescue treatment, collateral circulation and modified Thrombolysis in Cerebral Infarction grading system.
CV, coefficient of variation; DBP, diastolic blood pressure; HL test, Hosmer–Lemeshow test; max, maximum; min, minimum; SBP, systolic blood pressure; SD, standard deviation; SV, successive variation.

BPV parameters and clinical outcomes according to collateral status

After stratification by the collateral circulation, there were 210 (41.8%) patients with good collateral status and 292 (58.2%) patients with poor collateral status. The changes in the probability of the adverse outcome (90-day mRS score 3–6) and sICH associated with SBP SD based on collateral circulation are shown in Figure 2 (c/d). We found that the association between BPV and dichotomized mRS or sICH was different between the different collateral status.

For patients with good collateral status, the multivariate logistic regression showed that increases in SBP SD (OR, 1.161, 95% CI: 1.049–1.286, $p=0.004$), CV (OR, 1.198, 95% CI: 1.054–1.361, $p=0.006$), SV (OR, 1.124, 95% CI: 1.031–1.225, $p=0.008$), and SBP max (OR, 1.032, 95% CI: 1.000–1.066; $p=0.050$) were associated with a lower likelihood of favorable outcome at 3 months. In addition, higher SBP SD (OR, 1.210, 95% CI: 1.057–1.386, $p=0.006$), CV (OR, 1.275, 95% CI: 1.075–1.511, $p=0.005$), and SBP max (OR, 1.039, 95% CI: 1.005–1.079; $p=0.044$) were significantly associated with increased odds of sICH. However, there was no association of any DBP parameters with the outcome parameters in the multivariate logistic models.

For patients with poor collateral status, increases in DBP SD (OR, 1.165, 95% CI: 1.006–1.349, $p=0.042$), CV (OR, 1.111, 95% CI: 1.004–1.230, $p=0.042$), and DBP max (OR, 1.053, 95% CI: 1.009–1.098; $p=0.017$) were associated with a lower likelihood of favorable outcome at 3 months. In addition, higher SBP SD (OR, 1.091, 95% CI: 1.007–1.182, $p=0.033$) and CV (OR, 1.130, 95% CI: 1.018–1.254, $p=0.022$) were significantly associated with increased odds of sICH. Associations of BPV parameters with different outcomes based on collateral status are shown in Table 4. For all models, the p values for HL test ≥ 0.05.

Table 3. Blood pressure variability parameters of the study population according to sICH*.

	Unadjusted			Adjusted		
	sICH	No-sICH	*p*	OR (95% CI)	*p*	*p* for HL test
SBP						
Max	160 (20.6)	151 (19.7)	0.003	1.020 (1–1.041)	0.055	0.050
Min	102 (16.2)	103 (11.9)	0.815	0.970 (0.937–1.003)	0.072	0.529
CV	12.69 (6.48)	9.73 (3.44)	<0.001	1.156 (1.064–1.257)	0.001	0.110
SV	16.93 (12.55)	13.49 (5.52)	0.005	1.043 (0.998–1.089)	0.059	0.482
SD	16.11 (8.21)	12.13 (4.66)	<0.001	1.118 (1.049–1.192)	0.001	0.229
DBP						
Max	94 (14.0)	90 (12.5)	0.018	1.014 (0.979–1.050)	0.447	0.050
Min	55 (12.4)	55 (9.1)	0.963	0.986 (0.936–1.040)	0.615	0.529
CV	14.36 (5.23)	12.59 (3.93)	0.010	1.005 (0.920–1.098)	0.912	0.110
SV	11.55 (3.62)	10.21 (3.58)	0.002	1.034 (0.947–1.128)	0.458	0.482
SD	10.21 (3.25)	8.86 (2.85)	0.001	0.998 (0.883–1.127)	0.971	0.229

Adjusted for: baseline National Institutes of Health Stroke Scale and Alberta Stroke Program Early CT score, mean blood pressure, collateral circulation, and modified Thrombolysis in Cerebral Infarction grading system.
*4 patients no post-procedure imaging ($n = 498$).
CV, coefficient of variation; DBP, diastolic blood pressure; HL test, Hosmer-Lemeshow test; max, maximum; min, minimum; SBP, systolic blood pressure; SD, standard deviation; sICH, symptomatic intracranial hemorrhage; SV, successive variation.

Discussion

Our study mainly showed that patients with a higher BPV as measured by the SD and CV during the first 24 h after MT had a significantly higher risk of postprocedural sICH and lower odds of achieving good functional outcome at 90 days. Moreover, the relationship between BPV and clinical outcomes depended on the recanalization status. However, the collateral circulation status did not modify the association between BPV and outcomes.

To date, increasing evidence has supported the influence of BP on acute stroke outcome.[5,6,9,10] Moreover, BPV has increasingly been regarded as a novel risk factor that can predict the clinical outcomes of stroke patients.[13,14] However, these studies are small single-center studies, and most of the data is not from the modern thrombectomy device. In the current study, we found that elevated SBP variability, as measured by SD, CV, and SV during the first 24 h after MT, was associated with the poor functional outcome. Our study further expanded the understanding of the association of BPV with outcomes in patients with MT. In addition, the influence of BP min on the clinical outcomes of patients with MT has been rarely studied. Our study found that BP min appears to be positively correlated with good prognosis, although it is not statistically significant. This suggests that for patients with MT, although higher SBP is not conducive to functional recovery, it is necessary to maintain the minimum BP at a certain level. However, this conclusion still needs further research to confirm.

Theoretically, higher BP may increase the permeability of the blood–brain barrier and the risk of hemorrhage transformation in the setting of stroke.[19] Moreover, wide BPV may result in exacerbation of reperfusion injury. However, the independent association between BPV and sICH has not been well established in previous studies.[13,20] For example, a secondary analysis of the BEST (Blood Pressure after Endovascular Therapy for

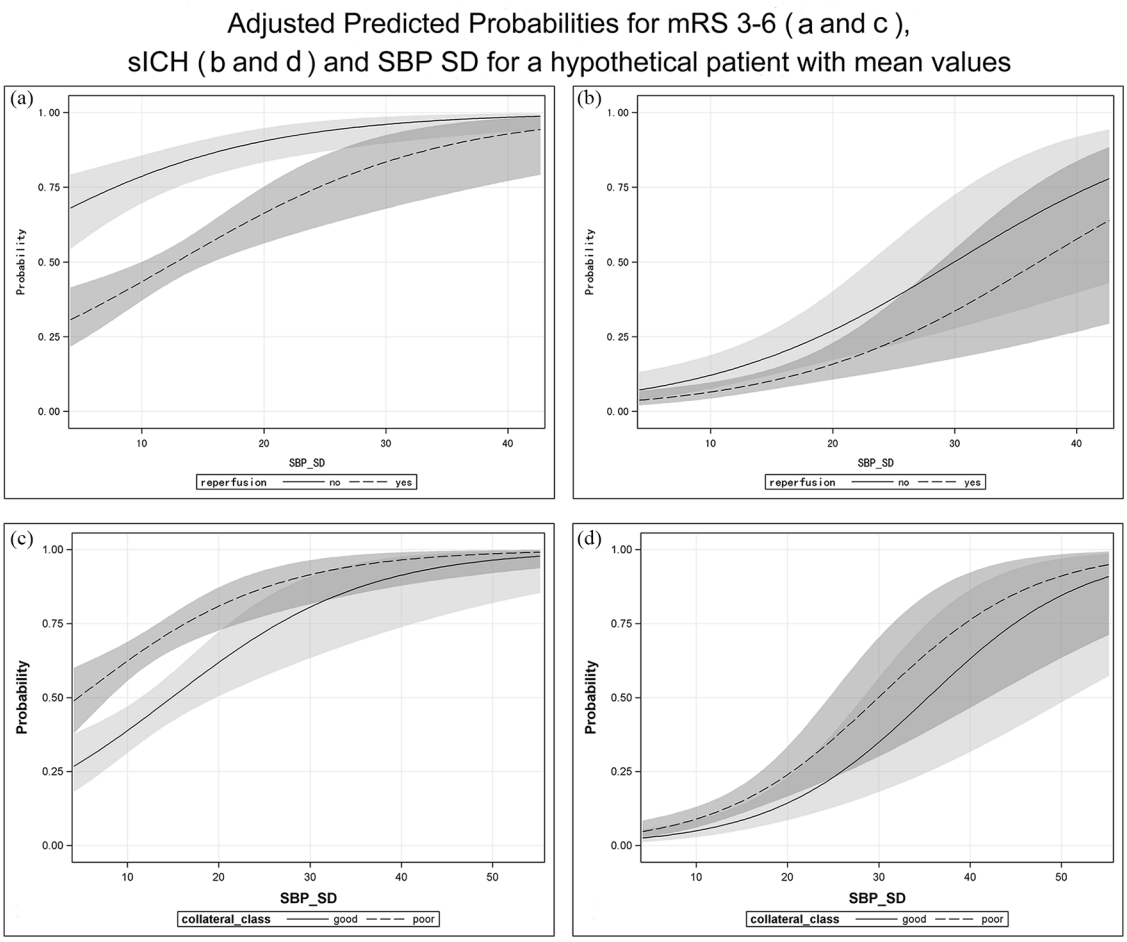

Figure 2. The adjusted predicted probabilities of the association between BPV (SBP SD) and poor outcome (a/c) or sICH (b/d). a/b, based on recanalization status; c/d, based on collateral status. The regression curve estimates the probability of outcomes for an average patient (mean age, 66.8 years; mean baseline NIHSS scores, 16.6; mean baseline ASPECT scores, 8.7; mean SBP: 124.7 mmHg). The grey area indicates the 95% confidence interval.
ASPECT, Alberta Stroke Program Early CT; BPV, blood pressure variability; NIHSS, National Institutes of Health Stroke Scale; SBP, systolic blood pressure; SD, standard deviation; sICH, symptomatic intracranial hemorrhage.

Ischemic Stroke) study found that higher BPV, measured by SD, CV, SV, and residual SD, could predict poorer neurological outcomes.[20] Nevertheless, they did not show the association of BPV with sICH. Furthermore, a recent meta-analysis showed similar results.[21] Inconsistent with these studies, our study demonstrated that higher SBP SD and CV could significantly increase the risk of postprocedural sICH. We speculated that the discrepancy may be due to differences in methodology or the heterogeneity of patients included in prior studies.

Notably, a higher rate of sICH was observed in our study. Several reasons could explain the difference. First, our studies may better reflect real-world practices. A multicenter registry program from China reported a similar incidence of sICH after endovascular treatment.[3] Second, the high proportion of intracranial atherosclerosis in Asian populations may explain the higher incidence of sICH. Third, the high rates of sICH may be due to the heterogeneity of included patients and the diversity of the evaluation criteria of sICH in different studies.

Although the negative impact of BPV on outcomes in MT patients has been confirmed in our study and the previously mentioned studies,[14,20] translating these observed relationships into clinical practice is still a major challenge. Recently, the ENCHANTED (Enhanced Control of

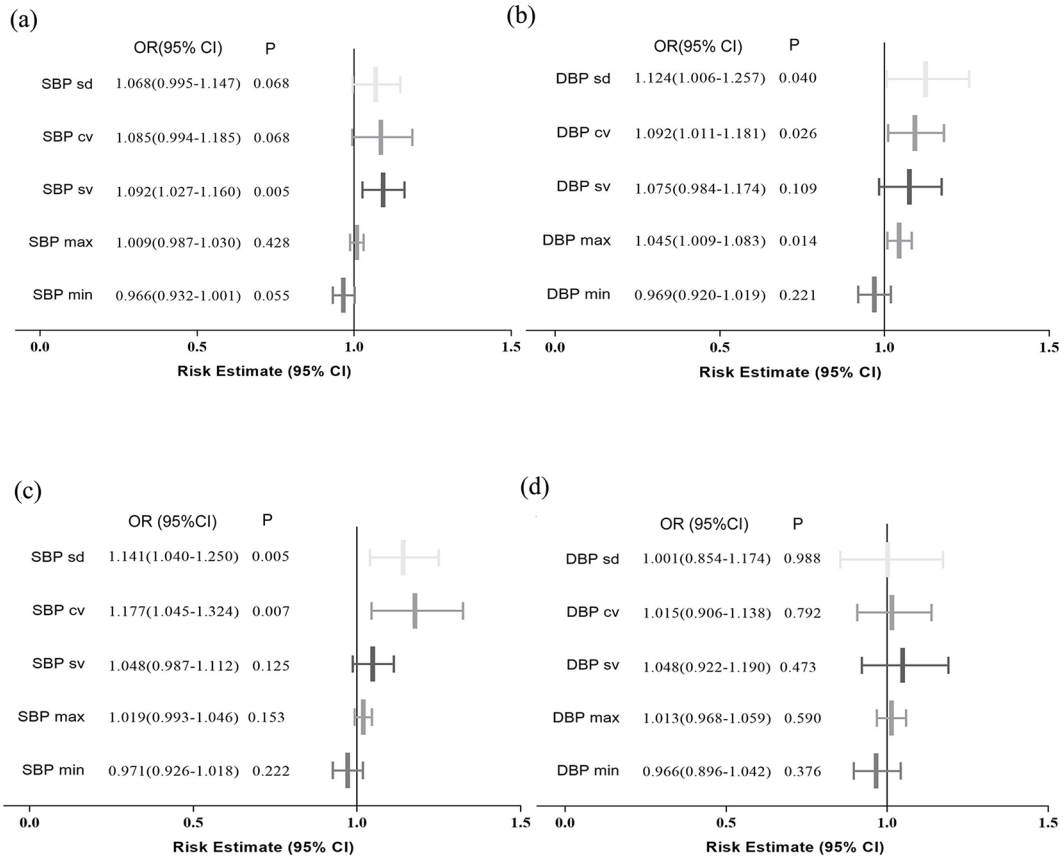

Figure 3. Odds ratios (OR) for poor outcome (mRS 3–6, a/b) or sICH (c/d) in patients with successful reperfusion.
CV, coefficient of variation; DBP, diastolic blood pressure; max, maximum; min, minimum; mRS, modified Rankin Scale score; SBP, systolic blood pressure; SD, standard deviation; sICH, symptomatic intracranial hemorrhage; SV, successive variation.

Hypertension and Thrombolysis Stroke Study) trial showed that BP reduction in patients treated with IVT did not improve clinical outcomes despite reducing the occurrence of intracranial hemorrhage.[22] Therefore, further randomized trials are imperative and urgently needed to determine whether the observed associations in the current study are causative and modifiable.[23]

However, before conducting a trial, it is important to understand the potential challenge that may affect the results of the trial. First, researchers need to specify appropriate BP targets.[24] Prior studies have suggested that higher SBP values after MT may lead to adverse outcomes.[9,10] Second, control mean BP while reducing BPV. Several studies, including this one, have shown that BPV still affects the clinical outcomes of MT patients after adjusting for mean BP.[20] Third, whether specific factors such as age and comorbidities may have an impact on BP management strategies remains to be elucidated.[25] Finally, reperfusion status and collateral circulation are important factors in regulating the effect of postoperative BP on the prognosis of patients treated with MT.[9,26]

The associations of BPV with outcomes in stroke patients based on reperfusion status have been investigated in prior studies.[9] However, the results have had some controversy. Delgado-Mederos *et al.*[27] found that SBP SD was associated with greater infarction lesion growth and worse clinical outcomes in non-recanalized patients but not in recanalized IVT-treated patients. Another study of intra-arterial therapies also showed that the association of SBP SD and SV were significantly associated with poor outcomes in patients with insufficient recanalization.[13] However, recent studies of MT showed that the associations of

Table 4. Blood pressure variability parameters of the different collateral status population according to clinical outcomes.

	90-day mRS 3–6				sICH			
	OR	**95% CI**	***p***	***p* for HL test**	**OR**	**95% CI**	***p***	***p* for HL test**
For patients with good collaterals								
SBP								
Max	1.032	1–1.066	0.050	0.385	1.039	1.001–1.079	0.044	0.540
Min	0.962	0.915–1.012	0.135	0.743	0.952	0.885–1.024	0.187	0.781
CV	1.198	1.054–1.361	0.006	0.174	1.275	1.075–1.511	0.005	0.941
SV	1.124	1.031–1.225	0.008	0.147	1.072	0.966–1.189	0.190	0.881
SD	1.161	1.049–1.286	0.004	0.391	1.210	1.057–1.386	0.006	0.934
DBP								
Max	1.018	0.968–1.070	0.498	0.385	0.984	0.913–1.059	0.662	0.540
Min	0.992	0.923–1.066	0.832	0.743	1.023	0.912–1.147	0.701	0.781
CV	1.027	0.927–1.139	0.609	0.174	0.883	0.744–1.048	0.155	0.941
SV	1.079	0.953–1.222	0.230	0.147	1.048	0.862–1.274	0.640	0.881
SD	1.010	0.873–1.168	0.893	0.391	0.821	0.642–1.050	0.117	0.934
For patients with poor collaterals								
SBP								
Max	0.993	0.968–1.019	0.610	0.261	1.003	0.976–1.032	0.807	0.219
Min	0.969	0.929–1.010	0.136	0.571	0.974	0.936–1.013	0.193	0.932
CV	1.025	0.925–1.135	0.641	0.804	1.170	1.018–1.254	0.022	0.107
SV	1.068	0.995–1.146	0.068	0.818	1.029	0.967–1.095	0.361	0.585
SD	1.018	0.937–1.106	0.677	0.805	1.091	1.007–1.182	0.033	0.287
DBP								
Max	1.053	1.009–1.098	0.017	0.261	1.021	0.979–1.066	0.325	0.219
Min	0.975	0.915–1.039	0.438	0.571	0.988	0.924–1.056	0.720	0.932
CV	1.111	1.004–1.230	0.042	0.804	1.036	0.928–1.158	0.527	0.107
SV	1.041	0.935–1.160	0.461	0.818	1.014	0.906–1.134	0.814	0.585
SD	1.165	1.006–1.349	0.042	0.805	1.054	0.903–1.231	0.506	0.287

Adjusted for: age, sex, baseline National Institutes of Health Stroke Scale and Alberta Stroke Program Early CT score, onset to reperfusion, Trial of ORG 10172 in Acute Stroke Treatment classification, mean blood pressure, occlusion site, modified Thrombolysis in Cerebral Infarction grading system.
CV, coefficient of variation; DBP, diastolic blood pressure; HL test, Hosmer-Lemeshow test; max, maximum; min, minimum; SBP, systolic blood pressure; SD, standard deviation; sICH, symptomatic intracranial hemorrhage; SV, successive variation.

BPV, as measured by SD, CV, SV, and time rate of BP variation, with sICH and poor 90-day functional outcome were found in patients with successful recanalization.[14,15,20] Moreover, in our study, similar results were displayed. We speculated that the discrepancy may be due to different population cohorts included in these studies. The possible mechanism is that, in the setting of restoration of blood flow to the ischemic core and penumbral areas, higher BPV may plausibly subject these regions to increased reperfusion injury.

Collateral circulation plays an important role in the pathophysiology of cerebral ischemia. BP is associated with arterial collateralization in ischemic stroke.[28] However, the association of BPV and outcome based on collateral status is unclear. In the present study, we found that a higher BPV after MT was associated with worse functional outcome, regardless of the collateral status. Although the results were surprising, a recent study also showed that the collateral status did not affect the association between dynamic BP parameters and functional outcomes.[29] Thus, future research still needs to explore this possible mechanism. In addition, in a subgroup analysis of collateral circulation, our results unexpectedly showed that DBP variability was associated with a 90-day functional outcome. However, the possible mechanism is unclear. A recent study[30] found that increased pulse pressure variability (PPV) was independently associated with adverse functional outcomes of patients treated with IVT. Moreover, PPV during MT was an independent predictor of worse clinical outcomes.[31] Hence, we speculated that DBP variability may change PPV, thus affecting the prognosis of patients with MT.

Although our study shows that BPV is an important clinical indicator affecting the prognosis of patients with MT, it is a pity that most BPV parameters cannot be obtained in time. This is bound to affect the practical application of BPV parameters. Previous studies have found that the effect of BP on outcomes may be different in different periods of 24 h after reperfusion therapy,[32,33] which provides the possibility for clinical application of BPV parameters. In addition, determining a reliable outcome-driven threshold of BPV from prospective registration study can provide theoretical help for further clinical randomized controlled trials.

This study has several limitations. First, the standardized BP measurement protocol was not specified. Moreover, the intraprocedural BP was not collected. Second, due to heterogeneous postprocedural imaging protocols, the final infarct volume was not obtained, which is a known predictor of functional outcome. In addition, we did not obtain preoperative oral anticoagulation or antithrombotic data, which may affect the occurrence of sICH. Finally, to ensure the consistency of patient selection at the in different centers, we included only patients highly recommended by the guidelines. Therefore, the findings cannot be applied to other patients.

In conclusion, our study found that high SBP SD and CV during the first 24 h after MT was a powerful predictor of worse clinical outcomes regardless of the collateral status. However, these relationships depended on the recanalization status. These results suggest that BPV reduction may improve clinical outcomes for patients with MT, but the postoperative recanalization status should be considered. Further randomized controlled trials are warranted to determine optimal BP management for MT patients.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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Supplemental material

Supplemental material for this article is available online.

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