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ORIGINAL RESEARCH

Post-Thrombectomy Pulse Pressure Trajectories and Outcomes in Middle-Aged and Older Stroke Patients

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Background: Endovascular thrombectomy (EVT) is an established treatment for acute ischemic stroke in elderly patients. Nonetheless, age-specific vascular pathophysiology in this population presents distinct challenges for postprocedural blood pressure management. Pulse pressure has been linked to clinical outcomes, however, evidence regarding the impact of its dynamic patterns following EVT remains limited.

Methods: This single-center retrospective cohort study included patients aged over 45 years who had achieved successful reperfusion following thrombectomy. Group-based trajectory modeling was applied to characterize the patterns of pulse pressure over the first 24 hours post-procedure. The primary outcome was functional status at 90 days, assessed using the modified Rankin Scale. The association between pulse pressure trajectories and functional outcome was examined using ordinal logistic regression, with adjustment for potential confounders. Furthermore, subgroup analysis was performed to assess whether this association differed between patients aged <75 years and those ≥75 years.

Results: Three distinct postoperative pulse pressure trajectories were identified: low-stable, moderate-increasing, and high-increasing. In the overall population, the moderate-increasing trajectory was associated with favorable 90-day functional outcomes after multivariate adjustment (adjusted OR, 0.52; 95% CI, 0.32–0.85), while no significant association was observed between the high-increasing and low-stable trajectories. Subgroup analysis revealed a significant interaction between age and trajectory group (*P* for interaction <0.05). The moderate-increasing trajectory was associated with better functional outcomes in patients aged ≥75 years (adjusted OR, 0.28; 95% CI, 0.13–0.62), whereas no statistically significant association was observed in the younger subgroup.

Conclusion: Among patients aged >45 years undergoing EVT, the 24-hour pulse pressure trajectory is associated with 90-day functional outcome, and this association is modified by age. For patients aged 75 years or older, maintaining a moderate pulse pressure level may be associated with improved functional recovery.

Keywords: blood pressure, stroke, thrombectomy, GBTM

Introduction

Ischemic stroke is a significant contributor to the global cardiovascular disease burden, with approximately 60% of cases occurring in individuals aged 70 years and above. The associated burden increases nearly exponentially with age.[1–4] For acute ischemic stroke, endovascular thrombectomy (EVT) has been established as a cornerstone of recanalization therapy. Nevertheless, the optimal post-procedural blood pressure management strategy remains unclear.[5,6] The 2026 AHA/ASA guideline provides specific recommendations for post-EVT blood pressure management, advising maintenance of systolic blood pressure below 180 mmHg during the first 24 hours and noting that intensive lowering to below

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140 mmHg within the first 72 hours may be harmful.[7] This systolic-focused approach is similarly reflected in other guidelines,[8–10] whereas pulse pressure management remains consistently unaddressed across all current consensus statements.

Pulse pressure (PP), defined as the difference between systolic and diastolic pressure, is a hemodynamic indicator of arterial stiffness and is independently associated with the progression of carotid atherosclerosis.[11–14] Recent studies further suggest that pulse pressure and its variability are strong predictors of adverse stroke outcomes, potentially offering superior predictive capability compared to systolic blood pressure variability. This association is particularly prominent in elderly patients.[15–17] On one hand, the cerebral autoregulatory range narrows, reducing the brain's tolerance and compensatory response to blood pressure fluctuations. On the other hand, increased arterial stiffness amplifies the magnitude of pulse pressure oscillations and exacerbates cerebral injury through mechanisms such as endothelial damage and blood-brain barrier disruption.[18,19] Consequently, the aging brain demonstrates increased susceptibility to dynamic changes in pulse pressure, whereby even minor circulatory perturbations may trigger hemodynamic responses, elevating the risk of perioperative instability. Additionally, previous studies have largely relied on traditional variability metrics to characterize blood pressure fluctuations, which may not capture the dynamic trajectory of blood pressure changes over time. In contrast, group-based trajectory modeling (GBTM) enables the identification of distinct blood pressure patterns within heterogeneous populations, offering a novel perspective for understanding the relationship between hemodynamic dynamics and clinical outcomes.

Thus, our study aims to identify distinct pulse pressure trajectory patterns based on blood pressure monitoring during the first 24 hours post-EVT in middle-aged and older patients and to investigate their association with 90-day functional outcomes.

Materials and Methods

Study Participants

The single-center retrospective observational study included 364 stroke patients admitted to Lishui Central Hospital between June 2021 and June 2023. Eligible patients underwent EVT within 24 hours of onset, obtained successful recanalization (defined as modified thrombolysis in cerebral infarction score ≥ 2b), had imaging-confirmed anterior circulation large vessel occlusion involving the internal carotid artery, middle cerebral artery (M1/M2 segments), or anterior cerebral artery (A1/A2 segments). Patients were excluded if incomplete baseline data or lacked follow-up data. After excluding 38 patients who had posterior circulation stroke, 2 patients whose time from onset to reperfusion was over 24 hours, 26 participants with insufficient BP data and 7 patients losing 90d-mRS, we finally included 287 subjects in total. The study protocol received approval from the Medical Ethics Committee of Lishui Central Hospital (Approval No.2025(I)-040-01), and all data were completely de-identified. To assess potential bias from these exclusions, we compared available baseline characteristics between included patients and those excluded due to missing data; the results are presented in Table S1. No significant differences were observed (all $P > 0.05$), suggesting a low risk of exclusion bias.

Data Collection and Outcome

Demographic, clinical, and procedural data were extracted from electronic medical records. Baseline variables included age, sex, smoking status, drinking status, body mass index (BMI), medical history (hypertension, diabetes, atrial fibrillation, and stroke), admission National Institutes of Health Stroke Scale (NIHSS) score, onset-to-reperfusion time, and post-EVT intravenous antihypertensive medication use. Additionally, due to the retrospective nature of the study, data on specific blood pressure management strategies were not fully captured. This includes information on the types of antihypertensive agents used and the treatment protocols applied. The absence of these data may introduce residual confounding. All patients had blood pressure recorded at standardized time points (immediately post-EVT and hourly for 24 hours thereafter), with each measurement documented alongside its corresponding post-procedural time. All patients had at least 12 BP measurements during the first 24 hours post-procedure. For the few missing time points attributable to clinical procedures, no imputation was applied. GBTM inherently accommodates irregular time intervals and missing data through its maximum likelihood estimation framework, allowing all available measurements to contribute to trajectory estimation without requiring complete data at all time points. The functional outcome was the score on the modified Rankin scale (mRS) at 90 days (range, 0 [no symptoms] to 6 [death]).

Blood Pressure Trajectory Analysis

We adopted GBTM via the TRAJ procedure in SAS software to characterize BP trajectories during the first 24 hours post-EVT.[20,21] In contrast to conventional longitudinal data analysis that assumes population homogeneity and estimates a single average developmental trajectory, group-based trajectory modeling is fundamentally premised on recognizing population heterogeneity in developmental pathways. For each candidate model (1–5 subgroups), starting with a third-order polynomial function, higher-order terms were sequentially removed if statistically non-significant ($p \geq 0.05$), whereas linear terms were retained regardless of significance. Model fit was systematically evaluated using Bayesian Information Criterion (BIC), Bayes factor (2ln(B10)), and average posterior probability (AvePP). The optimal model required concurrent satisfaction of: BIC closest to zero, 2ln(B10) >6, AvePP >0.7, and subgroup proportions >5%. We started with 1 group and increased the number of groups to 3 until the best-fitting model was established. These 3 trajectories fulfilled the model fit criteria defined above.

Statistical Analysis

After determining the blood pressure trajectory groups via GBTM, baseline characteristics were compared across groups using non-parametric tests or *t*-tests for continuous variables and chi-square tests for categorical variables. The association between trajectory groups and 90-day functional outcome (assessed by the ordinal mRS) was evaluated using ordinal logistic regression, which is appropriate for assessing the likelihood of improved functional outcomes across ordered categories. The low-stable trajectory group served as the reference. To examine the independent effect of trajectory patterns, covariates were adjusted sequentially: Model 1 adjusted for demographic factors (age, sex, BMI); Model 2 further incorporated baseline clinical characteristics (smoking history, hypertension, diabetes, atrial fibrillation); and Model 3 additionally included treatment-related variables (thrombolysis, onset-to-reperfusion time, post-procedural antihypertensive therapy).

To investigate whether the observed association was modified by key clinical factors, subgroup analyses were performed. All subgroup analyses were exploratory in nature. In accordance with the World Health Organization (WHO) age classification and gerontological conventions defining ≥75 years as the “late elderly” or “old-old” subgroup, patients were stratified into those aged <75 years and ≥75 years. Additional exploratory analyses were conducted according to history of hypertension, post-procedural antihypertensive treatment, and sex. All analyses were conducted with SPSS 25.0 (IBM Inc., Chicago, IL, USA), and a two-sided P value < 0.05 was considered statistically significant.

Result

Basic Characteristics

A total of 287 patients with anterior circulation large vessel occlusion undergoing endovascular therapy were included in the final analysis (Figure 1). The overall cohort had a median age of 72.1 years, 57.5% were male, and the median NIHSS score on admission was 15. Group-based trajectory model identified three distinct pulse pressure trajectories during the first 24 hours post-procedure (Figure 2): Trajectory 1 (Low-stable, n=125), characterized by persistently low pulse pressure throughout; Trajectory 2 (Moderate-increasing, n=113), exhibiting a gradual rise over 24 hours; and Trajectory 3 (High-increasing, n=49), with an early, rapid increase that remained elevated.

These trajectory groups displayed different clinical profiles (Table 1). Patients in the Low-stable group were relatively younger, had lower pre-stroke prevalences of hypertension and diabetes, a higher proportion of smokers, the lowest baseline systolic blood pressure and pulse pressure on admission, and the lowest rates of receiving antihypertensive therapy within 24 hours post-EVT. In contrast, the High-increasing group consisted predominantly of older, female patients, had the highest prevalences of hypertension and diabetes, significantly higher admission systolic blood pressure and pulse pressure, and the highest rates of thrombolysis, post-EVT antihypertensive therapy. The Moderate-increasing group generally exhibited characteristics intermediate to the other two. Notably, body mass index, drinking history,

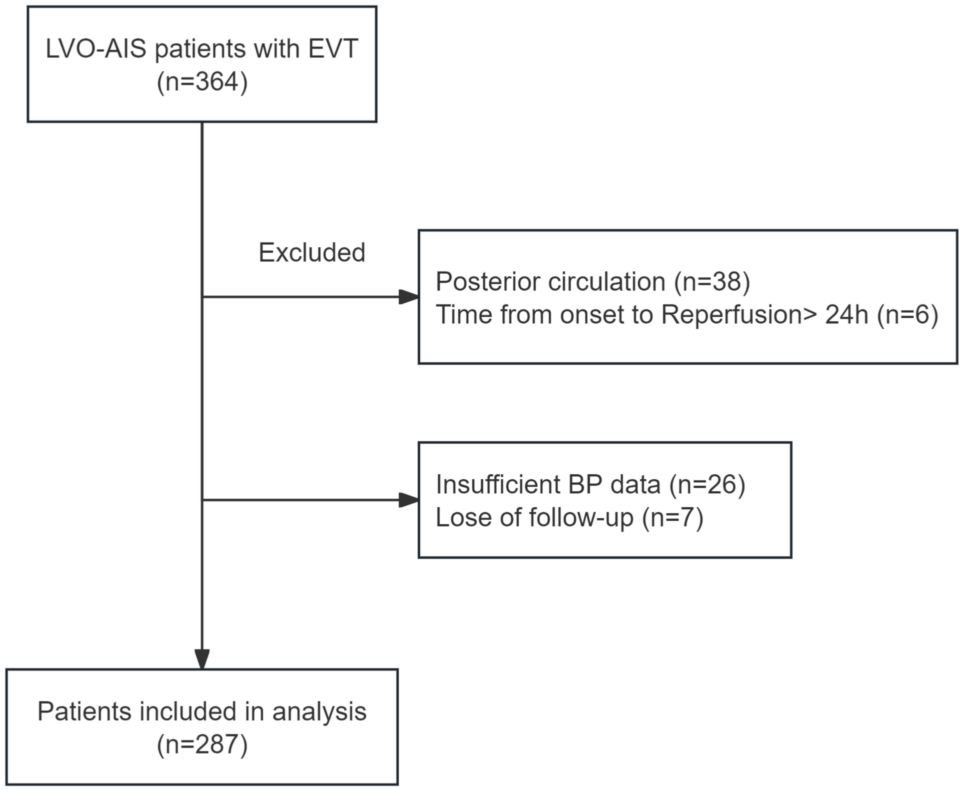

Figure 1 Flowchart of patient enrollment.
Abbreviations: LVO, indicates large vessel occlusion; AIS, acute ischemic stroke; EVT, endovascular thrombectomy; OTP, onset to puncture time; BP, blood pressure.

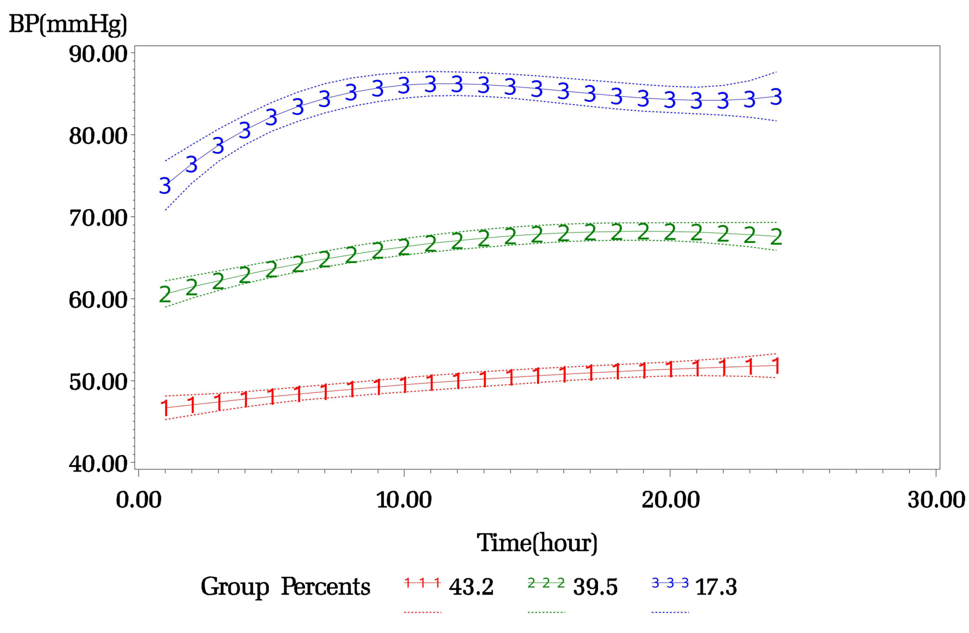

Figure 2 Pulse pressure trajectories in 24h after endovascular thrombectomy.

Table 1 Baseline Characteristics of Patients Following Endovascular Thrombectomy Stratified by Pulse Pressure Trajectory Group

Variables	Total (n=287)	PP Trajectory Groups			*p* value
		Low-Stable (n=125)	Moderate-Increasing (n=113)	High-Increasing (n=49)	
Demographics					
Male, n (%)	165(57.5)	81(64.8)	69(61.1)	15(30.6)	**<0.001**
Age (year), mean ± SD	72.1±10.8	68.9±11.3	73.9±9.6	75.9±10.0	**<0.001**
BMI (kg/m^2), mean ± SD	22.5±3.4	22.4±3.3	22.7±3.7	22.7±3.0	0.73
Medical History, n (%)					
Smoking	77(26.8)	37(29.6)	34(30.1)	6(12.2)	**0.04**
Drinking	95(31.9)	46(34.6)	36(31.6)	13(25.5)	0.49
Hypertension	171(59.6)	58(46.4)	70(61.9)	43(87.8)	**<0.001**
Diabetes	38(13.2)	9(7.2)	18(15.9)	11(22.4)	**0.02**
Atrial fibrillation	61(21.3)	29(23.2)	22(19.5)	10(20.4)	0.77
Stroke	57(19.9)	21(16.8)	23(20.4)	13(26.5)	0.35
Blood Pressure (mmHg), mean ± SD					
Admission PP	67.7±20.4	57.2±16.7	70.3±17.6	89.1±16.3	**<0.001**
Admission SBP	155.5±23.1	145.6±20.7	158.5±21.6	174.4±18.6	**<0.001**
Admission DBP	87.9±15.8	88.5±16.0	88.3±15.5	85.3±16.1	0.54
Clinical Characteristics, n (%)					
Admission NIHSS, median (IQR),	15(7)	16(7)	15(8)	16(6)	0.07
Time from onset to Reperfusion (min), mean ± SD	604.9±306.4	616.4±323.9	611.5±299.9	560.0±274.9	0.63
Thrombolysis	118(41.1)	45(36.0)	45(40.7)	27(55.1)	0.07
Antihypertensive Therapy	54(18.1)	10(8.0)	22(19.5)	21(42.9)	**<0.001**

Note: *p* values <0.05 are in bold,
Abbreviations: BMI, indicates body mass index; SD, Standard Deviation; PP, pulse pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; and NIHSS, National Institutes of Health Stroke Scale.

history of atrial fibrillation or prior stroke, admission diastolic blood pressure, initial stroke severity (NIHSS score), and onset-to-reperfusion time were comparable across all three groups (all p >0.05).

Trajectory Groups and Outcome

The results of the sequential multivariable-adjusted ordinal logistic regression analyses are presented in Table 2. After initial adjustment for demographic factors (Model 1), the moderate-increasing pulse pressure trajectory was independently associated with a higher likelihood of favorable 90-day functional outcome (adjusted odds ratio [aOR] 0.60, 95% confidence interval [CI] 0.37–0.95, *p*=0.029). This association remained significant after further adjustment for baseline clinical characteristics (Model 2) and treatment-related variables (Model 3), with the strength of the association increasing in the fully adjusted model (Model 3: aOR 0.52, 95% CI 0.32–0.85, *p*=0.008). In contrast, the high-increasing trajectory did not show a statistically significant association with functional outcome in any of the models.

Table 2 Adjusted Odds Ratio of 90-Day Modified Rankin Scale Scores by Pulse Pressure Trajectory

	Model 1*			Model 2†			Model 3‡		
	OR	95%CI	*p* value	aOR	95%CI	*p* value	aOR	95%CI	*p value*
Low-stable	Ref.			Ref.			Ref.		
Moderate-increasing	0.60	0.37–0.95	**0.029**	0.60	0.37–0.96	**0.033**	0.52	0.32–0.85	**0.008**
High-increasing	1.23	0.64–2.35	0.532	1.25	0.64–2.43	0.518	0.86	0.43–1.72	0.661

Note: *p* values <0.05 are in bold, *Model 1: Adjusted for patient age, sex, BMI. †Model 2: Adjusted for patient age, sex, BMI, smoking, hypertension, diabetes, atrial fibrillation. ‡ Model 3: Adjusted for patient age, sex, BMI, smoking, hypertension, diabetes, atrial fibrillation, thrombolysis, time from onset to reperfusion, antihypertensive therapy.
Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; Ref., reference.

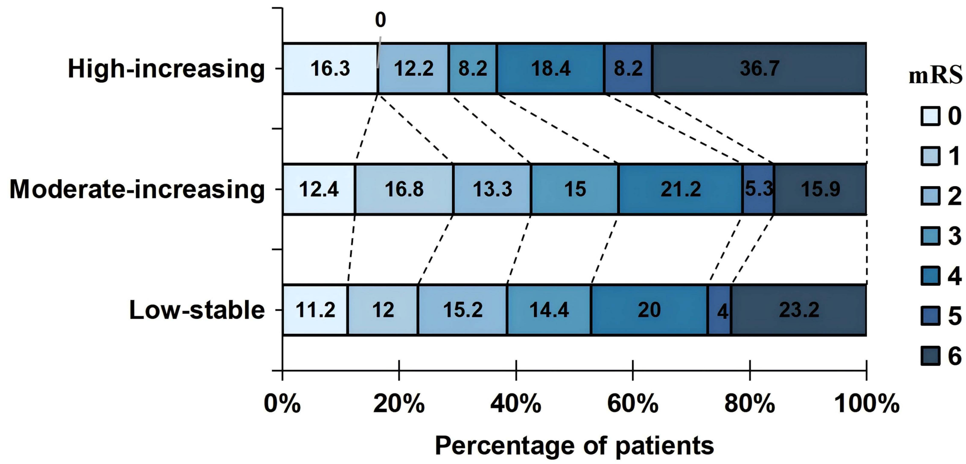

Figure 3 Distribution of modified Rankin Scale scores at 90 days among different pulse pressure trajectories.
Abbreviation: mRS, indicates modified Rankin Scale.

The trajectory group was independently associated with 90-day mRS scores. The distribution of mRS scores by trajectory group is shown in Figure 3. The moderate-increasing group exhibited significantly best outcome compared to the other two groups.

Subgroup Analyses

Subgroup analyses further elucidated the heterogeneity in the association between blood pressure trajectories and functional outcomes (Figure 4). A significant effect modification was observed in the age-stratified analysis (p for interaction = 0.04). Specifically, among patients aged 75 years or older, the moderate pulse pressure trajectory was independently associated with significantly improved 90-day functional outcome (aOR 0.28, 95% CI 0.13–0.62). In contrast, no statistically significant difference in outcomes was observed across trajectory groups in patients younger than 75 years (aOR for moderate trajectory 1.18, 95% CI 0.62–2.22; aOR for high trajectory 1.52, 95% CI 0.50–4.60).

In other exploratory subgroup analyses, although no statistically significant interactions were detected (all p for interaction > 0.05), consistent trends were observed whereby the moderate trajectory tended to be associated with more favorable outcomes. This association appeared more pronounced in women, in patients with a history of hypertension, and in those who received post-procedural antihypertensive therapy.

Discussion

The study included 287 acute stroke patients who underwent endovascular treatment, with an average age of 72.1 years. We identified three distinct trajectories of pulse pressure (PP) within the first 24 hours post-EVT. The moderate-increasing PP trajectory was associated with favorable 90-day functional outcome. This association suggested a age-dependence, being statistically significant in patients aged 75 years and older. In contrast, no significant difference in outcomes across PP trajectories was observed in patients younger than 75 years.

The findings of this study are consistent with and extend the existing literature. Prior research has established that the mean pulse pressure (PP) within 24 hours after endovascular thrombectomy (EVT) is an independent risk factor for symptomatic intracranial hemorrhage, poor functional outcomes, and mortality in stroke patients.[6,22–26] A recent study indicated that among patients with good collateral circulation, while 24-hour PP was not associated with functional dependence at 3 months, a higher PP level (59.4 ± 10.5 vs. 56.3 ± 7.6; OR 1.05; 95% CI 1–1.1) was significantly linked to increased 3-month mortality.[23] Further investigation involving 587 patients demonstrated that an elevated mean PP (>57.39 mmHg) was a stronger predictor of adverse outcomes compared to systolic or diastolic blood pressure alone, showing the highest adjusted odds ratio (aOR 2.39; 95% CI 1.58–3.62) and area under the curve (AUC=0.661; 95% CI 0.617–0.705).[24] Pulse pressure variability (PPV) has also been independently associated with poor outcomes. For instance, one study in patients with large vessel occlusion (LVO) reported that PPV from admission through the first 24 hours after intra-arterial therapy was independently associated with poor outcomes at 3

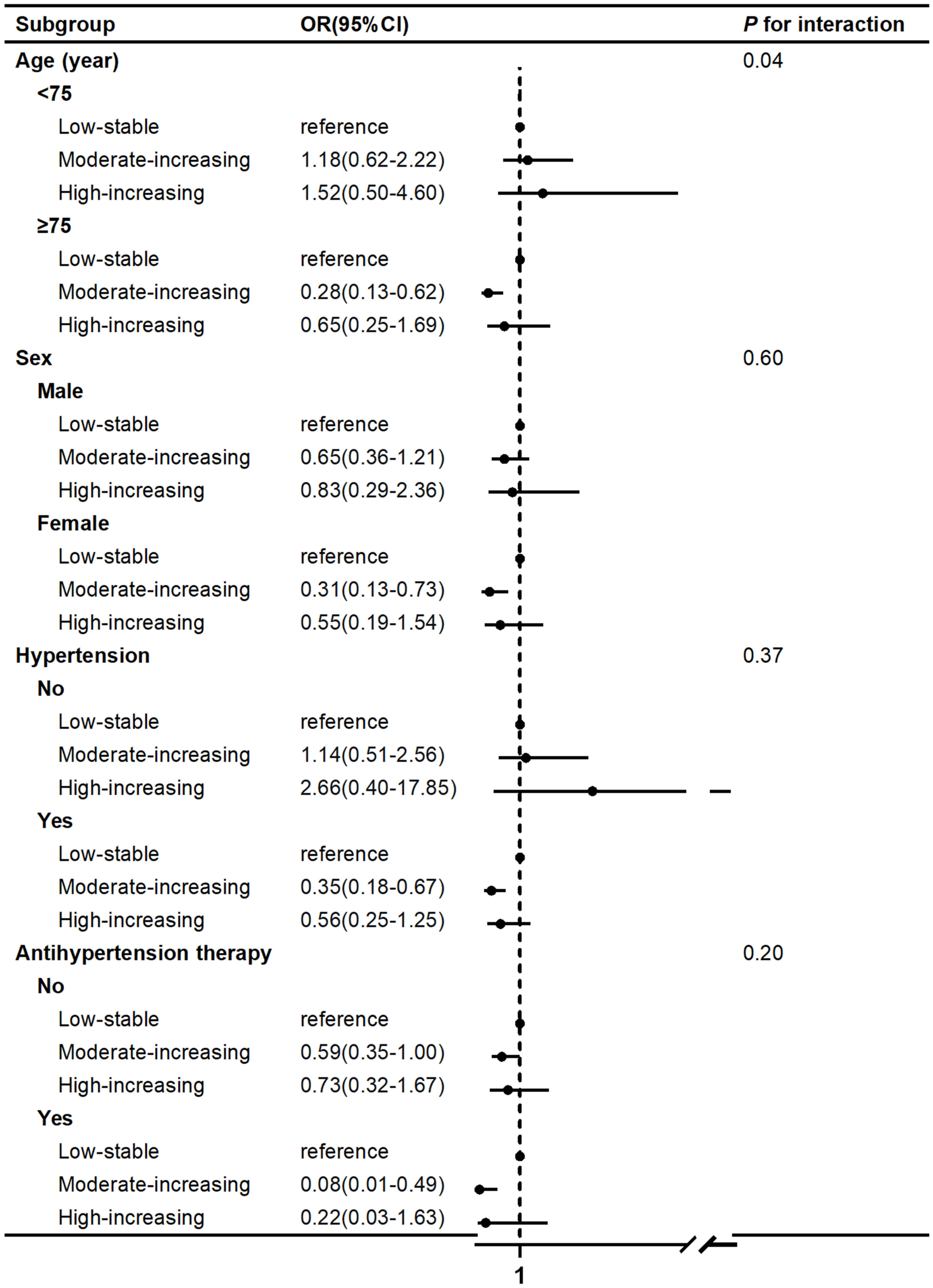

Figure 4 Association of Pulse Pressure Trajectories with 90-day modified Rankin Scale Scores Across Subgroups of Clinical Characteristics.
Notes: Circles represent the odds ratios, and the horizontal lines through them represent the 95% confidence intervals. The vertical reference line indicates an OR of 1. Bolded text for subgroup headers and category names is used solely to improve readability and does not indicate statistical significance.
Abbreviations: OR, indicates odds ratio; CI, confidence interval; Ref., reference.

months, with greater variability corresponding to a stronger association.[25] Another study found in univariable analysis that PPV measures were associated with higher 3-month all-cause mortality (OR=1.37, 95% CI: 1.01–1.85, P=0.04); however, this association did not remain statistically significant after adjustment for potential confounders including age.[26]

Existing research, however, has primarily focused on static measures of PP or variability as a summary measure of dispersion, failing to capture its continuous dynamic evolution over time. In the present study, we employed trajectory modeling for the first time to extend the analysis to continuous dynamic patterns. Notably, we found that not all dynamic patterns were detrimental, moderate-increasing trajectory was associated with favorable outcomes. This suggests that the clinical goal may not be limited to merely lowering PP or reducing its fluctuations, offering a novel strategic perspective

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for post-stroke blood pressure management. More importantly, this study provides the evidence that the association between dynamic pulse pressure patterns and outcomes may be age-dependent. The observed association was largely attributable to patients aged 75 years and older, with no clear pattern detected in younger patients.

The age-stratified effect observed in this study can be plausibly explained by the unique cerebrovascular pathophysiological alterations in the oldest-old.[12,18,19] First, age-related failure of cerebral autoregulation serves as a core mechanism. The aged brain exhibits increased susceptibility to any blood pressure fluctuation and unable to maintain stable perfusion.[5,27,28] Besides, progressive large artery stiffening constitutes another cornerstone. Age is a primary driver of arterial stiffening, whose direct hemodynamic manifestation is widened PP. Evidence indicates that a PP >80 mmHg often signifies severe arterial stiffness and is associated with plaque vulnerability and increased stroke risk.[11,13] So, the moderate-increasing PP trajectory may represent an optimal compromise. It provides sufficient perfusion pressure to avoid hypoperfusion near the lower limit of autoregulation, while its relatively gentle change likely limits insult to the microvasculature. Conversely, younger patients, with preserved vascular compliance and autoregulatory reserve, can tolerate a wider range of PP dynamics, thereby diluting a strong signal between specific trajectories and outcomes.

The strengths of this study include the use of advanced trajectory modeling for dynamic data analysis and the identification of age-related differences in the association between pulse pressure patterns and outcomes via stratification and interaction testing. From a clinical perspective, these findings suggest that attention to dynamic pulse pressure trajectories, in addition to static blood pressure values, may provide additional prognostic information. Based on distinct trajectory patterns, more precise and individualized blood pressure management strategies may be implemented. However, limitations exist. First, as a single-center retrospective study, generalizability may be limited. Multicenter prospective cohorts are needed to validate our findings. Second, the sample size was modest, particularly for the high-increasing trajectory group (n=49), which limited statistical power for subgroup comparisons. Third, despite adjusting for multiple confounders, residual confounding from unmeasured factors, including specific antihypertensive agents and the timing of their administration, cannot be excluded. Fourth, as an observational study, these findings are hypothesis-generating and do not imply causality. Future prospective studies with predefined trajectory targets are warranted.

Conclusions

This study suggests that post-EVT dynamic pulse pressure trajectories are associated with 90-day functional outcome, an association particularly pronounced in patients aged 75 years and older. Given the observational nature of this study, these findings should be considered exploratory and require validation in larger prospective cohorts.

Ethics Statement

This research was approved by the Ethics Committee of Lishui Municipal Central Hospital (Approval No.2025(I)-040-01). Informed consent for the research was obtained from the patients or their legal representative. Proxy consent was obtained from legal representatives for patients lacking consent capacity due to acute neurological deficits such as impaired consciousness, hemiplegia, or aphasia. The guidelines outlined in the Declaration of Helsinki were followed.

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Disclosure

The authors report no conflicts of interest in this work.

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