

Systematic Review

Global Prevalence of Isolated Systolic, Isolated Diastolic, and Systodiastolic Hypertension: A Systematic Review and Meta-Analysis

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Abstract

Arterial hypertension (HTN) is a global public health problem with three distinct subtypes: isolated systolic hypertension (ISH), isolated diastolic hypertension (IDH), and systodiastolic hypertension (SDH), each with unique clinical implications. This systematic review and meta-analysis aimed to determine the global prevalence of ISH, IDH, and SDH and their variability. Following PRISMA guidelines, a search was conducted in SCOPUS, Web of Science, PubMed, and EMBASE. A random-effects model with the Freeman-Tukey transformation was used for the meta-analysis, and a meta-regression was performed to assess temporal trends. Twenty-seven studies from five continents were included, revealing pooled global prevalence rates of 10.72% for ISH, 5.07% for IDH, and 11.71% for SDH. Extreme heterogeneity was observed ($I^2 = 100\%$), reflecting substantial methodological diversity. The meta-regression suggested an increasing trend for ISH over time, while non-significant decreasing trends were observed for IDH and SDH. In conclusion, all three HTN subtypes show clinically relevant prevalences, with ISH and SDH being nearly twice as common as IDH. The high heterogeneity underscores the urgent need for research standardization, and these findings highlight the importance of differentiating subtypes for more effective population-level screening and public health planning.

Keywords: hypertension; arterial pressure; prevalence; meta-analysis; epidemiologic factors; public health



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1. Introduction

Arterial hypertension (HTN) is classically defined as systolic blood pressure (SBP) values equal to or greater than 140 mmHg and/or diastolic blood pressure (DBP) values equal to or greater than 90 mmHg, measured repeatedly and in a standardized manner during clinical consultation [1]. HTN is considered one of the main public health problems worldwide, affecting more than one billion people and responsible for a significant percentage of the global burden of morbidity and mortality [2]. HTN contributes to approximately 10.4 million deaths annually and accounts for 7% of global disability-adjusted life years (DALYs) [3]. This significant health burden, combined with its role as the leading modifiable risk factor for cardiovascular disease, stroke, and kidney failure [4,5], positions HTN as a declared priority for health systems worldwide, as reflected in major international

initiatives like the World Health Organization's Global Hearts Initiative and Sustainable Development Goals [6,7].

Within this general spectrum, HTN subtypes are recognized, including isolated systolic hypertension (ISH), which occurs when only systolic blood pressure is elevated; isolated diastolic hypertension (IDH), when only diastolic blood pressure exceeds normal values; and systodiastolic hypertension (SDH), in which both systolic and diastolic pressures are elevated. Each subtype has distinct pathophysiological and clinical implications, underscoring the need for a more detailed approach to their diagnosis and management [8–10].

Despite the clinical relevance of distinguishing between these HTN subtypes, a significant gap remains in the global epidemiological understanding of their relative distributions. A comprehensive review of the literature reveals that while numerous studies (over 14,500 records initially identified in our search) have examined HTN prevalence, fewer than 30 studies have specifically reported differentiated data on all three HTN subtypes using comparable diagnostic criteria. Existing reviews, such as those by Mills et al. [11] and the NCD Risk Factor Collaboration [2], have focused on overall HTN prevalence but have typically failed to differentiate between subtypes. Even specialized studies examining subtypes, such as those by Geldsetzer et al. [12], are limited by their regional focus or lack of meta-analytic synthesis. To our knowledge, no comprehensive systematic review and meta-analysis has previously synthesized the worldwide prevalence of ISH, IDH, and SDH simultaneously, nor examined their geographic variations and temporal trends.

This distinction is critical because each subtype presents different pathophysiological mechanisms, cardiovascular risk profiles, and may respond differently to antihypertensive treatments [8–10]. Recent clinical guidelines, including the 2024 ESC Guidelines [1] and the 2020 International Society of Hypertension Practice Guidelines [8–10], increasingly emphasize the importance of personalized blood pressure management approaches. Yet, specific recommendations for subtype-differentiated care remain limited by insufficient global prevalence data. For instance, ISH predominates in older populations due to arterial stiffening, while IDH is more common in younger individuals with increased peripheral resistance [13]. These differences directly impact treatment decisions; therefore, a global assessment of HTN subtype prevalence addresses a fundamental knowledge gap and provides a foundation for more tailored approaches to HTN management across diverse populations, as called for by contemporary clinical practice guidelines.

As the prevalence of HTN has changed over the last few decades due to multiple demographic and epidemiological factors, it is essential to determine which of these subtypes presents the highest prevalence worldwide [1]. In this context, conducting a systematic review and meta-analysis of the prevalence of HTN by subtype is fundamental to precisely understanding the magnitude of the problem and guiding clinical and public health decision-making. Additionally, examining the sources of variability in prevalence estimates across different populations and study methodologies will provide crucial insights for interpreting these global estimates and informing evidence-based clinical practice.

2. Materials and Methods

2.1. Research Design

A SR with meta-analysis was designed to estimate the prevalence of HTN subtypes worldwide. The review protocol was developed following the guidelines of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), with appropriate adaptations for prevalence reviews [14] (See Supplementary Material S1). The PRISMA 2020 checklist is provided in Supplementary Material S2.

2.2. Search Strategy

A comprehensive literature search was conducted using the following databases: Scopus, Web of Science (including the SciELO catalog, which comprehensively covers Latin American and Caribbean literature), PubMed, and EMBASE. The selection of these sources followed the recommendations of the Cochrane Collaboration, which suggests covering databases with broad coverage of biomedical and health sciences literature. To maximize search sensitivity, terms related to HTN subtypes (“isolated systolic hypertension,” “isolated diastolic hypertension,” “systodiastolic hypertension”) and the outcome of interest (“prevalence”) were included, using Boolean operators (AND, OR) and controlled terms such as Medical Subject Headings (MeSH) in PubMed, adjusting strategies according to the specific syntax of each database. We also included Spanish terms (“hipertensión sistólica,” “hipertensión diastólica,” “hipertensión sistodiastólica”) to capture relevant literature from Spanish-speaking regions. No language restrictions were applied during the search, and we were prepared to translate non-English articles if identified as relevant during the screening process.

Supplementary Material S3 presents the detailed strategy adapted to each platform. It describes the specific search equations used for each database and the justifications for their inclusion in this study.

2.3. Selection Criteria

Inclusion criteria:

- Observational studies, primarily of cross-sectional design.
- Studies were included if they reported prevalence of hypertension subtypes (ISH, IDH, or SDH) based on direct blood pressure measurements.
- Studies where hypertension classification relied on measured blood pressure values rather than self-reported diagnosis or antihypertensive medication use. This criterion was implemented to minimize misclassification bias, as participants on effective antihypertensive treatment may have altered blood pressure profiles that do not reflect their underlying hypertension subtype. Studies that explicitly reported, including only untreated participants, or that did not specify treatment status but used measured blood pressure for classification, were considered eligible.
- Studies using the following standardized cut-off points for HTN subtypes:
 - ISH: SBP $\geq$ 140 mmHg and DBP < 90 mmHg;
 - IDH: DBP $\geq$ 90 mmHg and SBP < 140 mmHg;
 - SDH: SBP $\geq$ 140 mmHg and DBP $\geq$ 90 mmHg.
- Studies with probabilistic or non-probabilistic sampling methods.
- No publication language restrictions.

The 140/90 mmHg cut-off points were selected to ensure consistency with the majority of current international guidelines, including the 2024 ESC Guidelines [1], 2020 International Society of Hypertension Guidelines [10], and most national guidelines. While the 2017 ACC/AHA guidelines use lower thresholds ($\geq$ 130/80 mmHg) [15], the 140/90 mmHg definition remains the global standard adopted by the World Health Organization, European Society of Cardiology, and most international hypertension societies. This approach maximizes the comparability of our results with the largest body of existing literature and ensures global applicability of our findings [8–10].

Exclusion criteria:

- Studies focused on specific subpopulations (pregnant women, individuals with specific comorbidities, or captive groups);
- Case reports, letters to the editor, systematic reviews, and bibliometric reviews;

- Publications without original data;
- Studies not representing the general population.

Rationale for selection criteria: To standardize the comparison of results and consider the consistency in HTN definitions across most international guidelines, except for some, like the 2017 guideline, we chose the aforementioned cut-off points [8–10]. These exclusion criteria were applied for several methodological reasons. First, studies restricted to specific clinical populations—such as pregnant women, or patients with diabetes or chronic kidney disease—were excluded because they do not represent the general adult population. These groups have distinct pathophysiological conditions and clinical management considerations that alter blood pressure patterns and would introduce significant heterogeneity in prevalence estimates, limiting the generalizability of findings to community-dwelling adults. Second, institutional or captive populations (e.g., nursing homes, prisons) typically have different demographic profiles and comorbidity burdens that are not representative of the general community-dwelling population, potentially skewing prevalence estimates. Third, including these specialized populations would complicate the interpretation of results, as the distinctions between HTN subtypes might reflect the underlying condition rather than general population patterns. This approach sought to ensure the consistency and relevance of the data for the prevalence meta-analysis, guaranteeing the comparability of results based on the adopted definition of HTN and maximizing the generalizability of our findings to the broader adult population.

2.4. Study Selection Process

The search strategy was applied to all selected databases (SCOPUS, Web of Science, PubMed, and EMBASE), and the results were exported to the Rayyan program (Cambridge, MA, USA) for management and screening. Three independent reviewers (VJVP, LAMVS, JJBC) simultaneously and masked conducted the initial review of titles and abstracts, that is, without knowing the other reviewer's inclusion or exclusion criteria. Upon completing this phase, the blinding was lifted, and both reviewers compared their decisions.

Discrepancies were debated until a consensus was reached. When an agreement could not be reached, a four-member review panel served as an arbitrator to make the final decision (FEZM). This approach ensured that objectivity and reliability were maintained when selecting relevant articles for subsequent full-text evaluation.

2.5. Risk of Bias Assessment

The risk of bias assessment was conducted independently by three reviewers (VJVP, LAMVS, JJBC) for all studies ultimately included in this systematic review. Any disagreements between reviewers were resolved through discussion, and when consensus could not be reached, a panel of four independent reviewers (FEZM) was consulted to make the final decision. For this purpose, the tool proposed by Munn et al. [16], specifically designed for prevalence studies and widely recognized for its ability to evaluate the methodological quality of this type of design, was used. The reviewers assessed ten specific criteria: (1) sample representativeness of the target population; (2) appropriateness of sampling methods; (3) adequacy of sample size; (4) comprehensive description of subjects and setting; (5) sufficient coverage in data analysis; (6) use of valid methods for condition identification; (7) reliability of condition measurement; (8) appropriateness of statistical analysis; (9) identification of confounding factors; and (10) objective identification of subpopulations.

For each criterion, studies were classified as “Low risk” (criterion fully met), “High risk” (criterion not met), or “Unclear risk” (insufficient information to determine). For example, a study would be rated “Low risk” for sample representativeness if it used a nationally representative sampling frame, “High risk” if it used a convenience sam-

ple without justification, and “Unclear risk” if the sampling frame was not adequately described. Studies with standardized blood pressure measurement protocols, multiple measurements, and validated devices would receive “Low risk” ratings for criteria related to condition measurement.

Subsequently, the number of criteria assessed as “Low risk” was added to obtain an overall score per study. Following the proposed methodology by Munn et al., scores ranging from 0 to 3 were considered to have a high risk of bias, 4 to 6 were considered moderate risk, and 7 to 10 were considered low risk. Any discrepancy in the assessment was resolved through discussion and, when necessary, through the intervention of a third reviewer.

2.6. Statistical Analysis

Quantitative analyses were performed using R statistical software (version 4.2.2) (Vienna, Austria). All statistical analyses were conducted independently by two investigators (VJVP and JJBC) who compared their results to ensure consistency, particularly regarding the degree of heterogeneity. Any discrepancies were resolved through consensus between both reviewers. For the meta-analysis, only studies that provided sufficient data on the prevalence of HTN subtypes, including the total number of participants and the number of cases, were included. The metaprop function from the meta package [17] was used, employing the Freeman–Tukey double arcsine transformation ($sm = “PFT”$) to stabilize the variance of proportions [18]. This transformation was specifically chosen over alternatives, such as the logit transformation, because it performs better for studies with proportions close to 0 or 1, and for studies with small sample sizes, both of which were present in our dataset [19]. The confidence interval (CI) was calculated using the Wilson Score method ($method.ci = “WS”$) [20], which provides more accurate coverage than the Wald method, especially for extreme proportions [21].

Given the expected high degree of heterogeneity among studies, derived from differences in populations, measurement protocols, or diagnostic definitions, a random effects model was applied following the DerSimonian and Laird approach ($method.tau = “DL”$) [22]. This model was selected over a fixed-effects model because it accounts for both within-study and between-study variability, making it more suitable for analyzing studies from diverse settings and populations [23]. While the very high observed heterogeneity ($I^2 = 100\%$) indicates substantial between-study variability, this is not unexpected in prevalence meta-analyses of conditions influenced by multiple demographic, geographic, and methodological factors [24]. Rather than undermining the validity of our approach, this heterogeneity underscores the importance of our stratified analyses and meta-regression by publication year in examining temporal factors contributing to these variations. Meta-regression analysis was limited to publication year due to the remarkable variability and inconsistent reporting of other methodological factors (measurement devices, protocols, age criteria) across studies, which prevented meaningful statistical analysis of these variables.

Heterogeneity assessment was performed through the I^2 statistic and Cochran’s Q test, which the metaprop function automatically estimates. Forest plots were generated to graphically summarize the results of each investigation and the combined global prevalence. Additionally, a stratified meta-analysis was conducted by country to obtain specific regional estimates. No other strata were considered in this study.

3. Results

3.1. Selection of Articles in the Flow Diagram

Initially, 14,500 records were identified through database searches, and this number was reduced to 6898 after removing duplicates. During the screening phase, 6707 records were excluded due to: non-representative populations ($n = 2580$, including patients with

specific comorbidities, pregnant women, pediatric populations, and occupational cohorts); a lack of assessment of HTN subtype prevalence ($n = 1845$, primarily studies reporting only overall HTN without subtype differentiation); ineligible study designs ($n = 1392$, such as reviews, case reports, and intervention studies); or inconsistent diagnostic criteria ($n = 890$, including non-standard blood pressure thresholds or unclear measurement protocols). Of the 191 articles evaluated in full, 163 were excluded mainly due to incomplete subtype data, inability to extract relevant numerators/denominators, or duplicate reporting. Finally, 27 studies were included in both the qualitative and quantitative syntheses [25–51] (distributed according to HTN subtypes: ISH ($n = 27$), IDH ($n = 21$), and SDH ($n = 15$)). For a comprehensive visualization of the selection process and specific exclusion criteria, refer to Figure 1.

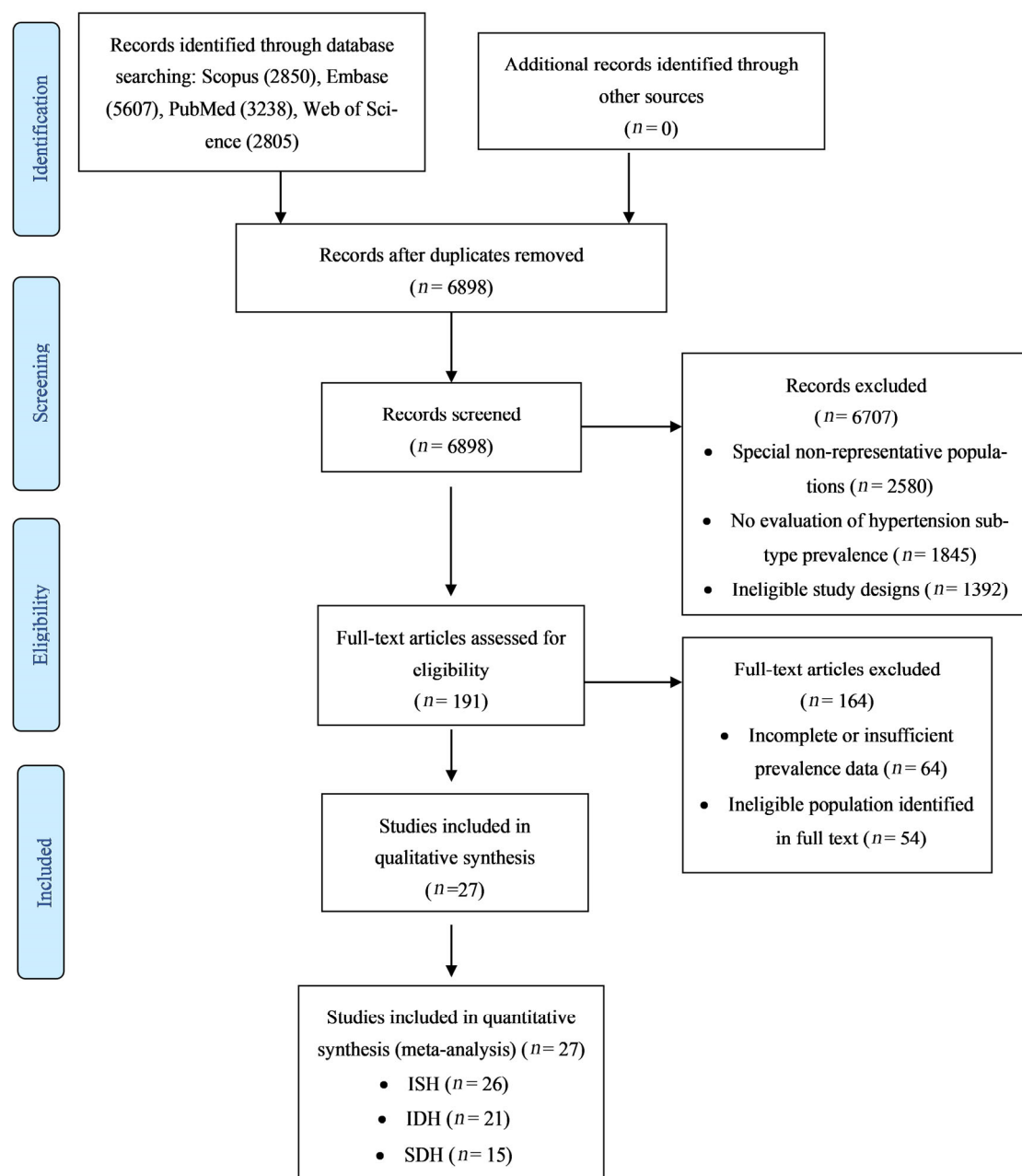


Figure 1. Flowchart of Study Selection.

3.2. Characteristics of Selected Studies

Supplementary Material S4 presents the main characteristics of 27 studies evaluating the prevalence of HTN subtypes. These studies were published between 2002 and 2024, covering five geographical regions: Europe (Italy, The Netherlands), Asia (Iran, China, India, Korea, Vietnam, Saudi Arabia, Bangladesh, Nepal), Africa (Cameroon, Nigeria, Uganda), North America (USA), and South America (Peru), representing a total of 15 countries distributed globally. Most studies are cross-sectional, although some cohort-type studies were also included.

Study population characteristics showed considerable heterogeneity across the included investigations. Most studies used probabilistic sampling for participant selection ($n = 18$, 67%), while nine studies (33%) employed non-probabilistic sampling methods. Age inclusion criteria varied substantially: some studies included broad adult populations starting from 15 or 18 years, while others focused on specific age groups such as adults older than 35, 40, or 65 years. Due to this heterogeneity in age reporting (with some studies providing means, others medians, and others only ranges), calculating a pooled mean age was not feasible. Sample sizes varied considerably, ranging from small studies (109 and 406 participants) to very large population-based samples, with the largest study including over 828,000 individuals from China.

Sex distribution was relatively balanced across studies, with female participation ranging from 23.7% to 67.4% (median: 52.5%). However, three studies did not report the sex distribution. Regarding socioeconomic status and cardiovascular risk factors, the included studies showed substantial variation in reporting approaches. While some studies were conducted in rural settings, others focused on urban populations, and several included mixed populations. Given the inconsistent reporting of socioeconomic indicators and the primary focus on prevalence estimation rather than risk factor analysis, a comprehensive demographic synthesis was not feasible.

Blood pressure measurement protocols varied considerably across studies. Both auscultatory and oscillometric methods were employed, with monitors from reputable brands such as Omron (various models including HEM-7430, HEM-741C, HEM-7051-E), Microlife, UA-767, and Baumanometer being used. Some studies utilized mercury sphygmomanometers while others employed automated digital devices. Measurement protocols ranged from single readings to three consecutive measurements, with approximately 40% of studies not specifying detailed measurement procedures. Several authors provided specific details about cuff size, number of repeated measurements, and intervals between readings, while others referred generically to “standard protocol” or “trained clinical staff.” While all included studies used the 140/90 mmHg cut-off point to define HTN, the referenced guidelines showed diversity, including JNC 7, WHO/ISH, European guidelines, Chinese guidelines, and country-specific recommendations. This methodological heterogeneity in blood pressure assessment likely contributes to the extreme statistical heterogeneity observed ($I^2 = 100\%$) in our meta-analyses.

Regarding bias analysis, most studies obtained a score ranging from 7 to 9, placing them in the low-risk category. This indicates that they presented adequate sampling (generally probabilistic), relatively complete descriptions of the population, appropriate blood pressure measurement methods, and competent statistical analysis. On the other hand, a smaller number of investigations, such as Agrawal (2006) [25], Azantsa (2010) [33], Biswas (2011) [27], Midha (2012) [28], Nhon (2018) [37] and Borah (2020) [43], showed scores of 6 or lower, classifying them at moderate risk. This rating is commonly associated with certain limitations in describing the setting, measurement methodology, or sample coverage. It is worth noting that no study was assigned to the high-risk level (see Supplementary Material S5).

3.3. Meta-Analysis of ISH, IDH, and SDH

In the ISH meta-analysis (Figure 2), where each horizontal line represents an individual study with its 95% confidence interval and the size of squares indicates study weight, the estimated pooled prevalence was 10.72% (95% CI: 8.83–12.76) [25–39,41–51], represented by the diamond at the bottom of the plot. The forest plot reveals considerable heterogeneity among studies ($I^2 = 100\%$; $p < 0.001$). Results by country, grouped in the plot by geographic regions, show significant variations: for example, in The Netherlands, the lowest proportion was observed (2.91%) [36], while in Vietnam, the highest frequency of ISH was reached (31.70%) [33].

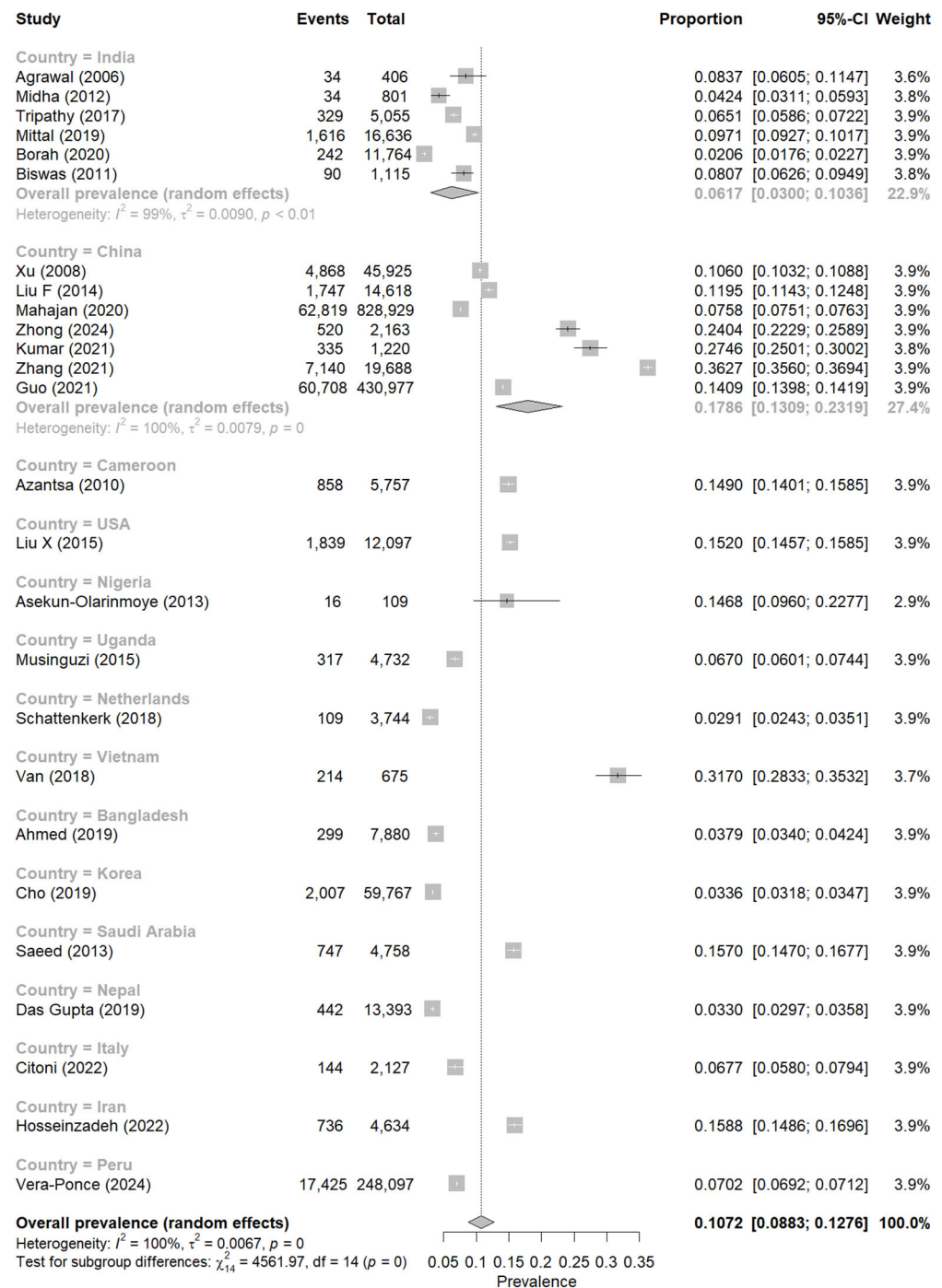


Figure 2. Meta-analysis of the prevalence of ISH.

Regarding the IDH meta-analysis (Figure 3) [25,27–29,32–36,38–44,46,48–51], constructed with the same visual framework where individual study estimates are displayed horizontally with their confidence intervals, the estimated global prevalence was 5.09% (95% CI: 4.13–6.15%), with considerable heterogeneity among studies ($I^2 = 100\%$; $p = 0$). The forest plot visualization highlights marked differences in point estimates at the country level, with values ranging from 1.55% in Peru [51] to 18.38% in Italy [49].

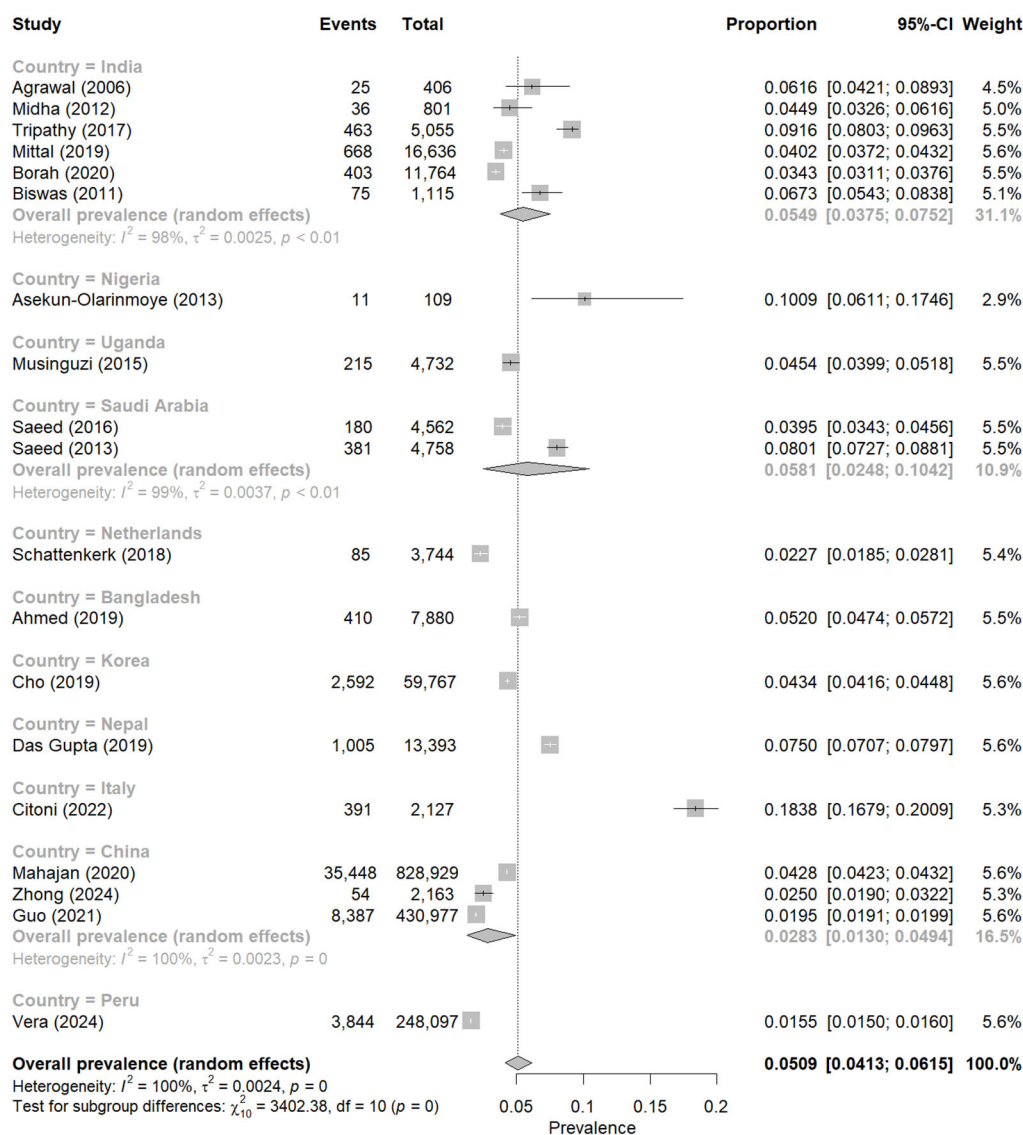


Figure 3. Meta-analysis of IDH prevalence.

On the other hand, in the case of the SDH meta-analysis (Figure 4), the global prevalence was estimated at 11.71% (95% CI: 8.67–15.13%) [27,28,32,36,38–44,46,49–51], also showing considerable heterogeneity ($I^2 = 100\%$; $p = 0$) as visualized by the wide spread of individual study estimates across the plot. At the country level, the forest plot reveals marked differences in the estimates, with values ranging from 3.28% in Peru [51] to 47.25% in Italy [49]. Relatively high prevalences were also recorded in Saudi Arabia (18.10%) [34,40] and some studies in China (16.37% reported by Zhong) [50]. In comparison, significantly lower proportions were found in countries such as Korea (3.48%) (40), Peru (3.28%) [51], and the Netherlands (3.98%) [36].

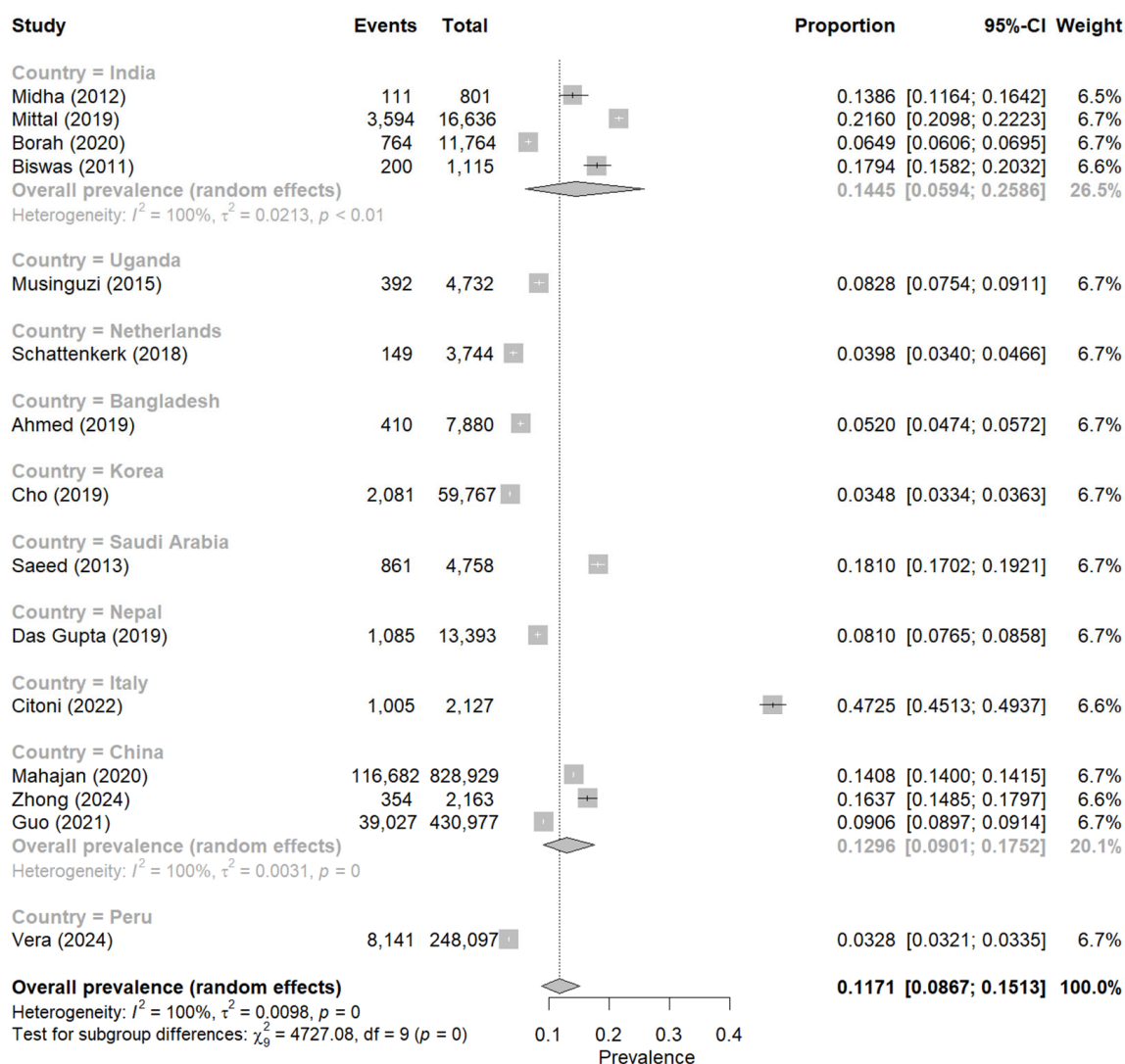


Figure 4. Meta-analysis of the prevalence of SDH.

3.4. Meta-Regression of ISH, IDH, and SDH

The meta-regression performed concerning the year of publication as an explanatory variable for the three HTN subtypes (Figure 5) shows differentiated trends across the three panels (A, B, and C). In these bubble plots, each circle represents a study, with the circle size proportional to study precision. The x-axis represents the publication year, and the y-axis shows the transformed prevalence estimate. For ISH (panel A), a significant increasing trend in reported prevalence over time is observed (red dashed line). In contrast, both IDH (panel B) and SDH (panel C) show decreasing trends over time, although these trends did not reach statistical significance.

There is a wide dispersion around these trends in all cases, reflected in the broad confidence intervals (pink shaded band surrounding the regression line), indicating that estimates differ substantially between different studies. The variable size of the bubbles in the graphs represents the heterogeneity in the sample sizes of the included studies, where some exceed one million participants, contributing to the differentiated precision of the estimates. The slope of each regression line indicates the magnitude and direction of change in prevalence over time for each type of HTN.

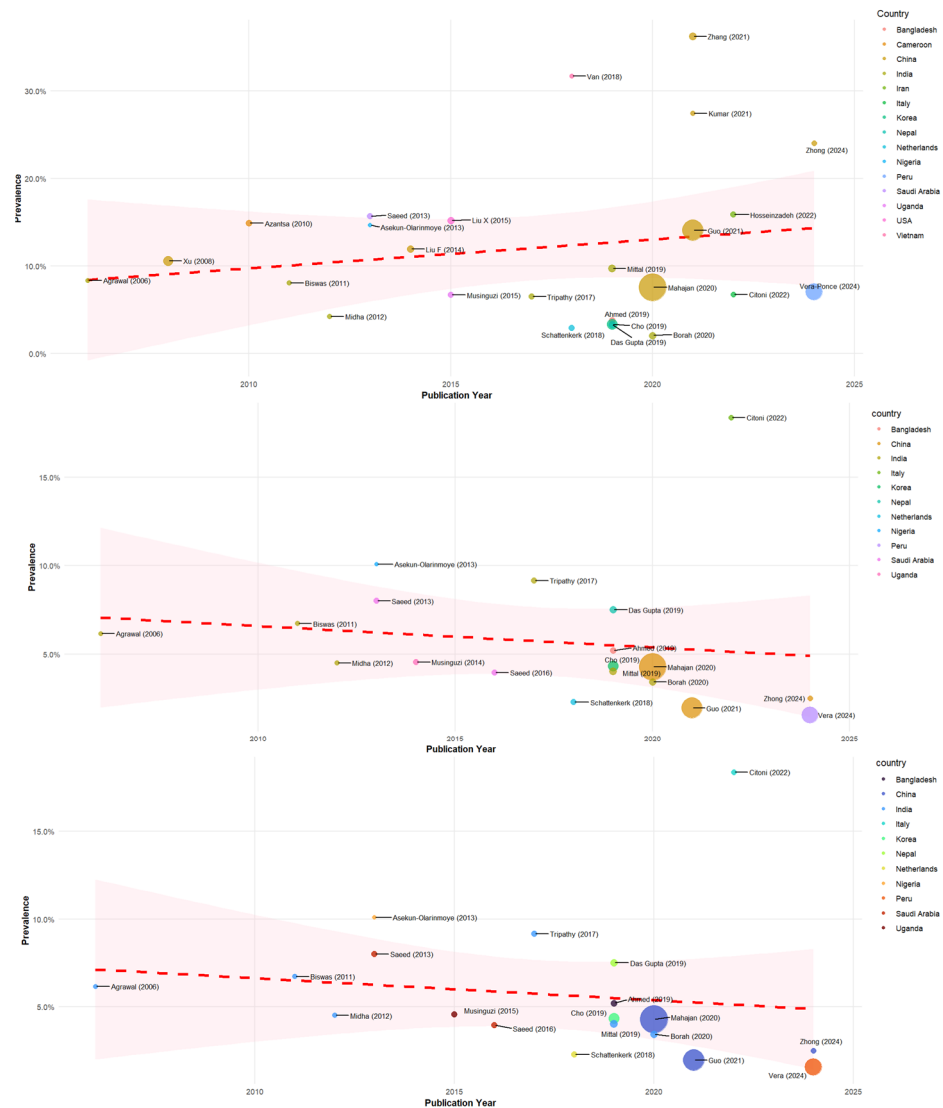


Figure 5. Meta-regression of the prevalence of ISH (top), IDH (middle) and SDH (bottom) Red dashed line shows temporal trend with 95% confidence Interval.

3.5. Publication Bias Assessment

The assessment of publication bias was conducted using funnel plots and Egger's test for each subtype of HTN. Visual inspection of funnel plots (Supplementary Material S6) showed some asymmetry, particularly for the ISH and SDH meta-analyses, suggesting potential publication bias. However, Egger's test did not reach statistical significance for any of the three subtypes (ISH: $p = 0.142$; IDH: $p = 0.253$; SDH: $p = 0.187$). Nevertheless, given the limited power of Egger's test with our sample sizes and the presence of extreme heterogeneity, we cannot definitively rule out the possibility of publication bias affecting our pooled prevalence estimates. The distribution of studies across different sample sizes and prevalence estimates suggests that the observed heterogeneity is more likely due to genuine differences between populations and methodologies rather than selective reporting.

4. Discussion

4.1. Summary of Main Findings

The results of this systematic review with meta-analysis reveal that all three HTN subtypes present relevant proportions within the adult population on a global scale. The three subtypes show similar prevalences, with a slight predominance of ISH and SDH

over IDH. However, marked variability was observed between countries and regions, as evidenced by the different meta-analyses and the high degree of statistical heterogeneity. While we acknowledge the extreme heterogeneity observed ($I^2 = 100\%$), our pooled prevalence estimates represent the best available global synthesis for clinical decision-making. These values, derived from 27 independent population-based studies across five continents, provide clinicians and public health practitioners with essential quantitative data for hypertension subtype management, despite the methodological diversity that characterizes current research in this field.

For this reason, we conducted meta-regression analysis specifically by publication year, as this was the only variable consistently reported across all studies. This analysis revealed distinct temporal trends for each subtype: a significant increase for ISH, while IDH and SDH exhibited non-significant decreasing trends, all with considerable dispersion. These findings address the primary objective of the research globally: to estimate the magnitude of HTN by subtype and identify the differences that exist at an international level, providing an updated perspective that can inform future interventions and health policies.

4.2. Comparison with Previous Literature

Recent research on the epidemiology of HTN has shown the importance of studying this public health problem at a global level. Mills et al. [11] reported that approximately 1.13 billion people suffer from HTN worldwide, with a general prevalence ranging between 30% and 45% of the adult population. Our findings provide a more granular understanding of this overall prevalence by showing that it is composed of distinct subtypes with specific distributions: ISH (10.72%), IDH (5.07%), and SDH (11.71%), totaling a global prevalence of approximately 27.5% across all subtypes. This is somewhat lower than Mills' estimate, potentially reflecting our stricter inclusion criteria, which focus on studies with standardized diagnostic definitions.

The NCD Risk Factor Collaboration [2] documented substantial variations in overall HTN prevalence across regions, ranging from 23.1% to 50.0% in different countries, but without distinguishing between subtypes. Our study not only confirms this regional variability but extends it by demonstrating that the distribution of subtypes also varies significantly by geography. For instance, we found ISH prevalences ranging from 2.91% in the Netherlands to 31.70% in Vietnam, and SDH prevalences ranging from 3.28% in Peru to 47.25% in Italy. These variations likely reflect differences in demographic profiles, particularly age distributions, genetic factors, and lifestyle patterns, across populations.

Geldsetzer et al. [12], in their cross-sectional study of 44 low-income and middle-income countries, found an overall HTN awareness of only 39.2% and treatment rates of 29.9%, suggesting that many cases of HTN subtypes remain undiagnosed. This aligns with our finding that IDH (5.07%) had the lowest global prevalence among subtypes, which might partially reflect underdiagnosis rather than true lower occurrence, as IDH can be asymptomatic and is less frequently screened for in some regions.

Our findings highlight important regional variations in subtype distribution. For instance, we found IDH to be the least prevalent subtype globally (5.07% vs. 10.72% for ISH and 11.71% for SDH), yet our country-specific analyses revealed substantial heterogeneity, with IDH prevalence ranging from 1.55% in Peru to 18.38% in Italy. This geographic variability underscores the significance of population-specific factors in determining the distribution of subtypes and the need for regionally tailored HTN screening and management approaches, as increasingly acknowledged in recent clinical practice guidelines outlined by Whelton et al. [15] and the 2024 ESC Guidelines [1].

4.3. Factors Explaining Variability

The marked heterogeneity observed in the meta-analyses of HTN subtypes reflects both biological and methodological factors. From a pathophysiological perspective, the three subtypes represent distinct hemodynamic profiles that vary systematically with age and vascular health. ISH, characterized by elevated systolic blood pressure with normal diastolic values, predominates in older adults due to progressive arterial stiffening and reduced vascular compliance, which increase pulse wave velocity and systolic pressure while diastolic pressure remains stable or even decreases [52,53]. This age-related arterial remodeling involves structural changes in the vessel wall, including elastin degradation and collagen deposition, which reduce the elastic buffering capacity of large arteries [54]. In contrast, IDH, defined by elevated diastolic pressure with normal systolic values, is more common in younger adults and typically results from increased peripheral vascular resistance in the absence of significant arterial stiffness [55,56]. SDH represents combined elevation of both systolic and diastolic pressures, generally reflecting a more advanced stage of vascular dysfunction with contributions from both increased peripheral resistance and reduced arterial compliance [57]. These pathophysiological distinctions help explain part of the geographic and demographic variability observed across studies, as populations with different age structures and cardiovascular risk profiles naturally exhibit different subtype distributions.

Beyond these biological factors, methodological differences across studies contribute substantially to the observed heterogeneity, despite all included studies using the same diagnostic cut-off point of 140/90 mmHg. The type of device and the blood pressure measurement technique contribute significantly to this variability. While some studies employed mercury auscultatory monitors, others used automatic oscillometric devices with different measurement protocols [58]. This methodological heterogeneity introduces potential differential misclassification bias, as oscillometric devices may systematically overestimate diastolic blood pressure compared to auscultatory methods, potentially leading to higher IDH prevalence estimates in studies using automated devices. The inconsistent reporting of measurement protocols across studies compounds this issue, as each investigation essentially employed different methodological approaches, making direct comparison challenging. Similarly, the number of measurements, the interval between readings, and the patient's position can modify the recorded blood pressure values, generating results that are not comparable between studies if not adequately described [59]. International guidelines have recently emphasized the importance of these methodological considerations to ensure accurate and reproducible measurements [10].

Additionally, the sociodemographic composition and epidemiological particularities of the analyzed populations play a relevant role in the prevalence discrepancies. Factors such as age, sex, body mass index, and the presence of comorbidities, including diabetes or chronic kidney disease, affect the manifestation of HTN and the likelihood that systolic versus diastolic elevation will predominate, or vice versa [2]. For example, in aging populations, arterial stiffness tends to increase, promoting ISH. In contrast, in younger people, IDH is more frequent due to increased peripheral vascular resistance [13]. These differentiated pathophysiological patterns, in part, explain the geographical variability observed in our study.

The methodological heterogeneity is further illustrated in Supplementary Material S4, where we have added columns detailing the specific blood pressure measurement devices and protocols used across studies. This additional information reveals considerable variability, as measurement devices ranged from various Omron models (HEM-7430, HEM-741C, HEM-7051-E) to other brands, including Microlife, UA-767, and Baumanometer. Some studies used mercury sphygmomanometers, while others employed oscillometric devices.

Measurement protocols also differed substantially, with some studies performing single readings while others conducted three consecutive measurements. Approximately 40% of the studies did not specify detailed measurement protocols. This methodological diversity in blood pressure assessment likely contributes significantly to the extreme heterogeneity observed ($I^2 = 100\%$). Although the limited number of studies in each methodological category prevented formal subgroup analyses or meta-regression focused on measurement techniques, the documented variability in measurement approaches provides important context for interpreting the wide range of prevalence estimates across studies.

The meta-regression results reinforce this interpretation by showing divergent temporal trends among HTN subtypes. These differences can be attributed to improvements in health systems and access to diagnosis and treatment, as well as to global changes in lifestyle, including nutritional transitions and accelerated urbanization [2]. The significant increasing trend observed in ISH, contrasting with the non-significant decreasing trends in IDH and SDH, possibly reflect the variable effectiveness of preventive and therapeutic strategies according to the HTN subtype and changes in the cardiovascular risk profiles of different populations [60].

The observed increasing trend in ISH prevalence over time may partially reflect the aging global population and improved detection of systolic hypertension, particularly as healthcare systems have enhanced their focus on cardiovascular screening in older adults over the past two decades [61]. This trend appears consistent with demographic transitions where populations are aging and arterial stiffness becomes more prevalent. In contrast, the non-significant decreasing trends in IDH and SDH could suggest the success of public health interventions targeting modifiable risk factors, such as obesity, physical inactivity, and sodium intake, which tend to affect younger populations where IDH is more prevalent, and comprehensive approaches that address multiple cardiovascular risk factors simultaneously in SDH cases [62]. These interventions may have had a particularly strong impact on peripheral vascular resistance and overall cardiovascular risk management. However, alternative explanations, including changes in diagnostic practices, measurement protocols, or population sampling over time, cannot be ruled out.

However, the wide confidence intervals observed in our meta-regression analyses indicate substantial uncertainty around these temporal trends, and the non-significant nature of IDH and SDH trends suggests that these patterns should be interpreted cautiously [63]. Additionally, the use of publication year as a proxy for data collection period may introduce inaccuracy in temporal estimates, as the lag between data collection and publication can vary across studies. The variability in trends may also reflect differences in healthcare system development, diagnostic practices, and population characteristics across the studies included in our analysis, emphasizing the need for more standardized longitudinal surveillance of hypertension subtypes globally [64,65].

4.4. Clinical and Public Health Implications

The findings of this meta-analysis underscore the epidemiological importance of distinguishing between HTN subtypes in population health surveillance and public health planning. The distinct prevalence patterns observed for ISH, IDH, and SDH across different age groups and geographical regions suggest that each subtype may require consideration of different underlying pathophysiological mechanisms and risk profiles [8–10]. The higher prevalence of ISH in older populations aligns with known age-related vascular changes and arterial stiffness [13], while the distribution of IDH in younger adults corresponds with patterns of increased peripheral vascular resistance reported in previous cardiovascular research [62]. SDH, presenting the highest overall prevalence in our analysis, represents a complex phenotype that may reflect more advanced stages of vascular dysfunction [1,10].

These epidemiological patterns provide a foundation for understanding the population-level burden of different hypertension phenotypes and may inform targeted screening strategies according to age and demographic profiles [15,65].

Furthermore, the distinct prevalence patterns of these HTN subtypes across age groups have important implications for cardiovascular risk assessment and disease prevention strategies. The high prevalence of ISH in older populations, combined with established associations between isolated systolic elevation and arterial stiffness, highlights the need for age-specific screening approaches that recognize the predominance of this subtype in elderly individuals. Similarly, the identification of IDH prevalence patterns in younger adults provides epidemiological context for understanding cardiovascular risk distribution across the lifespan and may inform the design of age-appropriate prevention programs.

From a population perspective, these results suggest the need to design public health strategies that specifically target HTN by subtype. While general interventions (for example, reduction of sodium consumption, increase in physical activity, or weight control) may be beneficial at any age, focusing preventive and screening measures on specific groups—older adults for isolated systolic and younger people for isolated diastolic—contributes to optimizing resource allocation and the impact of interventions.

At the health policy level, decision-makers can support lines of action that promote the standardization of diagnostic methods, health education for different age groups, and continuous epidemiological surveillance of HTN. Given the notorious regional differences evidenced in the meta-analysis, it is essential to adapt prevention and management strategies to local conditions, considering cultural, socioeconomic, and genetic aspects specific to each environment.

Ultimately, the differentiation of HTN subtypes in both clinical and population contexts constitutes a fundamental step in reducing the global burden of cardiovascular diseases. The prevalence patterns identified in this analysis can inform diagnostic priorities and support the development of health policies aimed at blood pressure control, potentially contributing to more effective mitigation of the negative consequences associated with HTN in terms of quality of life and healthcare costs. Therefore, this integrated and specific vision of each HTN subtype contributes to evidence-based planning for more efficient and equitable management of a condition that remains a major challenge in public health.

Finally, it is important to note that while our analysis focused on the general adult population to establish reference prevalence estimates for hypertension subtypes, future research examining these subtypes in specific clinical populations could provide valuable insights. For instance, comparative studies in pregnant women, patients with diabetes, or those with chronic kidney disease may reveal distinct epidemiological patterns and help elucidate pathophysiological mechanisms underlying subtype distribution in these groups. Such investigations would complement our findings by characterizing how comorbid conditions modify the natural history and prevalence of isolated systolic, isolated diastolic, and systolic-diastolic hypertension. We encourage researchers to conduct dedicated systematic reviews or primary studies in these populations as they represent important research priorities.

4.5. Strengths and Limitations

One of the main strengths of this systematic review with meta-analysis lies in the broad geographical and demographic coverage of the included studies, which offers a global panorama of the prevalence of HTN subtypes. Likewise, prestigious databases were utilized, following the recommendations of the Cochrane Collaboration and the PRISMA guidelines adapted for prevalence studies, to ensure an exhaustive search and a transparent methodology. On the other hand, using a risk of bias assessment tool specifically designed

for prevalence studies provides greater rigor in assessing the methodological quality of primary studies.

However, this work also presents limitations that should be considered when interpreting the findings. Firstly, the protocol for this systematic review was not prospectively registered in a public repository such as PROSPERO. The absence of a pre-published protocol may increase the risk of selective reporting. However, given that this is a prevalence study focused on a descriptive estimate, the risk of biasing results toward a specific outcome is arguably lower than in reviews of interventions, where multiple outcomes might be compared. Nevertheless, to mitigate this concern, we have adhered strictly to the PRISMA guidelines throughout the review process. The high heterogeneity among studies may affect the precision of global estimates, as various diagnostic definitions, blood pressure measurement protocols, and population profiles were employed. In addition, the inclusion of observational studies with sometimes incomparable designs, and the fact that some reports did not provide detailed descriptions of their methodology (for example, the number of measurements, cuff size, or intervals between readings), make stricter comparisons difficult. Additionally, while statistical tests for publication bias were not significant, the limited number of studies for each subtype and extreme heterogeneity may have reduced our ability to detect publication bias, which remains a potential concern.

An important limitation is the lack of age-standardized prevalence estimates. HTN subtypes show strong age dependency, with isolated systolic hypertension being more prevalent in older adults and isolated diastolic hypertension in younger populations. Although we conducted subgroup analyses by age categories when data were available, the heterogeneity in age reporting across studies precluded comprehensive age adjustment. Furthermore, publication year was used as a proxy for data collection period in the meta-regression analyses, which may not accurately reflect true temporal trends due to variable lags between data collection and publication. Additionally, the included studies did not systematically differentiate between primary and secondary hypertension; however, given that secondary hypertension accounts for less than 10% of all cases and population-based studies do not routinely perform the diagnostic workup required to identify secondary causes, our findings predominantly reflect primary hypertension. These limitations highlight the need for future prevalence studies to adopt standardized reporting practices, including age-stratified data presentation and clear documentation of data collection periods, to improve the precision and comparability of global burden estimates.

5. Conclusions

In conclusion, this systematic review and meta-analysis provides a comprehensive synthesis of hypertension subtype prevalence across five geographical regions (Europe, Asia, Africa, North America, and South America), demonstrating that ISH (10.72%, 95% CI: 8.83–12.76), IDH (5.07%, 95% CI: 3.43–6.96), and SDH (11.71%, 95% CI: 8.67–15.13) collectively represent distinct epidemiological entities with substantial global burden. The key finding is that all three subtypes show clinically relevant prevalences, with ISH and SDH being approximately twice as prevalent as IDH globally. Importantly, we identified divergent temporal trends: ISH prevalence shows an increasing trend over time, while IDH and SDH show non-significant decreasing trends, indicating evolving epidemiological patterns that require subtype-specific public health responses. The extreme heterogeneity observed ($I^2 = 100\%$) underscores the critical need for methodological standardization in hypertension subtype research. While our findings provide valuable insights across multiple continents, future research should include greater representation from underrepresented regions such as Oceania to achieve truly comprehensive global coverage.

Based on these epidemiological findings, we recommend several priority areas for public health action and future research: development of standardized surveillance systems to monitor temporal trends in hypertension subtypes and better understand the drivers of observed prevalence patterns; implementation of uniform blood pressure measurement protocols following current international guidelines to address the extreme methodological heterogeneity observed in current research; establishment of age-stratified screening programs that recognize the differential distribution of subtypes across age groups (ISH predominating in older adults, IDH in younger populations, and SDH across the lifespan); design of longitudinal cohort studies to track natural history and transitions between subtypes, particularly factors associated with progression to combined systolic-diastolic elevation; expansion of prevalence research to underrepresented geographical regions, particularly Oceania and undersampled areas within represented continents; and adaptation of public health strategies to account for documented regional variations in subtype distribution, considering local demographic, cultural, and socioeconomic contexts. These epidemiologically informed priorities can guide resource allocation and policy development to address the substantial and heterogeneous global burden of hypertension subtypes.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/cardiovascmed28010003/s1>, S1: Review protocol with detailed methodology and analysis plan; S2: PRISMA 2020 checklist and flow diagram for study selection; S3: Full search strategies for PubMed, Scopus, Web of Science (including SciELO), and EMBASE, including search strings, filters, and execution dates; S4: Characteristics of included studies; S5: Risk of bias assessment for included studies; S6: Funnel plots, sensitivity analyses, and additional forest plots.

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