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Research Article

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Prognostic Value of Visit-to-Visit Blood Pressure Variability for Cardiovascular Events Among Adults with and Without Hypertension: A Systematic Review and Meta-Analysis 2026

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Abstract

Introduction: *Evidence indicates that elevated visit to visit blood pressure variability is associated with adverse cardiovascular outcomes and strongly associated with stroke, coronary heart disease, heart failure, and cardiovascular mortality. Therefore this review is aimed to estimate the prognostic value of visit-to-visit blood pressure variability for cardiovascular outcomes between adults with hypertension and those without hypertension.*

Methods and materials: *A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, the Cochrane Library, and google scholar from database inception to the July 2026. The methodological quality of the included studies was independently assessed by all reviewers using an appropriate Joanna Briggs Institute critical appraisal tool. Meta-analysis was carried out using a random-effects method using the STATA™ Version 14 software.*

Result: *13 studies involving 37, 4342 participants were included in this meta-analysis. The pooled proportion of stroke events was 6.46 % (95% CI: 5.32–7.61) and for death was 9.48 (95% CI: 6.71–12.25) among patients with and without hypertension. The highest pooled mortality proportion was 8.22% (95% CI: −1.24–17.67) among participants with hypertension. Similarly, the highest pooled proportion of stroke events was 2.68% (95% CI: −0.17–5.53) among participants with comorbid stroke and hypertension*

Conclusion: *This systematic review and meta-analysis indicates that greater visit-to-visit blood pressure variability is associated with an increased risk of adverse cardiovascular outcomes and suggests additional prognostic information beyond conventional blood pressure levels. Therefore, standardized measurement is essential to have clinical significance.*

Keywords: *Prevalence, Visit-to-Visit Blood Pressure Variability, Cardiovascular Events among adults, Hypertension, meta-analysis.*

Introduction

Cardiovascular diseases (CVDs) remain a major disease burden and mortality worldwide, placing a substantial burden on individuals, health systems, and societies. Sustained elevated blood pressure (BP) is one of the most important modifiable determinants of cardiovascular risk, and strongly associated with stroke, coronary heart disease, heart failure, and cardiovascular mortality [1-4].

lood pressure is a dynamic physiological parameter that fluctuates over time as a consequence of complex interactions among autonomic regulation, vascular function, neuro-hormonal activity, behavioral factors, medication adherence, and environmental influences [5-7]. Accordingly, repeated BP measurements obtained during routine clinical visits demonstrate substantial variability between visits [8]. It is considered a physiological marker of autonomic nervous system control and has prognostic significance [9].

Evidence indicates that elevated visit to visit blood pressure variability (VVV-BPV) is associated with adverse cardiovascular outcomes [10, 11] and its' prognostic relevance of not limited to individuals with hypertension [12, 13]. Although early evidence demonstrated the associations between BP variability and cardiovascular outcomes among individuals with variability of BP levels [14-16].

Despite increasing of evidences, important uncertainties remain. Previous studies have done on combined heterogeneous populations and cardiovascular outcomes [17], making it difficult to determine whether the prognostic value of VVV-BPV is consistent across specific outcomes such as stroke, myocardial infarction, heart failure, and cardiovascular mortality.

Furthermore, previous reviews have established an overall association between VVV-BPV and cardiovascular risk, there is a need to clarify whether this prognostic association differs between adults with hypertension and without hypertension and suggests that the prognostic significance of BP may extend beyond its average or single-visit value. Also, current hypertension guidelines primarily emphasize the level of BP and achievement of recommended BP targets [18]. Therefore, this systematic review and meta-analysis aims to comprehensively evaluate the prognostic value of visit-to-visit blood pressure variability for cardiovascular events among adults with and without hypertension.

Objectives of the review

- ✓ To estimate the prognostic value of visit-to-visit blood pressure variability for cardiovascular outcomes between adults with hypertension and those without hypertension

Methods and materials

Study design and reporting

This systematic review and meta-analysis were reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) statement [19].

Eligibility criteria

Population- Studies involving adults aged ≥18 years with hypertension, without hypertension, or mixed populations evaluating visit-to-visit variability in systolic blood pressure (SBPV), diastolic blood pressure (DBPV), or overall blood pressure variability.

Outcomes- studies reporting at least one cardiovascular outcome, including cardiovascular mortality, coronary heart disease, myocardial infarction, stroke, and heart failure

Study design- Prospective or retrospective cohort studies, longitudinal observational studies, and secondary analyses of randomized controlled trials with longitudinal follow-up.

Publication status and language- Full-text studies published in peer-reviewed journals, as well as eligible unpublished studies (e.g., preprints, theses, dissertations, and reports), were eligible for inclusion, provided that they were available in English. Whereas studies which evaluate BP variability without reporting cardiovascular outcomes, cross-sectional studies without longitudinal outcome assessment, and case reports, reviews, and conference abstracts without sufficient data is were excluded from this review.

Information sources and search strategy

A comprehensive literature search was conducted in PubMed, Scopus, Web of Science, the Cochrane Library, and google scholar from database inception to the July 31, 2026. Additional studies were identified by screening the reference lists of included studies and relevant systematic reviews and by conducting forward citation tracking of key eligible studies.

The search strategy was combined three major concepts: blood pressure variability, cardiovascular outcomes, and prognosis. Search terms are:- "blood pressure variability," "visit-to-visit variability," "visit-to-visit blood pressure variability," "systolic blood pressure variability," "diastolic blood pressure variability," "cardiovascular events," "cardiovascular mortality," "stroke," "myocardial infarction," "coronary heart disease, " "congestive heart failure," "heart failure," "major adverse cardiovascular events," and "prognosis".

Study selection and data extraction

All identified records were imported into reference management software and duplicate records were removed. All reviewers independently screened titles and abstracts against the predefined eligibility criteria. Potentially eligible studies were undergone full-text assessment. Any disagreement between reviewers during screening resolved through discussion. For studies were consensus cannot be reached, a third reviewer was consulted.

A standardized data-extraction form containing first author name, publication year, study setting; study design, sample size, hypertension status, and cardiovascular events were used. Four reviewers independently extract data from each eligible study.

Outcomes

The primary outcome was cardiovascular events: which include stroke, myocardial infarction, coronary heart disease, heart failure, and cardiovascular death. When a study reports multiple cardiovascular outcomes, each outcome was extracted separately.

Quality assessment of the studies

The methodological quality of the included studies was assessed independently by all reviewers using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for prevalence studies and analytical cross-sectional studies [20]. Discrepancies were resolved through consensus. Studies were categorized as having low, moderate, or high risk of bias based on their overall quality scores.

Data synthesis and meta-analysis

Because substantial clinical and methodological heterogeneity is anticipated across studies, a random-effects model was used as the primary meta-analytic approach. Statistical heterogeneity was assessed using the Cochran Q test and quantified using the I^2 statistic. I^2 values of approximately 25%, 50%, and 75% was interpreted as low, moderate, and high heterogeneity, respectively [21]. Subgroup, sensitivity analyses, and meta-regression were conducted to identify source of heterogeneity.

Potential small-study effects and publication bias was assessed visually using funnel plots and statistically using Egger's regression test. A statistical analysis was conducted using Stata version 14 software. Meta-analytic estimates were presented using forest plots, while funnel plots was used to assess small-study effects.

Result

Study selection and characteristics

According to the PRISMA flow diagram, a total of 4329 records were identified through database searching and other sources. After removing 874 duplicates, 3455 records remained for title and abstract screening. Following screening, 1067 articles were excluded, and 2309 full-text articles were assessed for eligibility. Of these, 2296 studies were excluded due to eligibility criteria and not reporting the outcome of interest. Finally, thirteen studies met the eligibility criteria and were included in the analysis (Fig 1).

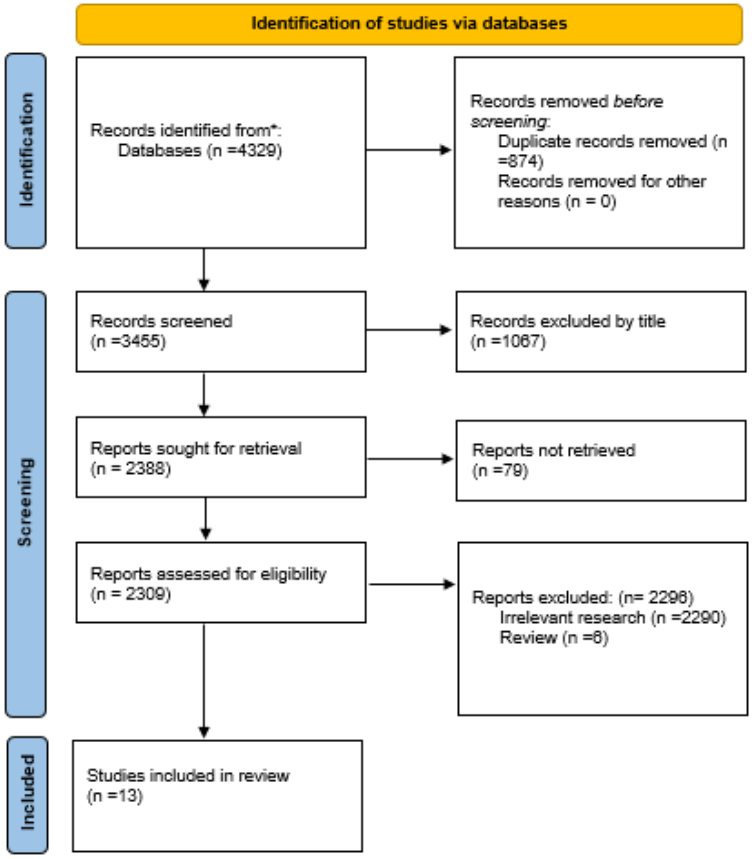

Figure 1: PRISMA flow diagram of study selection for Pooled prognostic value of visit-to-visit blood pressure variability for cardiovascular outcomes.

Thirteen studies [22-34] had a total of 37, 4342 participants and with good methodological quality. The final sample size for these studies ranged from 1877 [26] -118,114 [30]. Most studies were conducted in North America. The highest burden from cardiovascular event was stroke (26%) and Coronary heart disease (CHD) (38%). Most of the studies are population wide studies. From the included thirteen studies, four studies reported MI and coronary heart disease as cardiovascular event (Table 1).

Table 1: characteristics of the study included in systematic review and meta-analysis.

Authors name	Study area	Study design	Sample size	Death 95% CI	Stroke 95%CI	MI 95%CI	CHD 95%CI
Muntner P, (2015)	Multi-nation	Cohort	25814	7(6.68-7.31)	2(1.82-2.17)	-	4(0.3.76-4.23)
Heshmatollah A, (2022)	Netherland	Cohort	9958		9.8(9.21-10.3)	-	-
Suchy-Dicey AM, Wallace ER, (2013)	USA	Cohort	3852	21(19.7-22.2)	5(5.61-4.38)	5(4.31-5.68)	-
Mehlum MH, (2018)	Multination	Cohort	13803	7.9(7.45-8.35)	-	-	11.3(10.7-11.8)
Wu C(2017)	USA	Cohort	1877	11(9.58-12.41)	8(6.77-9.22)	8(6.77-9.22)	-
Rodriguez CJ(2014)	USA	Cross-sectional	4480	-	26(24.71-27.28)	24(22.74-25.25)	-
Fabsitz RR(2025)	USA	Cross-sectional	3352	14.6(13.4-15.7)	5(4.26-5.73)	7(6.13-7.86)	36(34.37-37.62)

Shimbo D(2012)	Multicenter	Cross-sectional	58228	-	1(0.91-1.08)	-	-
Yu JM,(2014)	China	Cohort	118114	-	3(2.90-3.09)	-	-
Dai H, (2017)	China	Cohort	57927	-	1(0.91-1.08)	-	-
Dai L, (2018)	China	Cohort	52387	2(1.88-2.11)	-	-	-
Li HL,(2025)	Taiwan	Cohort	16945	3.4(3.12-3.67)	-	-	-
Liu M, (2022)	USA	Cohort	7605	-	-	-	38(36.90-9.09)

Prognostic value of visit-to-visit blood pressure variability for cardiovascular outcomes

The pooled proportion of stroke events was 6.46 % (95% CI: 5.32–7.61), with substantial heterogeneity among the included studies (I^2 = 99.8%, P < 0.001) among patients with and without hypertension (Figure 2).

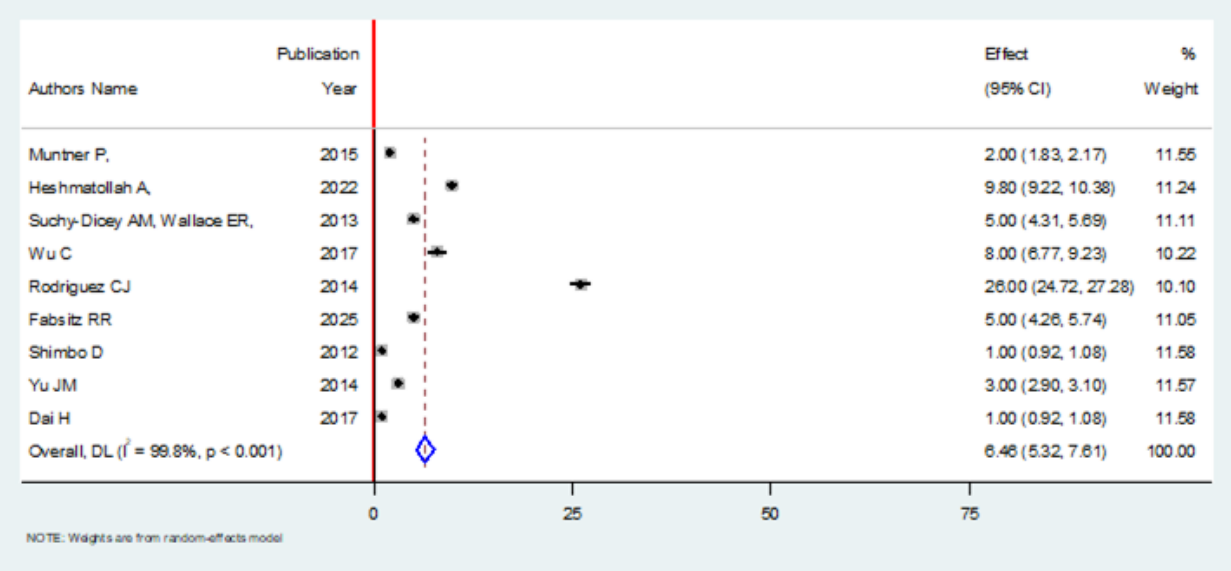

Figure 2: Forest plot showing the pooled prognostic value of visit-to-visit blood pressure variability for stroke.

The pooled effect estimate for death was 9.48 (95% CI: 6.71–12.25), with heterogeneity index across the studies reporting mortality outcomes (I^2 = 99.8%, P < 0.001) among patients with and without hypertension (Figure 3).

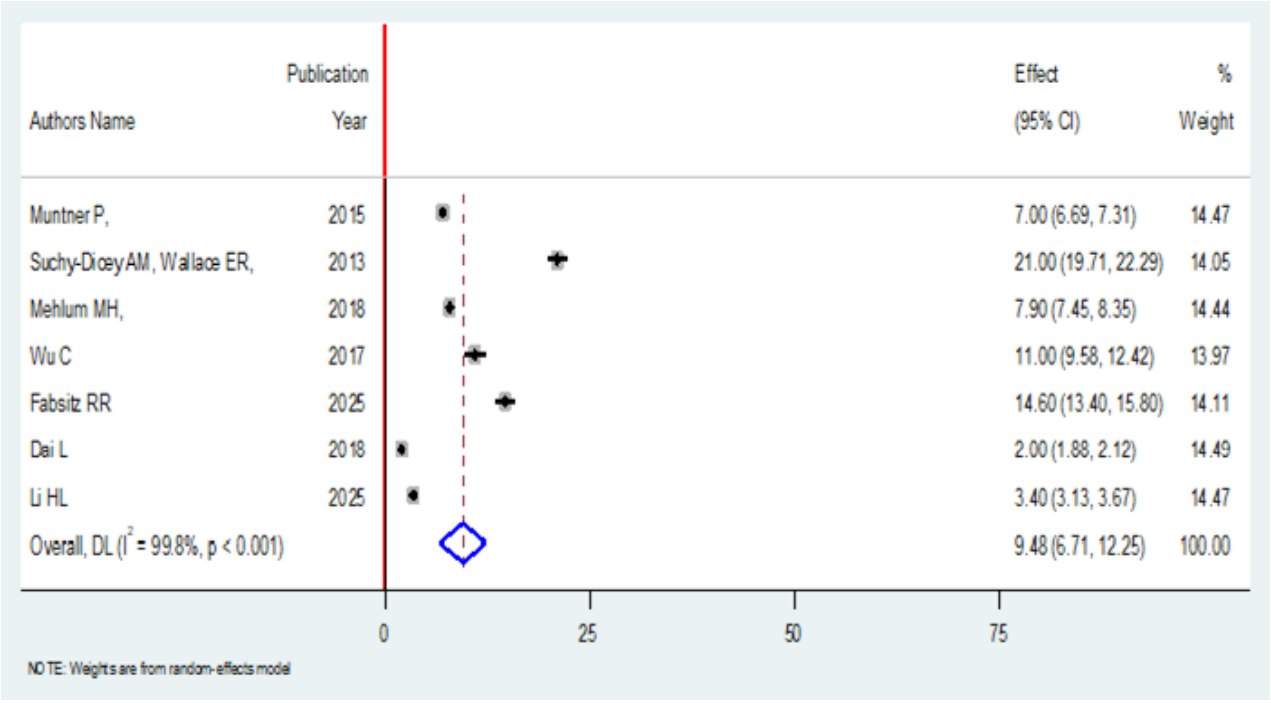

Figure 3: Forest plot showing the pooled prognostic value of visit-to-visit blood pressure variability for cardiovascular death Sub-group analysis.

Subgroup analysis was conducted to assess different cardiovascular events among participants with and without hypertension. Accordingly, the highest pooled mortality proportion was 8.22% (95% CI: −1.24–17.67; I^2 = 0.0%) among participants with hypertension. Similarly, the highest pooled proportion of stroke events was 2.68% (95% CI: −0.17–5.53; I^2 = 0.0%) among participants with comorbid stroke and hypertension (Fig 4 & 5).

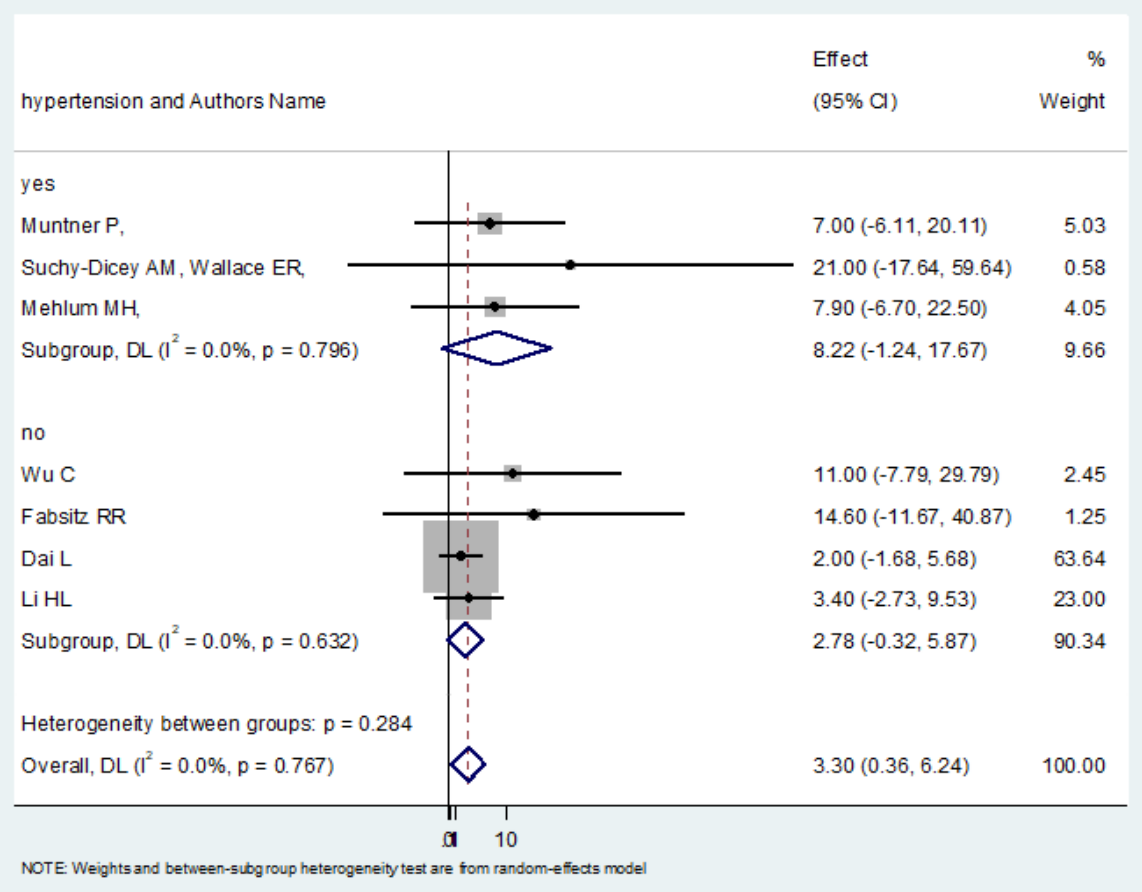

Figure 4: Subgroup analysis of pooled prognostic value of visit-to-visit blood pressure variability for cardiovascular death with and without hypertension.

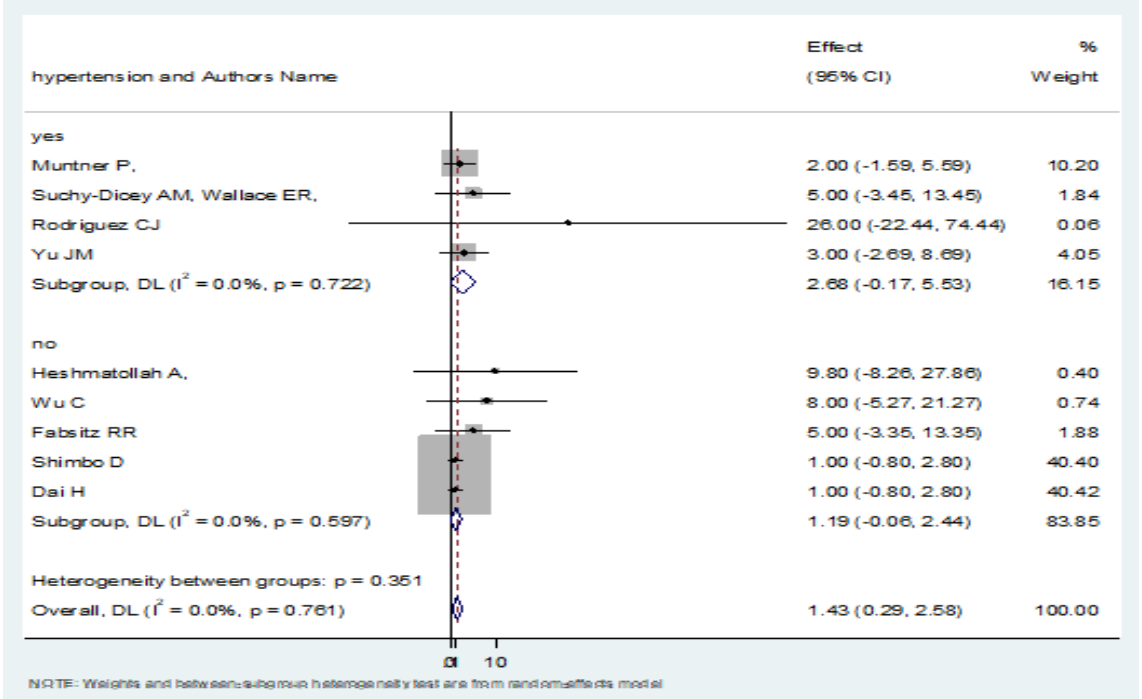

Figure 5: Subgroup analysis of pooled prognostic value of visit-to-visit blood pressure variability for stroke with and without hypertension.

Meta-regression and publication bias

Given the substantial heterogeneity among the included studies (I^2 = 99.8%), meta-regression analyses were performed to investigate whether publication year and sample size explained part of the observed between-study heterogeneity. Neither publication year nor sample size was significantly associated with the pooled estimates. For stroke, the corresponding P-values for sample size and publication year were 0.575 and 0.736, respectively, while for mortality they were 0.396 and 0.203, respectively.

Potential small-study effects and publication bias were assessed using Egger's regression test and visual inspection of funnel plots (Fig 6 &7). Egger's test did not indicate statistically significant funnel-plot asymmetry for stroke (P = 0.151) and mortality egger's regression test demonstrated statistically significant asymmetry (intercept = 0.3565, 95% CI: 0.2045–0.5085; p = 0.001), suggesting the presence of small-study effects and potential publication bias among the included studies. Therefore, Duval and Tweedie's trim-and-fill method was performed to assess the potential influence of publication bias on the pooled estimate. But not significant.

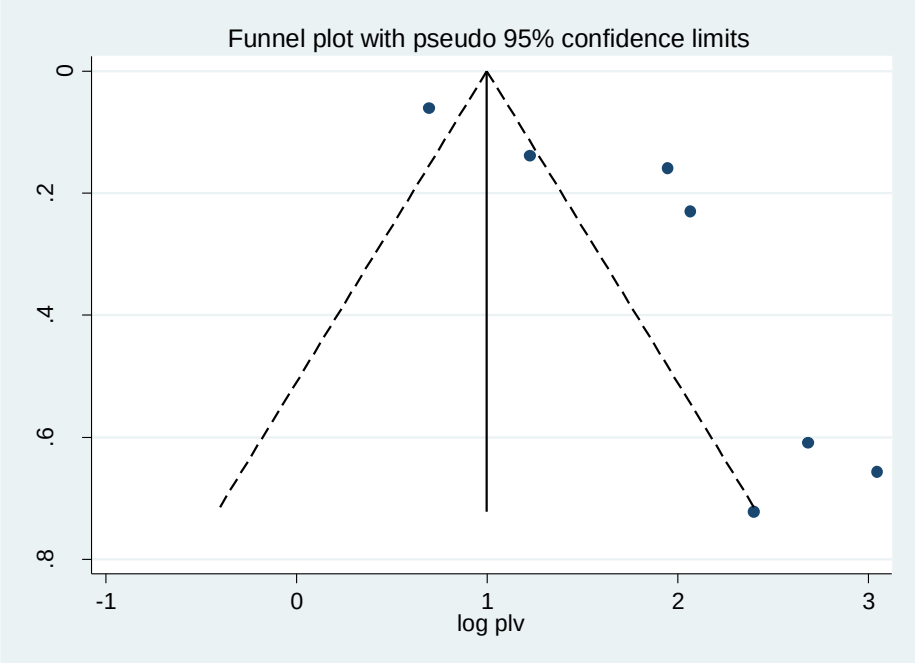

Figure 6: Funnel plot to test publication bias in 7 studies with 95% confidence limits.

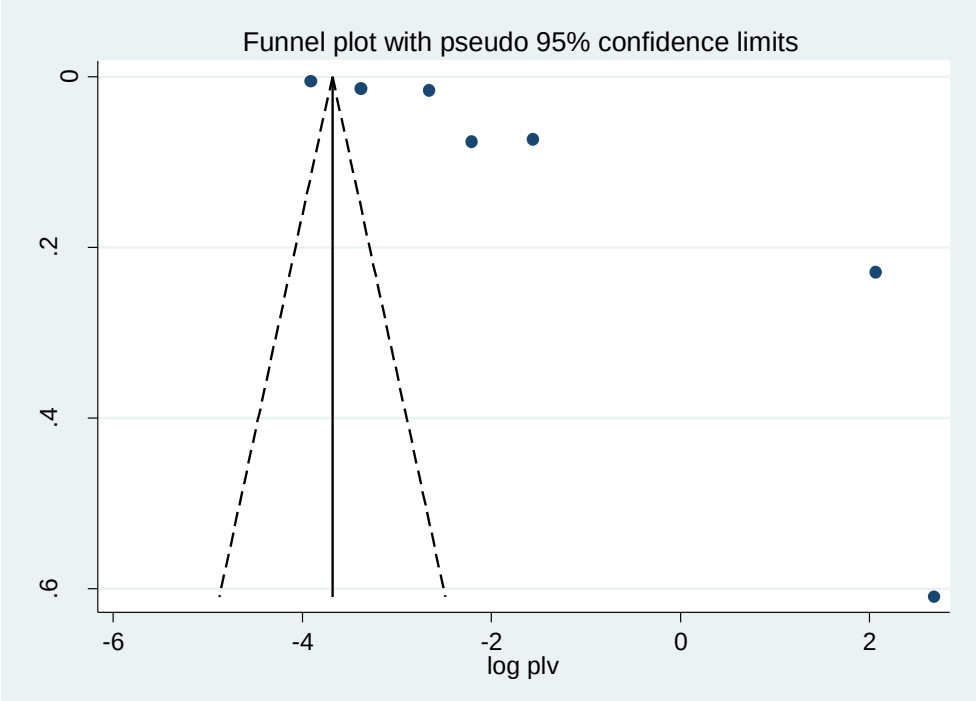

Figure 7: Funnel plot to test publication bias in 8 studies with 95% confidence limits.

Sensitivity analysis

Sensitivity analysis was performed to determine how various sources of uncertainty contribute to the overall uncertainty among the studies, but the results indicated that uncertainty has an insignificant influence on pooled burden (Fig 8).

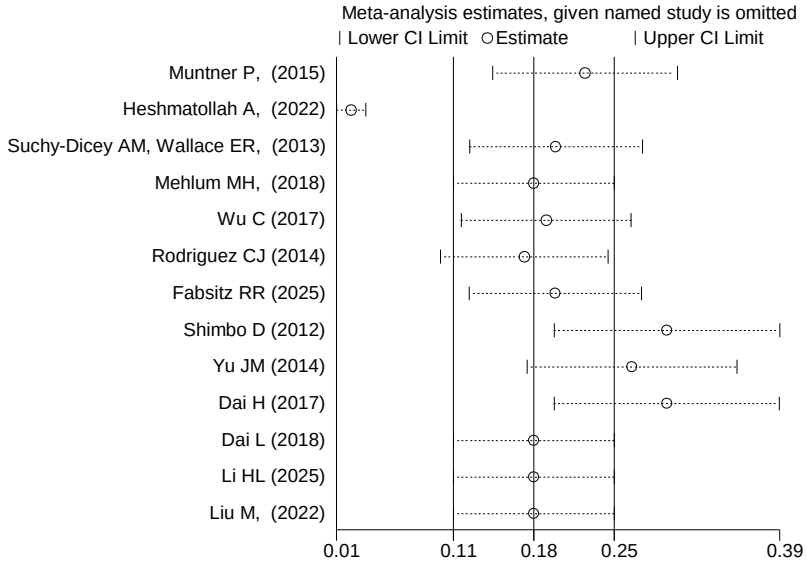

Figure 8: Sensitivity analysis of pooled prognostic value of visit-to-visit blood pressure variability for cardiovascular outcomes for each study being removed one at a time.

Discussion

Studies indicated that visit-to-visit SBPV was associated with an increased risk of stroke, especially in terms of the time of variation: especially long-term, is strongly correlated with a higher risk of ischemic, hemorrhagic strokes, and all cause of mortality and used as a strong predictor for future cardiovascular events in this elderly population [35-38].

In the present meta-analysis, the pooled proportion of stroke events among participants with and without hypertension was 6.46% (95% CI: 5.32–7.61%), while the pooled estimate for death was 9.48% (95% CI: 6.71–12.25%. These findings are consistent with previous evidence demonstrating that visit-to-visit blood pressure variability (VVBPV) is an important predictor of both stroke and mortality [35, 38]. Evidences indicated that repeated variations in blood pressure impose intermittent mechanical stress on the vascular endothelium, promote endothelial dysfunction, arterial remodeling and stiffness, and accelerate atherosclerotic plaque formation and instability. In addition, excessive BP fluctuations may impair cerebral autoregulation, resulting in periods of cerebral hypoperfusion as well as excessive vascular pressure, thereby increasing susceptibility to both ischemic and hemorrhagic cerebrovascular events [39-41].

In the subgroup analysis, the highest pooled mortality proportion was 8.22% (95% CI: −1.24–17.67) among participants with hypertension and the highest pooled proportion of stroke events was 2.68% (95% CI: −0.17–5.53) among participants with comorbid stroke and hypertension. This finding might be explained by the cumulative vascular effects of persistent elevated blood pressure and increased blood pressure variability and blood pressure-related vascular damage to adverse outcomes.

Limitation of the study

This review had the following limitations: - First, the substantial heterogeneity across studies limits the precision of the pooled estimates the results should be interpreted cautiously. The lack of studies from many parts of the world may affect the generalizability of the findings.

Conclusion

This systematic review and meta-analysis indicates that greater visit-to-visit blood pressure variability is associated with the occurrence of adverse cardiovascular outcomes among adults, including those with and without hypertension. The prognostic association appears to be relevant across individual cardiovascular outcomes and suggest that visit-to-visit blood pressure variability may provide additional prognostic information beyond conventional blood pressure levels.

However, differences in blood pressure measurement schedules, follow-up duration, and adjustment for confounding factors across studies may contribute to heterogeneity and limit direct comparability of the evidence. Further well-designed prospective studies using standardized approaches to measuring and reporting visit-to-visit blood pressure variability are necessary to incorporate into routine cardiovascular risk assessment.

Declaration

Ethics approval and consent to participant

Not applicable

Consent for publication

Not applicable

Availability of data and materials

all the data analyzed during the current systematic review and meta-analysis is available with reasonable request from corresponding author.

Competing interests
all the authors declare that they have no competing interests
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