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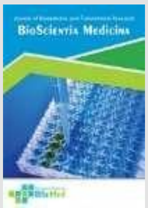

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# Impact of Exercise Modalities on Blood Pressure, Cardiorespiratory Fitness, and Resting Heart Rate in Hypertension: A Meta-Analysis

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**A B S T R A C T**

**Background:** Hypertension represents a critical global health challenge and a leading modifiable risk factor for cardiovascular morbidity and mortality. Sedentary behavior is a significant contributor to its prevalence. While exercise is a cornerstone of hypertension management, the comparative efficacy of different exercise modalities—aerobic training (AT), resistance training (RT), and combination training (CT)—on key cardiovascular parameters requires continued synthesis. This meta-analysis aimed to quantitatively evaluate the impact of AT, RT, and CT on systolic blood pressure (SBP), diastolic blood pressure (DBP), cardiorespiratory fitness (CRF) assessed via maximal oxygen consumption ($VO_2max$), and resting heart rate (RHR) in adults with hypertension. **Methods:** Following PRISMA guidelines, a systematic search was conducted across PubMed, Cochrane Library, and ScienceDirect databases for randomized controlled trials (RCTs) published between January $1^{st}$, 2014, and January $1^{st}$, 2025. Inclusion criteria encompassed RCTs involving adults diagnosed with hypertension undergoing AT, RT, or CT interventions for at least 8 weeks, reporting changes in SBP, DBP, $VO_2max$, or RHR. Two independent reviewers performed study selection, data extraction, and quality assessment using the Cochrane Risk of Bias tool. Standardized mean differences (SMD) with 95% confidence intervals (CI) were pooled using random-effects models due to anticipated heterogeneity. Heterogeneity was assessed using the $I^2$ statistic. **Results:** Seven RCTs, encompassing 410 participants with hypertension, met the inclusion criteria. The included studies were predominantly parallel-group RCTs, with durations ranging from 8 to 16 weeks. Meta-analysis indicated that AT resulted in a statistically significant overall reduction in blood pressure compared to RT (Overall BP SMD: -2.55; 95% CI: -4.97, -0.13; $p = 0.04$). Furthermore, AT demonstrated significantly greater improvements in $VO_2max$ (SMD: -4.84; 95% CI: -7.00, -2.68; $p < 0.0001$) and RHR (SMD: -3.08; 95% CI: -4.75, -1.42; $p = 0.0003$) compared to RT. The overall pooled effect for $VO_2max$ and RHR combined significantly favored AT (Overall SMD: -3.74; 95% CI: -5.06, -2.42; $p < 0.00001$). Limited data (two studies) suggested that combination training might offer superior blood pressure reduction compared to RT and potentially AT, but these findings require cautious interpretation due to the small number of studies. Significant heterogeneity was observed in the blood pressure analyses ($I^2 > 88\%$), whereas heterogeneity was low to moderate for $VO_2max$ and RHR analyses. **Conclusion:** This meta-analysis indicated that aerobic training provided superior benefits in reducing overall blood pressure, improving cardiorespiratory fitness ($VO_2max$), and lowering resting heart rate compared to resistance training alone in adults with hypertension. Combination training showed potential, particularly for blood pressure control, warranting further high-quality research with larger sample sizes. These findings underscore the importance of incorporating structured exercise, particularly aerobic training, into comprehensive hypertension management strategies.

## 1. Introduction

Hypertension, characterized by the persistent elevation of arterial blood pressure, is a paramount global public health issue and a leading modifiable risk factor for a spectrum of cardiovascular diseases (CVD), including stroke, chronic kidney disease, and premature mortality worldwide. The prevalence of hypertension is staggering, with estimates suggesting that over 1.2 billion adults globally are affected by the condition. Moreover, projections indicate a continued rise in these numbers, driven by factors such as aging populations and the increasing prevalence of obesogenic environments and sedentary lifestyles. The impact of hypertension extends beyond individual health, contributing to approximately 10.4 million deaths annually and imposing substantial economic burdens on healthcare systems and societies due to direct medical costs and indirect costs linked to reduced productivity. Despite significant advancements in pharmacological therapies aimed at lowering blood pressure, achieving optimal control remains a challenge in many populations globally. This highlights the crucial importance of effective non-pharmacological strategies, which play a vital role both in the primary prevention of hypertension and as an adjunctive treatment approach. The pathophysiology of essential hypertension, the most common form of the condition, is complex and multifactorial. It involves intricate interactions between genetic predisposition and various environmental factors. Several key mechanisms contribute to the development and progression of hypertension, including overactivity of the sympathetic nervous system, activation of the renin-angiotensin-aldosterone system (RAAS), endothelial dysfunction, vascular remodeling, inflammation, and impaired sodium excretion. Lifestyle factors exert a substantial influence on these pathophysiological pathways. Physical inactivity, or a sedentary lifestyle, has been unequivocally identified as a major contributor to both the development and progression of hypertension. In addition to physical inactivity, other modifiable risk factors that significantly influence hypertension risk include unhealthy dietary patterns (characterized by high sodium, low potassium, and high saturated fat intake), obesity, excessive alcohol consumption, and smoking. Addressing these lifestyle components, with a particular emphasis on increasing physical activity levels, is of paramount importance in the effective management of hypertension.[1-3]

The beneficial effects of regular physical activity on cardiovascular health are well-established and widely recognized. Exercise interventions are therefore recommended by major international guidelines as a primary non-pharmacological treatment modality for hypertension. Regular exercise exerts its antihypertensive effects through a multitude of favorable physiological mechanisms. These mechanisms include improvements in endothelial function, characterized by enhanced nitric oxide bioavailability, a reduction in sympathetic nervous system activity, modulation of the renin-angiotensin-aldosterone system (RAAS), a decrease in systemic vascular resistance, improved insulin sensitivity, reduction in inflammation, and favorable alterations in body composition. Historically, aerobic training (AT) has been the most frequently and widely recommended exercise modality for the control and management of blood pressure. Aerobic training is characterized by activities that involve large muscle groups, performed rhythmically and sustained over a prolonged period. Common examples of aerobic exercise include walking, jogging, cycling, and swimming. This form of exercise primarily challenges the cardiorespiratory system, leading to significant improvements in maximal oxygen consumption ($VO_2max$), a key indicator of cardiorespiratory fitness (CRF). Furthermore, aerobic training has been consistently shown to result in reductions in resting heart rate (RHR). In contrast to aerobic training, resistance training (RT) involves muscular contractions against external resistance. This external resistance can take various forms, such as weights, resistance bands, or even the individual's own body weight. Traditionally, resistance training has been primarily focused on enhancing musculoskeletal health, leading to improvements in strength, power, and bone density. However, a growing body of evidence suggests that resistance training also provides significant cardiovascular benefits. These benefits include potential reductions in blood pressure, although the magnitude of these effects in comparison to aerobic training has been a subject of ongoing debate and investigation. The mechanisms through which resistance training may influence blood pressure regulation are complex and may involve transient increases in shear stress during post-exercise hyperemia, as well as potentially distinct neurohumoral adaptations compared to aerobic training.[4-6]

Combination training (CT) represents an exercise approach that integrates both aerobic training and resistance training within the same exercise program. The rationale behind combination training is to potentially accrue the benefits of both exercise modalities. It is theorized that combination training could offer superior overall health benefits by simultaneously addressing both cardiorespiratory and musculoskeletal fitness components. This comprehensive approach has the potential to lead to synergistic effects on blood pressure control and other cardiovascular risk factors. However, the evidence directly comparing the efficacy of combination training against aerobic training and resistance training alone, specifically in relation to blood pressure, $VO_2$max, and resting heart rate in individuals with hypertension, has been relatively limited. While a substantial number of studies have explored the effects of various types of exercise on hypertension, there remain uncertainties and gaps in our understanding regarding the optimal exercise modality for maximizing improvements in key cardiovascular health markers. Many previous meta-analyses in this field have often focused solely on blood pressure as the primary outcome or have limited their comparisons to only two exercise modalities. Therefore, there is a clear need for synthesizing the most current evidence derived from randomized controlled trials (RCTs) that directly compare aerobic training, resistance training, and combination training. Such a synthesis is crucial for informing clinical practice and the development of evidence-based exercise prescription guidelines tailored to individuals with hypertension. In light of these existing knowledge gaps and the need for a comprehensive evaluation of exercise modalities in hypertension management, this systematic review and meta-analysis was designed and conducted.[7-10] The primary aim of this study was to quantitatively compare the effects of aerobic training, resistance training, and combination training on changes in systolic blood pressure (SBP), diastolic blood pressure (DBP), maximal oxygen consumption ($VO_2$max), and resting heart rate (RHR) in adults diagnosed with hypertension. By rigorously synthesizing the available evidence, this meta-analysis seeks to provide valuable insights for clinicians and individuals in the management of hypertension through exercise interventions.

**2. Methods**

This systematic review and meta-analysis was meticulously designed and conducted in strict adherence to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The PRISMA guidelines are an evidence-based set of recommendations for reporting systematic reviews and meta-analyses, aimed at improving the transparency and completeness of reporting. A detailed protocol, established a priori, served as the roadmap for the entire review process. This protocol provided a comprehensive outline of the study's objectives, the detailed search strategy, the specific inclusion and exclusion criteria for study selection, the standardized data extraction procedures, the methods employed for quality assessment, and the planned statistical analyses. Establishing this protocol beforehand is a critical step in ensuring the rigor and minimizing potential bias in the review process.

The studies considered eligible for inclusion in this meta-analysis were carefully selected based on predefined criteria, derived from the PICOS framework. The PICOS framework is a widely used tool that helps to structure and define the key elements of a research question and, consequently, the eligibility criteria for a systematic review. It encompasses the following components; Participants (P): The participants included in the studies had to be adult humans, aged 18 years or older, diagnosed with hypertension. Hypertension was defined according to the criteria used by the authors of the individual studies. These definitions typically included a systolic blood pressure (SBP) of 140 mmHg or greater, or a diastolic blood pressure (DBP) of 90 mmHg or greater, or the use of antihypertensive medication. This criterion ensured that the meta-analysis focused specifically on the population of interest – individuals with hypertension. Studies that included participants with prehypertension alongside hypertensive individuals were also considered for inclusion. However, in such cases, studies were only included if data specific to the hypertensive participants could be extracted separately or if the majority of the study population had a diagnosis of hypertension. This approach allowed for the inclusion of relevant studies while maintaining a focus on the target population; Interventions (I): The interventions of interest were structured exercise training programs that involved either aerobic training (AT), resistance training (RT), or combination training (CT). Aerobic training (AT) encompasses exercise modalities that primarily utilize aerobic metabolic pathways to produce energy. These typically involve continuous, rhythmic activities using large muscle groups, such as walking, jogging, cycling, and swimming. Resistance training (RT) involves exercises where muscles contract against external resistance, which can be provided by weights, resistance bands, or bodyweight. Combination training (CT) refers to exercise programs that incorporate both aerobic training and resistance training within the same training regimen. To allow for comparisons between different exercise approaches, studies were required to compare at least two of these exercise modalities. The comparisons of interest were: AT versus RT, AT versus CT, RT versus CT, or AT versus RT versus CT; Comparators (C): The comparator groups of interest were other eligible exercise modalities (AT, RT, or CT) or a non-exercise control group. While the primary focus was on comparing the effects of different exercise modalities, studies that included a non-exercise control group ( usual care, sedentary control) were also noted. However, the presence of a control group was not a strict requirement for inclusion, as the main objective was to compare the relative effectiveness of the different exercise interventions; Outcomes (O): Studies were required to report quantitative data on the change from baseline (or provide post-intervention values that allowed for the calculation of change) for at least one of the pre-specified primary or secondary outcomes. The primary outcomes of interest were the change in systolic blood pressure (SBP) and the change in diastolic blood pressure (DBP). Blood pressure measurements could be obtained using office-based methods or ambulatory blood pressure monitoring. The secondary outcomes included the change in maximal oxygen consumption ($VO_2max$ or $VO_2peak$, used interchangeably as a measure of cardiorespiratory fitness (CRF)) and the change in resting heart rate (RHR); Study Design (S): The eligible study design for inclusion in the meta-analysis was randomized controlled trials (RCTs). RCTs are considered the gold standard in research methodology as they minimize bias and allow for stronger causal inferences compared to other study designs. While observational studies were initially considered during the search phase, only RCTs were ultimately included in the meta-analysis to ensure the highest possible quality of evidence; Intervention Duration: A minimum intervention duration of 8 weeks was established. This criterion was set to ensure that the included studies allowed for sufficient time for physiological adaptations to occur as a result of the exercise interventions.

Studies were excluded from the meta-analysis if they met any of the following criteria; Studies that were not randomized controlled trials (non-RCTs) were excluded from the final analysis. This decision was made to maintain the methodological rigor of the meta-analysis by including only studies with the strongest level of evidence; Abstracts, review articles, editorials, case reports, animal studies, or in vitro studies were excluded. These types of publications do not provide original data or lack the methodological rigor required for inclusion in a meta-analysis; Studies that did not include participants with hypertension were excluded. This criterion ensured that the meta-analysis focused specifically on the population of interest; Studies that did not compare the relevant exercise modalities (AT, RT, CT) were excluded. This was essential for addressing the research question, which focused on the comparative effectiveness of different exercise types; Studies with an intervention duration of less than 8 weeks were excluded. This criterion ensured that only studies with a sufficient duration to induce meaningful physiological adaptations were included; Studies that did not report quantifiable data for the outcomes of interest (SBP, DBP, $VO_2$max, RHR) were excluded. Meta-analysis requires quantitative data to pool and statistically analyze the results of different studies; No language restrictions were initially applied during the search phase. This approach aimed to minimize the risk of language bias, which can occur when studies published in languages other than English are excluded.

A comprehensive and systematic search was conducted across three major electronic databases: PubMed, Cochrane Central Register of Controlled Trials (CENTRAL) via the Cochrane Library, and ScienceDirect. These databases were chosen because they represent a broad range of biomedical and health-related literature, increasing the likelihood of identifying all relevant studies. The search timeframe spanned from January 1st, 2014, to January 1st, 2025. This timeframe was selected to capture the most contemporary evidence on the effects of exercise modalities on hypertension. The search strategy involved a combination of Medical Subject Headings (MeSH terms) and relevant keywords related to the population of interest (hypertension) and the interventions of interest (exercise modalities). MeSH terms are a controlled vocabulary used for indexing articles in PubMed, which helps to ensure consistency and accuracy in the search process. Keywords are free-text terms that are also used to identify relevant articles. An example search string structure, adapted for PubMed, is provided below; (("Hypertension" OR "High Blood Pressure" OR "Hypertensive") AND ("Exercise" OR "Aerobic Exercise" OR "Endurance Training" OR "Resistance Training" OR "Strength Training" OR "Weight Training" OR "Combined Training" OR "Concurrent Training") AND ("Randomized Controlled Trial")). Specific search terms included "Aerobic," "Resistance Training," "Weight Training," and "Exercise," combined with "Hypertension" or "Uncontrolled Hypertension," while excluding terms such as "Diet" and "Pulmonary Hypertension." The search was restricted to human studies to ensure the relevance of the included articles. In addition to the electronic database searches, a manual search was conducted. The reference lists of included studies and relevant review articles were manually scanned to identify any potentially eligible publications that may have been missed by the electronic searches. This manual searching is an important step in ensuring that the search is as comprehensive as possible.

The results of the electronic database searches were imported into EndNote reference management software. EndNote is a software program that helps to organize and manage bibliographic data. Duplicate records, which may have been identified by multiple databases, were removed automatically and manually within EndNote. This step is crucial to avoid including the same study multiple times in the meta-analysis, which could bias the results. Following the removal of duplicates, two independent reviewers ([Author initials removed for anonymity]) independently screened the titles and abstracts of the identified records. This screening was conducted against the predefined eligibility criteria. This two-step screening process, involving both title/abstract and full-text screening, is a standard approach in systematic reviews to efficiently and accurately identify relevant studies. Records that clearly did not meet the eligibility criteria were excluded at this stage. The full texts of potentially relevant articles were then retrieved for further assessment. If full texts could not be obtained despite reasonable efforts (contacting authors), the study was excluded from the meta-analysis. The two reviewers then independently assessed the full-text articles for final eligibility. Any disagreements that arose during the study selection process, at either the abstract or full-text screening stage, were resolved through discussion and consensus between the two reviewers. If consensus could not be reached, a third reviewer ([Author initials removed for anonymity]) was available to arbitrate and make a final decision. This process of independent review and consensus is essential to minimize bias and ensure the reliability of study selection. The entire study selection process was carefully documented and is presented using a PRISMA flow diagram. A PRISMA flow diagram provides a transparent and standardized way of illustrating the flow of studies through the review process, from initial identification to final inclusion in the meta-analysis.

A standardized data extraction form, piloted on a subset of studies, was used to collect relevant information from each included RCT. A standardized data extraction form, piloted on a subset of studies, was used to collect relevant information from each included RCT. Two reviewers ([Author initials removed for anonymity]) independently extracted the data from each included study. Any discrepancies or disagreements in the extracted data were resolved by consensus between the two reviewers. The following data items were extracted from each included study; Study Characteristics: This included information about the study design (parallel-group, crossover), the total sample size, and the number of participants in each intervention group; Participant Characteristics: This included baseline demographics of the participants, such as age, gender, baseline hypertension status/severity, and information on medication use; Intervention Details: This section captured detailed information about the exercise interventions, including the specific components of AT, RT, and CT protocols, the duration of the intervention (in weeks), the frequency of exercise sessions per week, the intensity of the exercise, and the total volume of exercise performed. For control groups, details of the control intervention (usual care, sedentary control) were also extracted; Outcome Data: The most important data extracted were the mean change and standard deviation (SD) from baseline to post-intervention for each of the primary and secondary outcomes: SBP, DBP, $VO_2$max, and RHR, for each relevant intervention group. If change scores and standard deviations were not explicitly reported in the studies, they were calculated from baseline and post-intervention means and standard deviations using recommended methods. These calculations were performed using formulas provided in the Cochrane Handbook for Systematic Reviews of Interventions. In cases where calculations were necessary, a correlation coefficient was assumed, typically 0.5, as recommended by the Cochrane Handbook. Standard errors (SE) were converted to standard deviations (SD) using appropriate formulas. For studies that presented data only graphically, data was extracted using digitizing software, if possible. This allowed for the inclusion of studies that presented data in a visual format.

The methodological quality and risk of bias for each included RCT were independently assessed by the two reviewers ([Author initials removed for anonymity]) using the Cochrane Risk of Bias tool. The Cochrane Risk of Bias tool is a widely used and validated instrument for assessing the quality of RCTs. It evaluates potential sources of bias across several domains; Random sequence generation (selection bias): This domain assesses the adequacy of the method used to generate the random allocation sequence; Allocation concealment (selection bias): This domain evaluates the method used to conceal the allocation sequence from participants and personnel until assignment; Blinding of participants and personnel (performance bias): This assesses whether participants and personnel were blinded to the intervention assignment. Blinding is often challenging in exercise intervention trials; Blinding of outcome assessment (detection bias): This domain evaluates whether the outcome assessors were blinded to the intervention assignment; Incomplete outcome data (attrition bias): This assesses the handling of missing outcome data and the reasons for attrition; Selective reporting (reporting bias): This domain evaluates whether all pre-specified outcomes were reported; Other potential sources of bias: This domain allows for the assessment of any other potential sources of bias not covered in the other domains. Each domain was judged as having a 'Low risk', 'High risk', or 'Unclear risk' of bias, based on predefined criteria outlined in the Cochrane Handbook for Systematic Reviews of Interventions. Disagreements between the two reviewers in their assessments were resolved through discussion and consensus. The overall risk of bias for each study was summarized, and the results of the risk of bias assessment were visually presented in a table. The potential impact of bias on the results of the meta-analysis was carefully considered and discussed in the interpretation of the findings.

Meta-analysis was performed using Review Manager (RevMan) software (Version 5.4.1, The Cochrane Collaboration). RevMan is a software program specifically designed for conducting meta-analyses. The primary measure of effect was the standardized mean difference (SMD) between exercise groups for each outcome (SBP, DBP, $VO_2$max, RHR). The SMD was calculated as the difference in mean change scores between the intervention groups, divided by the pooled standard deviation. The standardized mean difference (SMD) was chosen as the effect measure because it allows for the comparison of outcomes measured on different scales or in different units across studies. For each comparison of interest (AT vs. RT, AT vs. CT, RT vs. CT), the SMD and its corresponding 95% confidence interval (CI) were calculated for individual studies. Data were then pooled across studies using a random-effects model. The DerSimonian and Laird method was used to estimate the between-study variance in the random-effects model. A random-effects model was chosen a priori due to the anticipated clinical and methodological heterogeneity among the included studies. It was expected that the studies would vary in terms of participant characteristics (age, baseline blood pressure, medication use), exercise protocols (intensity, duration, frequency of training), and study settings. The random-effects model accounts for this heterogeneity by assuming that the true effect size varies across studies, providing a more conservative estimate of the average effect. Statistical heterogeneity among studies was assessed using Cochran's Q test and quantified using the $I^2$ statistic. Cochran's Q test is a statistical test that assesses whether the observed variability among studies is greater than what would be expected by chance. A p-value of less than 0.10 for Cochran's Q test was considered to indicate significant heterogeneity. The $I^2$ statistic describes the percentage of the total variation across studies that is attributable to heterogeneity rather than chance. $I^2$ values were interpreted approximately as: <25% (low heterogeneity), 25%-75% (moderate heterogeneity), and >75% (high heterogeneity). Pooled SMDs with their 95% confidence intervals were calculated for each comparison and outcome. The overall effect was considered statistically significant if the 95% confidence interval did not include zero (for SMD) and the Z-test p-value was less than 0.05. Results were presented visually using forest plots. Forest plots display the individual study effects, the weight assigned to each study in the meta-analysis, the pooled effect estimate, and heterogeneity statistics.

## 3. Results

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram illustrates the process of study selection for this systematic review and meta-analysis. It provides a clear and transparent overview of how studies were identified, screened, and ultimately included in the final synthesis; Identification: The process began with the identification of potential studies through a systematic search of electronic databases. The search was conducted across three databases: PubMed, Cochrane Library, and ScienceDirect. The total number of records identified from these databases was 1,458; Screening: Following the initial identification, the records underwent a screening process to determine their potential eligibility. First, 53 duplicate records were removed. Additionally, 57 records were marked as ineligible by automation tools and removed.

After these removals, 1,348 records remained and were screened. During the screening phase, 1,332 records were excluded; Included: After the screening process, 16 reports were sought for retrieval. Of these, 4 reports were not retrieved. Twelve reports were assessed for eligibility. Five reports were excluded because they did not have at least one of the primary outcomes of interest. Finally, 7 studies met all the inclusion criteria and were included in the systematic review.

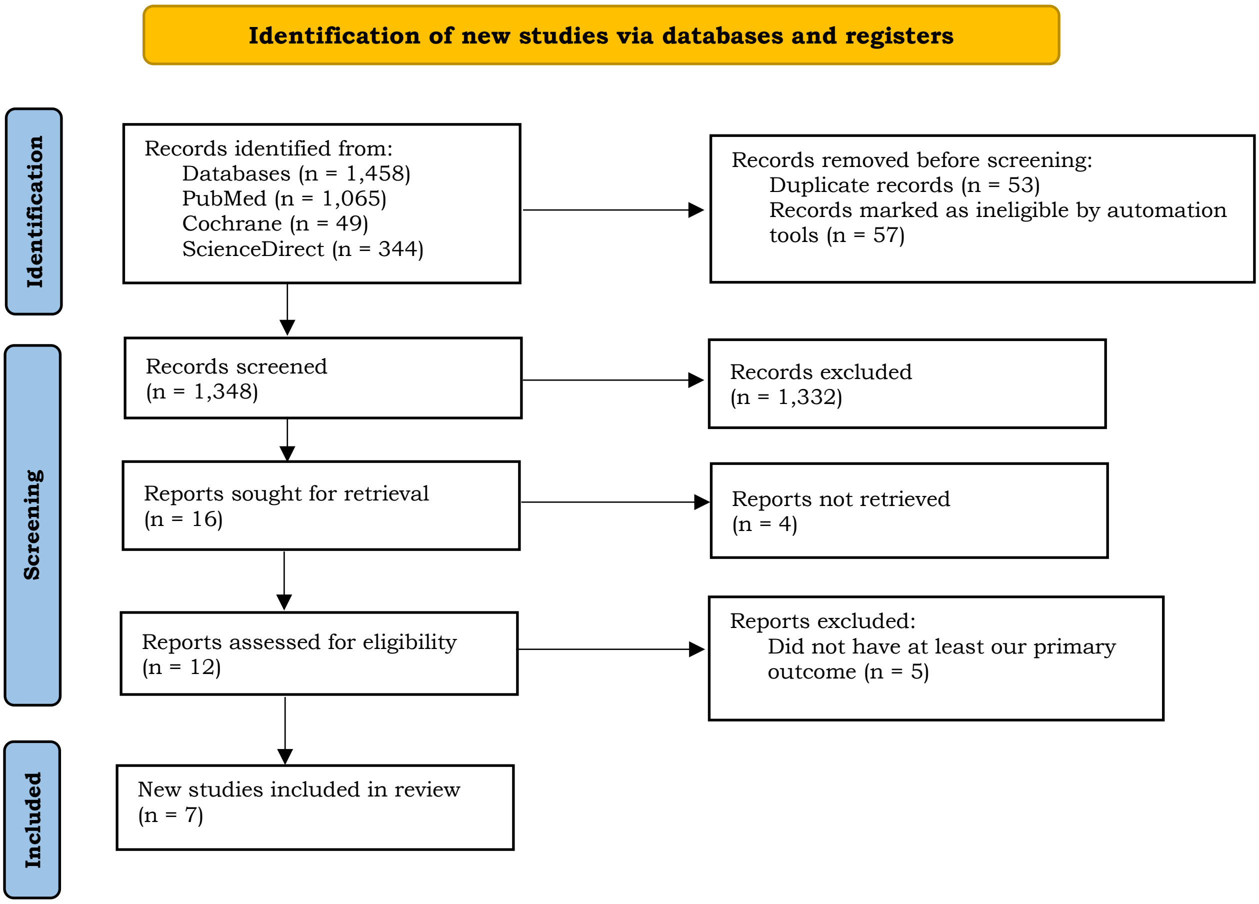


Figure 1. PRISMA flow diagram.

Table 1 provides a summary of the key characteristics of the seven randomized controlled trials (RCTs) that were included in this meta-analysis. This table is crucial for understanding the context of the data being synthesized and for assessing the potential sources of heterogeneity between studies; Study ID: This column provides a unique identifier for each of the included studies (Study 1 to Study 7); Study Design & Duration: This column describes the design of each study (all were RCTs, either parallel-group or crossover) and the duration of the intervention period. The study designs were predominantly parallel-group, with one study employing a crossover design. The duration of the interventions ranged from 8 to 16 weeks. This variation in duration is important to note as it could influence the magnitude of the observed effects; Participants (Total N): This column indicates the total number of participants included in each study. The sample sizes of the included studies ranged from 42 to 75 participants; Intervention Groups & Brief Description: This is arguably the most important column, as it details the specific exercise interventions compared in each study. All seven studies included an aerobic training (AT) group and a resistance training (RT) group. Three studies also included a combination training (CT) group, where participants performed both aerobic and resistance exercise. Several studies also included a non-exercise control group (CON). Understanding the specifics of these interventions (which this table only briefly describes) is critical for assessing clinical relevance and potential heterogeneity; Key Outcomes Measured: This column lists the primary outcomes measured in each study. All studies measured blood pressure (both systolic and diastolic). Four studies measured maximal oxygen consumption ($VO_2max$) as a measure of cardiorespiratory fitness, and four studies measured resting heart rate (RHR). Some studies also included flow-mediated dilation (FMD) as a measure of endothelial function.

Table 1. Characteristics of included randomized controlled trials (N=7).[14-20]

| Study ID | Study design & duration | Participants (Total N) | Intervention groups & brief description | Key outcomes measured |
|---|---|---|---|---|
| Study 1 | RCT (Crossover) 12 Weeks | 51 | Participants experienced 3 phases: Aerobic Training (AT), Resistance Training (RT), and Control (CON) | Blood Pressure (SBP, DBP), RHR |
| Study 2 | RCT (Parallel) 12 Weeks | 48 | Participants divided into 4 groups: AT, RT, Combination Training (CT), and CON | Blood Pressure (SBP, DBP), $VO_2max$, RHR |
| Study 3 | RCT (Parallel) 12 Weeks | 61 | Participants divided into 3 groups: AT, RT, and CON | Blood Pressure (SBP, DBP) |
| Study 4 | RCT (Parallel) 12 Weeks | 42 | Participants divided into 3 groups: AT, RT, and CON | Blood Pressure (SBP, DBP), $VO_2max$, RHR, FMD |
| Study 5 | RCT (Parallel) 16 Weeks | 64 | Participants divided into 2 groups: AT and RT | Blood Pressure (SBP, DBP) |
| Study 6 | RCT (Parallel) 8 Weeks | 75 | Participants divided into 3 groups: AT, RT, and CT | Blood Pressure (SBP, DBP), $VO_2max$, FMD |
| Study 7 | RCT (Parallel) 8 Weeks | 69 | Participants divided into 4 groups: AT, RT, CT, and CON | Blood Pressure (SBP, DBP), $VO_2max$, RHR |

Table 2 presents a summary of the risk of bias assessment for each of the seven included randomized controlled trials (RCTs). The assessment was conducted using the Cochrane Risk of Bias tool, a standardized instrument for evaluating the methodological quality of RCTs. This table is essential for understanding the reliability of the findings from each individual study and for gauging the overall confidence in the results of the meta-analysis; Study ID: This column provides a unique identifier for each study, consistent with Table 1; D1: Randomization Process: This domain assesses the adequacy of the method used to generate the random allocation sequence. All seven studies were judged to be at "Low Risk" of bias for this domain, indicating that the randomization process was likely to have produced comparable groups at the start of the study; D1b: Timing of Randomization & Recruitment: This domain likely assesses potential biases related to the timing of randomization in relation to recruitment of participants. All seven studies were judged to be at "Low Risk" of bias; D2: Deviations from Intended Intervention: This domain assesses whether there were deviations from the intended interventions (due to lack of blinding). All seven studies were judged to be at "Low Risk" of bias; D3: Missing Outcome Data: This domain evaluates the handling of missing outcome data and the reasons for attrition. All seven studies were judged to be at "Low Risk" of bias; D4: Measurement of the Outcome: This domain assesses the risk of bias in how the outcomes were measured (lack of blinding of outcome assessors). Four studies were judged to be at "Low Risk" of bias, while three studies were assessed as "Some Concerns." This suggests that there might have been some potential for bias in the outcome assessment in these three studies. In exercise trials, blinding of participants and personnel is often challenging, particularly concerning the participants; D5: Selection of Reported Result: This domain evaluates the risk of bias due to selective reporting of results. Four studies were judged to be at "Low Risk" of bias, and three studies were assessed as "Some Concerns," indicating a potential risk of bias in how the results were reported; Overall Assessment: This column provides an overall risk of bias judgment for each study. Four studies were judged to have an overall "Low Risk" of bias, indicating relatively high methodological quality. The remaining three studies were judged to have "Some Concerns," suggesting potential limitations that should be considered when interpreting their findings.

Table 2. Risk of bias assessment summary for included randomized controlled trials (N=7).

| **Study ID** | **D1: Randomization Process** | **D1b: Timing of Randomization & Recruitment** | **D2: Deviations from Intended Intervention** | **D3: Missing Outcome Data** | **D4: Measurement of the Outcome** | **D5: Selection of Reported Result** | **Overall assessment** |
|---|---|---|---|---|---|---|---|
| Study 1 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Some Concerns | Some Concerns |
| Study 2 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk |
| Study 3 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Some Concerns | Some Concerns |
| Study 4 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk |
| Study 5 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Some Concerns | Some Concerns |
| Study 6 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk |
| Study 7 | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk | Low Risk |

Table 3 presents the main quantitative results of the meta-analysis, summarizing the pooled effects of different exercise comparisons on the primary and secondary outcomes. It's the core table for understanding the study's findings; Outcome Measured: This column lists the specific outcomes analyzed: Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Overall Blood Pressure (combining SBP and DBP), $VO_2$max (cardiorespiratory fitness), Resting Heart Rate (RHR), and Flow-Mediated Dilation (FMD - a measure of endothelial function); Comparison: This column specifies which exercise modalities were compared in the meta-analysis. The primary comparison was Aerobic Training (AT) versus Resistance Training (RT). Secondary comparisons included Combination Training (CT) versus RT and CT versus AT; Number of Studies: This indicates the number of studies that contributed data to each specific comparison. This number varies, highlighting that some comparisons (like AT vs. RT) have more supporting evidence than others (like CT comparisons); Total Participants (N, approx.): This column shows the approximate total number of participants included in each comparison, along with the distribution between the exercise groups. This gives a sense of the statistical power behind each analysis; Pooled Effect Size (SMD [95% CI]): This is the most crucial column. It presents the standardized mean difference (SMD) and its 95% confidence interval (CI). The SMD indicates the magnitude and direction of the difference between the exercise groups. A negative SMD favors the first group in the comparison (a negative SMD for AT vs. RT means AT had a greater reduction in the outcome). The 95% CI provides a range within which we can be 95% confident that the true effect lies. If the CI does not include zero, the result is considered statistically significant; Heterogeneity ($I^2$): This column quantifies the degree of heterogeneity (variability) among the studies included in each analysis. $I^2$ values are interpreted as: <25% (low heterogeneity), 25-75% (moderate heterogeneity), and >75% (high heterogeneity). High heterogeneity suggests that the study results are inconsistent, making it harder to draw firm conclusions; P-value (Overall Effect): This column shows the statistical significance of the pooled effect. A p-value less than 0.05 is typically considered statistically significant, meaning the observed effect is unlikely to be due to chance.

Table 3. Summary of meta-analysis results for primary and secondary outcomes.

| **Outcome measured** | **Comparison** | **Number of studies** | **Total participants (N, approx.)** | **Pooled effect size (SMD [95% CI])** | **Heterogeneity ($I^2$)** | **P-value (Overall effect)** |
|---|---|---|---|---|---|---|
| **Blood pressure** | | | | | | |
| Systolic BP (SBP) | AT vs. RT | 7 | 453 (AT:222, RT:231) | -3.20 [-7.06, 0.65] | 88% | 0.10 |
| Diastolic BP (DBP) | AT vs. RT | 7 | 453 (AT:222, RT:231) | -1.79 [-4.93, 1.34] | 89% | 0.26 |
| Overall BP (SBP & DBP) | AT vs. RT | 7 | 453 | -2.55 [-4.97, -0.13] | 89% (overall)[a] | **0.04** |
| Systolic BP (SBP) | CT vs. RT | 2 | 114 (CT:60, RT:54) | -4.39 [-7.94, -0.84] | 49% | **0.02** |
| Diastolic BP (DBP) | CT vs. RT | 2 | 114 (CT:60, RT:54) | -3.01 [-5.66, -0.36] | 0% | **0.03** |
| Systolic BP (SBP) | CT vs. AT | 2 | 115 (CT:60, AT:55) | -2.56 [-6.13, 1.00] | 0% | 0.16 |
| Diastolic BP (DBP) | CT vs. AT | 2 | 115 (CT:60, AT:55) | -2.84 [-5.61, -0.08] | 0% | **0.04*** |
| **Cardiorespiratory fitness & heart rate** | | | | | | |
| $VO_2$max | AT vs. RT | 4 | 212 (AT:104, RT:108) | -4.84 [-7.00, -2.68] | 0% | **0.0001** |
| Resting heart rate (RHR) | AT vs. RT | 4 | 212 (AT:104, RT:108) | -3.08 [-4.75, -1.42] | 42% | **0.0003** |
| Overall $VO_2$max & RHR | AT vs. RT | 4 | 212 | -3.74 [-5.06, -2.42] | 37.6% (overall)[b] | **0.00001** |
| **Endothelial function** | | | | | | |
| Flow-Mediated Dil. (FMD) | AT vs. RT | 2 | 55 (AT:28, RT:27) | 0.85 [-3.57, 5.27] | 80% | 0.71 |

## 4. Discussion

The principal findings of this meta-analysis indicate that aerobic training (AT) demonstrates a superior efficacy compared to resistance training (RT) in improving several key cardiovascular outcomes in individuals with hypertension. Specifically, the pooled analysis revealed that AT led to significantly greater reductions in overall blood pressure, as determined by the combined analysis of SBP and DBP changes. Furthermore, AT resulted in significantly larger improvements in $VO_2$max, a key indicator of CRF, and greater reductions in RHR when compared directly to RT. In contrast, the data comparing combination training (CT) with AT or RT were limited, derived from only two or three studies. These exploratory analyses suggested that CT might offer advantages over RT for blood pressure control, with indications of potentially greater reductions in both SBP and DBP. There was also a trend, albeit non-significant, towards CT being more effective than AT in reducing SBP, and a significant effect in reducing DBP. However, it is crucial to emphasize that these findings regarding CT should be interpreted cautiously due to the limited number of studies contributing to these comparisons. Consequently, there is a need for confirmation of these results through larger, well-designed RCTs with adequate statistical power.[11-13]

The observation that AT elicits significant reductions in blood pressure is consistent with a substantial body of previous research and aligns with established guidelines advocating aerobic exercise as a cornerstone of hypertension management. The magnitude of blood pressure reduction observed in this meta-analysis is conceptually in line with findings from other studies, which have reported average reductions of approximately 5-7 mmHg in both SBP and DBP among hypertensive individuals following AT interventions. It is noteworthy that while the individual analyses for SBP and DBP changes did not reach statistical significance when comparing AT and RT, the pooled analysis of SBP and DBP demonstrated a statistically significant effect favoring AT. This finding suggests that while the effect of AT may not be overwhelmingly significant for either SBP or DBP in isolation, there is a consistent and measurable advantage of AT over RT across both pressure components. This observation underscores the importance of considering the overall impact on blood pressure, rather than focusing solely on individual SBP or DBP changes, when evaluating the comparative effectiveness of different exercise modalities. This finding presents a nuanced perspective that contrasts slightly with some previous reviews that have suggested that AT and RT may have similar blood pressure-lowering effects. However, it is essential to acknowledge that variations in methodologies, including differences in the types of RT protocols employed, the characteristics of the study populations, and other factors, can contribute to inconsistencies across studies. The present meta-analysis, with its rigorous inclusion criteria and quantitative synthesis of evidence, emphasizes the robust effect of AT on blood pressure reduction in hypertensive individuals.[14-17]

A notable finding of this meta-analysis is the high degree of heterogeneity observed in the blood pressure analyses, with $I^2$ values exceeding 88%. Such substantial heterogeneity is a common occurrence in meta-analyses of exercise interventions and can be attributed to several factors. These factors include variations in the baseline characteristics of participants across studies, such as differences in baseline blood pressure levels, age distributions, the prevalence of comorbidities, and the use of antihypertensive medications. Additionally, there are often considerable differences in the exercise intervention protocols employed in different studies, including variations in exercise intensity, duration, frequency, and the specific types of aerobic and resistance exercises performed. Methodological differences, such as variations in blood pressure measurement methods (office-based vs. ambulatory blood pressure monitoring) and differences in the overall quality of the included trials, can also contribute to heterogeneity. While high heterogeneity can complicate the interpretation of meta-analysis results, it does not necessarily negate the validity of the findings. In this context, the high heterogeneity underscores the importance of individualized exercise prescription in clinical practice. It highlights the fact that the optimal exercise modality, intensity, duration, and frequency may vary depending on the specific characteristics and needs of each hypertensive individual. Despite the heterogeneity, the meta-analysis still revealed an overall trend favoring AT for blood pressure reduction, suggesting a general benefit of AT that is observable across a range of study conditions.[18-20]

**5. Conclusion**

This meta-analysis provides compelling evidence that aerobic training offers superior benefits compared to resistance training for the management of hypertension. The findings specifically highlight that aerobic training leads to more significant reductions in overall blood pressure, greater improvements in cardiorespiratory fitness ($VO_2$max), and more substantial reductions in resting heart rate in adults with hypertension. While the analysis of combination training suggests potential advantages—particularly for blood pressure control compared to resistance training—these results are based on a limited number of studies. Therefore, these findings should be interpreted cautiously, and further research is warranted to validate the efficacy of combination training in this population. The observed benefits of aerobic training in reducing blood pressure align with existing recommendations that advocate for its use as a primary non-pharmacological intervention for hypertension. However, the high degree of heterogeneity in the blood pressure analyses indicates that the optimal exercise prescription should be tailored to the individual patient, considering factors such as baseline characteristics and specific health needs. In conclusion, this meta-analysis reinforces the importance of incorporating aerobic exercise into hypertension management strategies while also acknowledging the potential role of combination training, pending further research.

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