Journal of Exercise Science & Fitness 24 (2026) 200495

Contents lists available at ScienceDirect

Journal of Exercise Science & Fitness

journal homepage: www.elsevier.com/locate/jesf

Effects of high-intensity interval training on cardiovascular health: An umbrella review of systematic reviews and meta-analyses

Minghui Du [a], Bopeng Qiu [b,c], Ying Bai [d], Xinyu Zeng [e], Kai Xu [e], Enyi Ma [a], Liang Xia [a], Wei Zhang [f], Mingyue Yin [e,g,*]

[a] Sports Center, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China
[b] School of Strength and Conditioning, Beijing Sport University, Beijing, 100084, China
[c] Division of Sport Science & Physical Education, Tsinghua University, Beijing 100084, China
[d] Department of Sport and Exercise Sciences, Kunsan National University, Jeollabuk-do, 54150, South Korea
[e] School of Athletic Performance, Shanghai University of Sport, Shanghai, 200438, China
[f] School of Physical Education, Northeast Normal University, Changchun, Jilin, 130024, China
[g] Guangdong Provincial Key Laboratory of Speed Capability Research, Jinan University, Guangzhou 510632, China

ARTICLE INFO

Keywords:
High-intensity interval training
Moderate-intensity continuous training
Cardiovascular health
HIIT
MICT

ABSTRACT

Objectives: Despite considerable evidence on high-intensity interval training (HIIT) for cardiovascular benefits, overlapping studies and lack of systematic synthesis hinder understanding of its full effects and optimal prescription. This umbrella review synthesizes evidence and summarizes the cardiovascular benefits of HIIT across diverse populations.

Methods: We searched Embase, PubMed, Web of Science, and Cochrane Library for systematic reviews and meta-analyses on effects of HIIT on cardiovascular health. Evidence was stratified by population type, overlapping evidence was handled by predefined criteria, quality was assessed using AMSTAR 2, and results were visualized using forest plots.

Results: Initially, 1017 studies were retrieved, of which 54 were included. The results revealed that HIIT significantly improved blood pressure (SBP: −5.43 to −2.73 mmHg; DBP: −4.35 to −2.41 mmHg), resting heart rate (−4.35 to −2.17 bpm), and left ventricular ejection fraction (3.51% to 5.52%). Compared with other exercise modalities such as moderate-intensity continuous training, HIIT showed significant improvements in left ventricular ejection fraction (3.13% to 3.24%), left ventricular end-diastolic diameter (−4.69 to −2.55 mm), and flow-mediated dilation (0.35% to 2.57%), with comparable effects on blood pressure and heart rate.

Conclusion: HIIT demonstrates advantages over other exercise modalities in improving cardiac structure and volume, with comparable effects on blood pressure and heart rate. These benefits were observed across cardiovascular, metabolic, and apparently healthy populations. However, the current evidence does not support protocol-specific recommendations such as long-interval versus short-interval HIIT, and direct comparisons of different HIIT protocols are needed.

Abbreviations: HIIT, High-intensity interval training; LVEF, Left ventricular ejection fraction; LVM, Left ventricular mass; LVEDD, Left ventricular end-diastolic diameter; CIMT, Carotid intima-media thickness; LVEDV, Left ventricular end-diastolic volume; FMD, Flow-mediated dilation; CV, Cardiovascular; MICT, Moderate-intensity continuous training; T2DM, Type 2 diabetes mellitus; UR, Umbrella review; CAD, Coronary artery disease; HFrEF, Heart failure with reduced ejection fraction; HFpEF, Heart failure with preserved ejection fraction; HF, Heart failure; MIIT, Moderate-intensity interval training; MSD, Musculoskeletal disease; MIT, Moderate intensity training; HRR, Heart rate reserve; E/E′, Early diastolic mitral inflow velocity / Early diastolic mitral annular tissue velocity; E/A, Early diastolic mitral inflow velocity / Late diastolic mitral inflow velocity; DT, Deceleration time; CVD, Cardiovascular disease; MHR, Maximum heart rate; SHR, Submaximal heart rate; SBP, Systolic blood pressure; DBP, Diastolic blood pressure; RHR, Resting heart rate; PHR, Peak heart rate.

* Corresponding author. Shao Yifu Gymnasium, Shipai Campus, 601 Huangpu Avenue West, Tianhe District, Guangzhou 510632, Guangdong, China.
E-mail addresses: Mingyue0531@sus.edu.cn, mingyue.yin0531@gmail.com (M. Yin).

https://doi.org/10.1016/j.jesf.2026.200495
Received 21 January 2026; Received in revised form 19 June 2026; Accepted 29 June 2026
Available online 29 June 2026

1. Introduction

High-intensity interval training (HIIT) is defined as stimulation above moderate intensity with some intervals,[1] which, according to its specific protocol, is categorized into long-interval, short-interval, repeated-sprint, and sprint-interval training, and small-sided games.[1,2] Many recent studies have assessed the effect of HIIT on cardiorespiratory capacity (VO_2peak), metabolic function (e.g., fasting glucose, insulin), and fat reduction, accumulating substantial evidence. For example, an umbrella review (UR) considered HIIT to be more effective than no-exercise controls and moderate-intensity continuous training (MICT) in improving VO_{2peak} in adults.[3] Poon et al.[4] also observed that HIIT can significantly improve indicators of glycemic control and cardiac metabolism (e.g., glycated hemoglobin, fasting insulin) in patients with type 2 diabetes mellitus (T2DM). Another UR verified the effectiveness of HIIT in enhancing cardiovascular (CV)-metabolic health such as lowering blood pressure (BP), lipids, and low-density lipoprotein in adolescents and children, and recommended that HIIT be incorporated into physical activity promotion programs in schools and communities.[5] However, an umbrella review of the effects of HIIT on CV structure and function, particularly across diverse populations, is lacking, and the study results are inconsistent.

Indicators of CV structure and function, such as left ventricular ejection fraction (LVEF), left ventricular end-diastolic volume (LVEDV), and left atrial volume index (LAVI) serve as important intermediate indicators of CV disease (CVD). In the physiopathology of CV events, risk factors cause changes in intermediate indicators and thus result in CV events. For example, hypertension leads to myocardial hypertrophy through neurohumoral and biomechanical processes, thus causing heart failure (HF), in which myocardial hypertrophy acts as an important intermediate indicator of HF.[6] Relevant studies have noted that these intermediate indicators are closely linked to CVD morbidity and mortality,[7] may be more informative than traditional indicators (e.g., myocardial infarction MI, death) in the assessment of cardiac function,[8] and can be used as a reference and guide for predicting the future risk of CV events,[9] becoming important research issues in clinical treatment and public health.

The effects of HIIT on CV structure and function have been massively examined in meta-analyses. One meta-analysis found that HIIT is more effective than other types of exercise such as MICT in improving LVEF in patients with HF with reduced ejection fraction,[10] whereas Qin et al.[11] argued that HIIT demonstrates no prominent advantages over other types of exercise in improving LVEF in post-MI patients. Existing research suggests that the effects of HIIT on CV structure and function may vary across populations.[12,13] However, there is potential overlap across existing meta-analyses, and a systematic synthesis of the cardiovascular benefits of HIIT, particularly across different populations, is currently lacking. Therefore, a higher-level synthesis that integrates evidence across existing meta-analyses and diverse populations is needed to provide a more comprehensive and reliable evidence base for clinical practice.

As an emerging study method, an UR allows systematic retrieval, screening, and synthesis of multiple systematic reviews and meta-analyses[14] to provide holistic judgments on specific scientific questions by comparing the conclusions across studies[15] and obtain higher levels of evidence.[16] Therefore, we conducted this UR to systematically reanalyze the available evidence on the effects of HIIT on CV health, with a focus on the HIIT benefits on CV health across populations. Moreover, we compared HIIT with other exercise strategies, such as MICT, to assess the relative advantage and potential of HIIT in improving CV health indicators (e.g., BP, heart rate [HR], and cardiac structure and function). The findings will offer evidence-based recommendations for the development of exercise prescriptions in clinical and public health settings and the updating of CV health-related guidelines, contributing to the use of more personalized and precise exercise intervention strategies.

2. Methods

2.1. Registration

We developed a pre-specified protocol for this umbrella review, which was registered with PROSPERO (International Prospective Register of Systematic Reviews, CRD420251027905).

2.2. Study search and screening

We systematically searched Embase, PubMed, Web of Science, and Cochrane Library for systematic reviews and meta-analyses on the effects of HIIT on CV health up to March 2025. The detailed search strings are provided in Supplementary Table S1. Two investigators independently screened the title and abstract, and then reviewed the full text to include the eligible studies. Any discrepancy was settled by a third investigator.

2.3. Eligibility criteria

Meta-analyses of interventional studies were included, without restriction on whether they were randomized trials; observational studies, pathology reports, and reviews were excluded. We excluded network meta-analyses because their results typically include both direct and indirect comparisons, and the inclusion of indirect evidence may affect the results of our umbrella review. The study population included healthy people and people with any type of disease. The intervention was clearly-defined HIIT; the type of HIIT was not defined, given that the included studies might contain multiple types of HIIT and not strictly restrict or categorize the type of HIIT. The comparisons included no exercise, conventional therapy (including medication, lifestyle interventions, or unstructured small-scale exercise), and other exercise, and the studies without these comparisons or without describing the specific comparison were excluded. The outcome metrics were indicators of CV structure and function: systolic BP (SBP), diastolic BP (DBP), resting HR (RHR), peak HR (PHR), LVEF, LVEDV, left ventricular end-diastolic diameter (LVEDD), carotid intima-media thickness (CIMT), and LAVI. Indicators of cardiorespiratory capacity (VO_2peak) and metabolic health (HDL, LDL, and HOMA-IR) were excluded, as they reflect downstream metabolic or compensatory functional adaptations rather than direct measures of cardiac structural function.

2.4. Data extraction

Two investigators independently extracted the following data using a standardized data extraction form: first author, year of publication, study population, interventions, comparisons, outcome metrics, number of included studies, number of cases in the experimental and control groups (if applicable), I^2 and P-values (Q-test), effect sizes and 95% confidence intervals (CIs), and P-values (Egger's test). Any discrepancies were resolved through discussion or by consulting a third investigator.

2.5. Quality assessment and evidence grading

Quality assessment was performed using A Measurement Tool to Assess Systematic Reviews 2 (AMSTAR 2), a validated and reliable instrument designed to evaluate the methodological quality of systematic reviews, including those of interventional and observational studies.[17] Unlike the original version, AMSTAR 2 consists of 16 domains and places greater emphasis on critical aspects such as protocol registration, justification for excluding individual studies, and assessment of risk of bias in primary studies. Two investigators independently performed the quality assessment, with any discrepancies resolved through discussion with a third investigator. Furthermore, the quality of evidence for each outcome was evaluated using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach.[18,19] In this umbrella review, GRADE was applied at the level of each pooled effect size derived from the included meta-analyses, rather than at the level of the meta-analyses themselves. For each outcome, the quality of evidence was rated based on the information reported in the original meta-analyses, including risk of bias, inconsistency (I^2), imprecision (95% confidence intervals), and publication bias (Egger's test). This adaptation ensures that the GRADE assessment reflects the overall confidence in each pooled estimate, consistent with standard GRADE guidance for pairwise meta-analyses. Low- and very-low-quality evidence were not excluded from this umbrella review, as excluding them would limit the comprehensiveness of the synthesis. Moreover, GRADE ratings in exercise intervention research are often conservative due to inherent challenges such as lack of blinding and high protocol heterogeneity. Therefore, all evidence was retained and interpreted with caution, with conclusions drawn primarily from the consistency of effect directions across studies.

2.6. Classification method for UR literature

Using the UR methods of Poole et al.[20]and Huang et al.,[21] we first categorized the included studies by the study population (e.g., patient with heart failure, patient with myocardial infarction, patient with hypertension, patient with metabolic syndrome, and healthy children) and comparisons (e.g., no exercise, conventional therapy, and other exercise including MICT, moderate-intensity interval training MIIT, and moderate-intensity training MIT) to minimize overlapping of evidence. If multiple articles fall under the same category, only one will be selected. The selection is prioritized first by publication year; if the difference in publication years exceeds two years, the most recent article is chosen. Otherwise, the number of included primary studies is compared, with preference given to the article containing more primary studies. If the number of primary studies is identical, the AMSTAR 2 assessment result is used to select the article with higher methodological quality. In addition, a meta-analysis could be categorized into multiple categories if it included multiple subgroups of different interventions or comparisons.

2.7. Statistical analysis

Due to some heterogeneity across meta-analyses in the characteristics of the study population, and specific intensity, frequency, and cycle of interventions and comparisons, we only extracted data from the pooled results of the final included meta-analyses. If a meta-analysis reports both random-effects and fixed-effects model results, we prioritize the random-effects model unless there is strong homogeneity among the study populations, interventions, control measures, and outcome assessments, in which case we select the fixed-effects model results. Moreover, we will re-analyze the data if any studies with potentially outlier effect values are identified. For studies that inappropriately used a fixed-effects model, we will perform a re-analysis using a random-effects model instead.[22] In the present study, no such instances were identified. Heterogeneity was assessed using the I^2 statistic, with $I^2 >$ 75% considered considerable heterogeneity. In such cases, findings were interpreted with caution. Furthermore, all the evidence was divided into four categories according to the type of disease: CVD (e.g., HF, coronary heart disease), metabolic disease (e.g., T2DM, overweight, or obesity), musculoskeletal disease (MSD), and apparently healthy adults, adolescents, and children. For analysis, the 17 cardiovascular indicators were assessed, including blood pressure (SBP, DBP), heart rate (RHR, PHR, MHR, HRR, SHR), as well as cardiac structural and functional parameters (LVEF, LVEDV, LVEDD, LVM, CIMT, LAVI, E/A, E/E′, DT, FMD). The direction of effect sizes was standardized to ensure consistent clinical interpretation across outcomes. The effects of HIIT on CV outcomes versus other exercises were analyzed in each category, and the results were visualized by forest plots with the effect size, population, sample size, heterogeneity (I^2), publication bias (P-value in Egger's test), and grade of evidence. The results of meta-analyses reporting standardized and unstandardized effect sizes (SMD and MD) were separately displayed. MD was used when the original meta-analysis reported MD, and SMD was used when the original meta-analysis reported SMD.

3. Results

3.1. Included studies' characteristics

We initially retrieved 1017 studies. After screening based on the eligibility criteria, 54 studies were included (Fig. 1). After categorization according to the predefined criteria of the umbrella review, 33 articles were included in the final data analysis. Specifically, this umbrella review encompassed 17 indicators of cardiovascular structure and function, yielding 88 distinct pooled effect sizes from the included meta-analyses (n = 40 blood pressure-related, n = 24 heart rate-related, and n = 27 cardiac structure/function-related). A summary of the included evidence by population category is presented in Table 1.

The AMSTAR 2 assessment results indicated that the overall quality of the included studies was relatively low, as none of the studies provided a list of excluded literature or reported the funding sources of the included articles (Table 2). A total of 54.5% of the included studies reported having a pre-established methodology (Item 2); all studies accounted for the risk of bias (ROB) in the interpretation of results (Item 9); all studies employed appropriate statistical methods for synthesizing the results (Item 11); 60.6% of the studies provided a detailed discussion of heterogeneity (Item 14); and 60.6% conducted an analysis of publication bias (Item 15).

As revealed by the GRADE, only 5 pooled effect sizes had high quality, 38 had moderate quality, 31 had low quality, and 14 had very low quality (Supplementary Table S2). The low ratings were mainly due to considerable heterogeneity across studies and methodological limitations of the included meta-analyses.

3.2. Effect of HIIT among patients with cardiovascular disease

Forty-two pooled effect sizes assessed the effects of HIIT on CV outcomes in patients with CVD, of which 13 were on the comparison of HIIT with conventional therapy or no exercise (Fig. 2) and 29 on the comparison of HIIT with other exercise (Fig. 3).

3.2.1. HIIT vs. No exercise or conventional therapy

HIIT significantly reduced SBP (MD = −4.73 mmHg, 95% CI = −7.66 to −1.81, $I^2 = 65\%$),[23] DBP (MD = −4.35 mmHg, 95% CI = −8.20 to −0.49, $I^2 = 80\%$),[23] and RHR (MD = −2.17 bpm, 95% CI = −3.32 to −1.02, $I^2 = 0\%$)[23] in hypertensive patients compared with no exercise.

HIIT significantly increased LVEF (MD = 3.66%, 95% CI = 1.78 to 5.54, $I^2 = 8.5\%$)[12] but did not significantly affect LVEDV (MD = −2.13 mL, 95% CI = −9.57 to 5.32, $I^2 = 0\%$)[12] in heart failure with reduced ejection fraction patients compared with conventional therapy.

HIIT significantly increased PHR (MD = 5.60 bpm, 95% CI = 1.58 to 9.62, $I^2 = 0\%$)[24]in heart transplant patients compared with no exercise.

HIIT significantly reduced CIMT (MD = −0.06 mm, 95% CI = −0.09 to −0.02, $I^2 = 74\%$)[25] in patients with carotid atherosclerosis compared with no exercise.

HIIT showed no significant effects on PHR (SMD = 0.24, 95% CI = −0.24 to 0.72, $I^2 = 0\%$),[26] RHR (SMD = −0.01, 95% CI = −0.49 to 0.46, $I^2 = 32\%$),[26] and LVEF (SMD = 0.58, 95% CI = −0.02 to 1.19)[26] in patients with coronary artery disease post-percutaneous coronary intervention compared with conventional therapy.

HIIT significantly reduced SBP (MD = −5.43 mmHg, 95% CI = −8.82 to −2.04, $I^2 = 84\%$),[27] DBP (MD = −2.96 mmHg, 95% CI = −4.88 to −1.04, $I^2 = 80\%$),[27] and RHR (MD = −4.35 bpm, 95% CI = −7.04 to −1.66, $I^2 = 67\%$)[27] in patients with CVD (not specified types) compared with no exercise or conventional therapy.

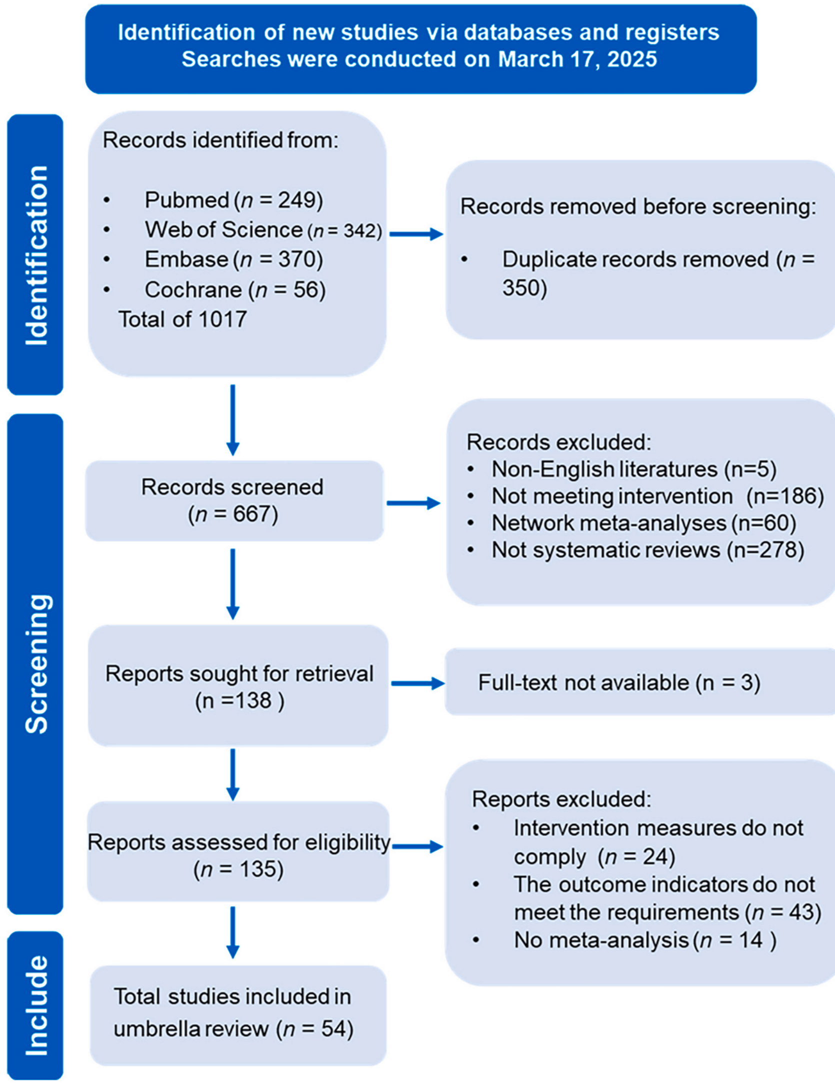

Fig. 1. Flowchart of selection of studies for inclusion.

Table 1
Summary of included meta-analyses by population category.

Population category	Number of comparisons	Range of primary studies per effect size	Study type
Cardiovascular disease	42	1 to 13	Meta-analysis
Metabolic disease	14	2 to 11	Meta-analysis
Musculoskeletal disease	3	4 to 5	Meta-analysis
Apparently healthy	29	3 to 54	Meta-analysis

Note: The number of comparisons refers to the total pooled effect sizes extracted from the included meta-analyses for each population category. The range of primary studies per effect size indicates the minimum to maximum number of original studies that contributed to each pooled estimate. All included studies were systematic reviews with meta-analyses.

3.2.2. HIIT vs. other exercise

HIIT did not significantly decrease SBP (MD = −1.09 mmHg, 95% CI = −3.19 to 1.02, I^2 = 0%)[28] or DBP (MD = −0.67 mmHg, 95% CI = −1.95 to 0.62, I^2 = 0%)[28] in hypertensive patients compared with MICT.

Compared with MICT in patients with coronary artery disease, HIIT significantly decreased DBP (MD = −3.43 mmHg, 95% CI = −5.76 to −1.09, I^2 = 60.2%),[29] but did not significantly reduce SBP (MD = −1.85 mmHg, 95% CI = −3.93 to 0.23, I^2 = 18.2%)[29]; HIIT significantly increased PHR (MD = 4.21 bpm, 95% CI = 1.07 to 7.36, I^2 = 0%)[29]; HIIT did not significantly improve LVEF (MD = 0.32%, 95% CI = −1.83 to 2.46, I^2 = 0%)[29] or LVEDV (MD = 0.91 mL, 95% CI = −3.68 to 5.49, I^2 = 0%).[29]

Compared with other exercise in post-MI patients, HIIT showed no significant effects on SBP (MD = 3.45 mmHg, 95% CI = −1.66 to 8.57, I^2 = 45%),[11] DBP (MD = −0.21 mmHg, 95% CI = −7.74 to 7.31, I^2 = 75%),[11] PHR (MD = 0.74 bpm, 95% CI = −2.82 to 4.30, I^2 = 0%),[11] RHR (MD = 1.60 bpm, 95% CI = −0.27 to 3.47, I^2 = 2%),[11] LVEF (MD = 4.46%, 95% CI = −5.75 to 14.68, I^2 = 87%),[11] and LVEDV (MD = −8.89 mL, 95% CI = −21.93 to 4.16, I^2 = 0%).[11]

Compared with MICT in heart failure with reduced ejection fraction patients, HIIT significantly increased LVEF (MD = 3.13%, 95% CI = 1.25 to 5.02, I^2 = 68%)[10] but did not significantly affect RHR (MD = −0.15 bpm, 95% CI = −1.68 to −1.37, I^2 = 0%)[10] or PHR (MD = 0.50 bpm, 95% CI = −2.69 to 3.69, I^2 = 0%).[10]

In heart failure with preserved ejection fraction patients, HIIT did not significantly decrease LAVI (MD = −1.71 mL/m^2, 95% CI = −5.58 to 2.17, I^2 = 22%)[30] compared with MICT; HIIT significantly increased E/A (MD = 0.13, 95% CI = 0.03 to 0.23, I^2 = 67%)[31] compared with MIIT; HIIT did not significantly affect E/E' (MD = 0.39, 95% CI = −2.40 to 3.18, I^2 = 0%),[31] LAVI (MD = −0.13 mL/m^2, 95% CI = −23.19 to 22.93,

Table 2
AMSTAR 2 evaluation results of the literature.

Included MA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Luo 2024	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	N	N	Y	Y	Y
Edwards 2023a	Y	Y	Y	PY	Y	N	N	PY	Y	N	Y	N	N	Y	Y	Y
Edwards 2022	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	N	Y	Y	Y	Y
Yin 2024	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	N	Y	Y	Y	Y
Serrablo-Torrejon 2020	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	N	Y	N	N	Y
Wang 2024	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	N	Y	Y
Menjie 2022	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Qiu 2018	Y	Y	Y	PY	Y	N	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Qiu 2024	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	N	Y	Y
He 2024	Y	Y	Y	PY	N	N	N	PY	Y	N	Y	Y	Y	Y	N	Y
Batacan 2017	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	N	Y
Cao 2021	Y	Y	Y	PY	N	N	N	PY	Y	N	Y	Y	Y	N	Y	Y
Garcia-Hermoso 2016	Y	N	Y	PY	Y	N	N	PY	Y	N	Y	Y	Y	N	Y	Y
Li 2022	Y	Y	Y	PY	N	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Mesquita 2023	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	N	N	Y	N	Y
Casana 2022	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	N	N	Y	Y	Y
Gao 2025	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Zhang 2021	Y	N	Y	PY	Y	N	N	PY	Y	N	Y	N	N	Y	NA	Y
Gao 2023	Y	Y	Y	PY	N	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Carpes 2022	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	N	NA	Y
Liang 2024	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Kwok 2022	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	N	N	N	Y	Y
Engel 2018	Y	N	Y	PY	N	N	N	PY	Y	N	Y	N	N	Y	N	Y
Mattioni Maturana 2021	Y	Y	Y	PY	N	N	N	PY	Y	N	Y	Y	Y	N	Y	Y
Siddiqi 2023	Y	N	Y	PY	N	Y	N	PY	Y	N	Y	N	N	N	NA	Y
Lai 2023	Y	Y	Y	PY	N	Y	N	PY	Y	N	Y	N	N	N	NA	Y
Yang 2024	Y	Y	Y	PY	N	N	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Tucker 2019	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	N	N	N	NA	Y
Qin 2022	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	N	N	N	NA	Y
Qi 2024	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	NA	Y
Edwards 2023b	Y	N	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Fuertes-Kenneally 2023	Y	Y	Y	PY	Y	Y	N	PY	Y	N	Y	Y	Y	Y	Y	Y
Conceiçao 2021	Y	N	Y	PY	N	Y	N	PY	Y	N	Y	N	N	N	N	Y

Note: ITEM – DESCRIPTION.
1. Did the research questions/inclusion criteria include the components of PICO?.
2. Did the review contain an explicit statement that the review methods were established prior to the conduct of the review?.
3. Did the review authors explain their selection of the study designs for inclusion in the review?.
4. Did the review authors use a comprehensive literature search strategy?.
5. Did the review authors perform study selection in duplicate?.
6. Did the review authors perform data extraction in duplicate?.
7. Did the review authors provide a list of excluded studies and justify the exclusions?.
8. Did the review authors describe the included studies in adequate detail?.
9. Did the review authors assess the RoB in studies that were included in the review?.
10. Did the review authors report on the sources of funding for the studies included in the review?.
11. If meta-analysis was performed did the review authors use appropriate methods for statistical combination of results?.
12. If meta-analysis was performed, did the review authors assess the potential impact of RoB in individual studies on the results of the meta-analysis?.
13. Did the review authors account for RoB in individual studies when interpreting the results of the review?.
14. Did the review authors provide a satisfactory explanation for, and discussion of, any heterogeneity observed in the results of the review?.
15. If they performed quantitative synthesis did the review authors investigate publication bias?.
16. Did the review authors report any potential sources of conflict of interest, including any funding they received for conducting the review?.
Abbreviations: N, No; NA, Not applicable (no meta-analysis); PY: Partial Yes; Y, Yes.

$I^2 = 0\%$),[31] DT (MD = 4.64 ms, 95% CI = −562.36 to 571.63, $I^2 = 0\%$),[31] or LVEF (MD = −2.39, 95% CI = −12.16 to 7.38, $I^2 = 0\%$).[31]

In patients with HF (not specified types), HIIT significantly decreased LVEDD (MD = −3.62 mm, 95% CI = −4.69 to −2.55, $I^2 = 0\%$)[32] but did not significantly affect LAVI (MD = −1.49 mL/m^2, 95% CI = −4.90 to 1.92, $I^2 = 48\%$)[32] or E/E' (MD = −0.33, 95% CI = −1.68 to 1.03, $I^2 = 18\%$)[32] compared with MICT; HIIT significantly increased LVEF (MD = 3.24%, 95% CI = 1.70 to 4.80)[33] compared with MIT.

Compared with MICT in heart transplant patients, HIIT significantly increased PHR (MD = 3.35 bpm, 95% CI = 0.83 to 5.87, $I^2 = 0\%$),[24] but did not significantly improve HR reserve (MD = 4.79 bpm, 95% CI = −0.05 to 9.62, $I^2 = 0\%$).[24]

Compared with MIT in patients with CVD (not specified types), HIIT significantly improved FMD (MD = 1.46%, 95% CI = 0.35 to 2.57, $I^2 = 80.12\%$).[34]

3.3. *Effect of HIIT among patients with metabolic disease*

Fourteen pooled effect sizes assessed the effects of HIIT on CV outcomes in patients with metabolic disease, of which nine were on the comparison of HIIT with conventional therapy or no exercise (Fig. 4) and five on the comparison of HIIT with other exercise (Supplementary Fig. S1).

3.3.1. *HIIT vs. No exercise or conventional therapy*

In patients with T2DM, HIIT significantly enhanced FMD (MD = 2.62%, 95% CI = 1.42 to 3.82, $I^2 = 23\%$)[35] as compared to no exercise, and significantly enhanced LVM (MD = 17.04 g, 95% CI = 5.45 to 28.62, $I^2 = 0\%$),[13] LVEF (MD = 5.52%, 95% CI = 2.31 to 8.73, $I^2 = 0\%$),[13] and LVEDV (MD = 19.44 mL, 95% CI = 13.72 to 25.17, $I^2 = 42\%$)[13] as compared to conventional therapy.

In patients with metabolic syndrome (MetS), HIIT significantly lowered SBP (MD = −4.44 mmHg, 95% CI = −6.82 to −2.06, I^2 =

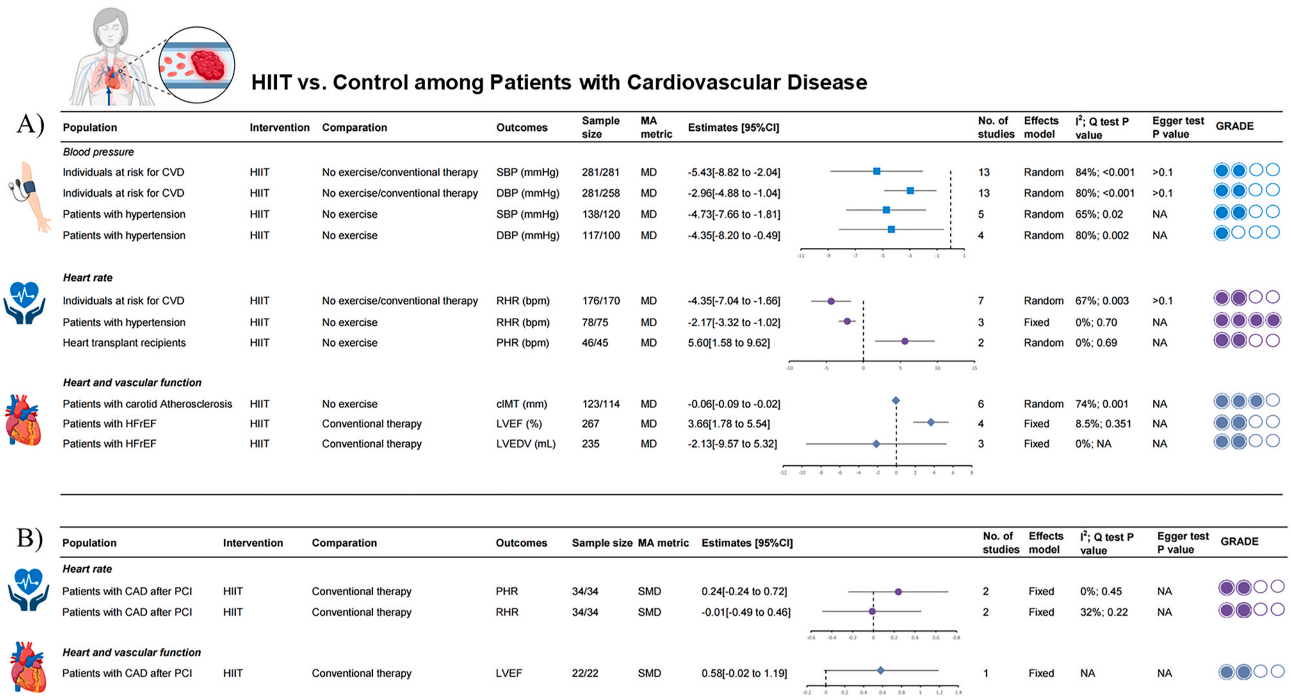

Fig. 2. Forest plot comparing HIIT versus no exercise or conventional therapy among patients with cardiovascular disease. Panel A (MD) and Panel B (SMD). CAD, coronary artery disease; PCI, percutaneous coronary intervention; HFrEF, heart failure with reduced ejection fraction; HRR, heart rate reserve; cIMT, carotid intima-media thickness; NA, not available. Effect sizes of PHR and LVEF on the right side of the central axis indicate support for HIIT; effect sizes of SBP, DBP, RHR, and cIMT on the left side of the central axis indicate support for HIIT. LVEDV require comprehensive evaluation based on disease characteristics and other indicators.

57%)[36] and DBP (MD = −3.60 mmHg, 95% CI = −5.43 to −1.78, I^2 = 45%)[36] as compared to no exercise.

In overweight or obese adults, HIIT significantly lowered SBP (SMD = −0.35, 95% CI = −0.60 to −0.09, I^2 = 48%),[37] DBP (SMD = −0.38, 95% CI = −0.65 to −0.10, I^2 = 54%),[37] and RHR (SMD = −0.33, 95% CI = −0.56 to −0.09, I^2 = 43%)[37] as compared to no exercise.

3.3.2. HIIT vs. other exercise

HIIT did not significantly enhance FMD (MD = 4.79%, 95% CI = −2.90 to 12.49, I^2 = 75.6%)[38] in patients with T2DM as compared to MICT.

In overweight and obese adolescents and children, HIIT significantly reduced SBP (SMD = −0.64, 95% CI = −1.05 to −0.22, I^2 = 44.9%),[39] but did not significantly reduce DBP (SMD = −0.13, 95% CI = −0.88 to 0.61, I^2 = 82.1%)[39] compared with MICT; compared with other exercise, HIIT also significantly lowered SBP (SMD = −0.39, 95% CI = −0.69 to −0.09, I^2 = 1%),[40] but did not significantly reduce DBP (SMD = −0.31, 95% CI = −0.68 to 0.06, I^2 = 30%).[40]

3.4. Effect of HIIT among patients with musculoskeletal disease

Only three meta-analyses assessed the effects of HIIT on CV outcomes in MSD populations (Supplementary Fig. S2). Compared with no exercise, small-scale interventions, or conventional therapy, HIIT did not significantly reduce SBP (SMD = −0.06, 95% CI = −0.43 to −0.30, I^2 = 0%), DBP (SMD = 0.07, 95% CI = −0.29 to 0.44, I^2 = 0%),[41] or RHR (SMD = −0.20, 95% CI = −0.45 to 0.05, I^2 = 0%).[41]

3.5. Effect of HIIT in the apparently healthy population

The effects of HIIT on CV outcomes in the apparently healthy adults, adolescents, and children were assessed by 29 pooled effect sizes, of which 14 were on the comparison of HIIT with conventional therapy or no exercise (Fig. 5) and 15 on the comparison of HIIT with other exercise (Fig. 6).

3.5.1. HIIT vs. No exercise or conventional therapy

In adults, HIIT significantly reduced SBP (MD = −3.20 mmHg, 95% CI = −4.55 to −1.86, I^2 = 82.11%),[42] DBP (MD = −2.41 mmHg, 95% CI = −3.56 to −1.25, I^2 = 90.13%),[42] and RHR (MD = −3.90 bpm, 95% CI = −4.93 to −2.85, I^2 = 79.96%),[42] and significantly improved LVEF (MD = 3.51%, 95% CI = 1.81 to 5.20, I^2 = 69.20%)[42]; it had no significant effect on E/A (MD = −0.02, 95% CI = −0.16 to 0.11, I^2 = 64.85%).[42]

In adolescents and children, HIIT significantly reduced SBP (MD = −2.73 mmHg, 95% CI = −4.67 to −0.79, I^2 = 65%)[43] and DBP (MD = −2.42 mmHg, 95% CI = −4.45 to −0.38, I^2 = 70%)[43] compared with no exercise, and significantly increased maximal HR (MD = 5.91 bpm, 95% CI = 1.24 to 10.58, I^2 = 97%).[43]

In older adults, HIIT significantly reduced SBP (SMD = −0.29, 95% CI = −0.54 to −0.03, I^2 = 0%)[44] and RHR (SMD = −0.36, 95% CI = −0.67 to −0.05, I^2 = 0%)[44] compared with no exercise, but did not significantly reduce DBP (SMD = −0.25, 95% CI = −0.61 to 0.11, I^2 = 36.1%).[44]

In females, HIIT significantly reduced RHR (SMD = −0.50, 95% CI = −0.87 to −0.12, I^2 = 0%)[45] compared with no exercise, but did not significantly reduce SBP (SMD = −0.44, 95% CI = −0.96 to 0.08, I^2 = 33.9%)[45] or DBP (SMD = −0.33, 95% CI = −0.94 to 0.28, I^2 = 51.54%).[45]

3.5.2. HIIT vs. other exercise

In adults, HIIT was significantly less effective than isometric exercise in improving SBP (MD = 5.29 mmHg, 95% CI = 3.97 to 6.61, I^2 = 86%)[46] and DBP (MD = 3.25 mmHg, 95% CI = 2.53 to 3.96, I^2 = 70%),[46] but significantly more effective than isometric exercise in lowering RHR (MD = −2.45 bpm, 95% CI = −3.31 to −1.78, I^2 = 22%).[46] As compared to MICT, HIIT did not significantly reduce SBP (SMD = −0.31, 95% CI = −0.64 to −0.02, I^2 = 0%)[47] or DBP (SMD = 0.09, 95% CI = −0.36 to 0.54, I^2 = 49%).[47]

In adolescents and children, HIIT did not significantly reduce SBP (SMD = −0.35, 95% CI = −0.78 to 0.09, I^2 = 58.3%)[48] or DBP (SMD =

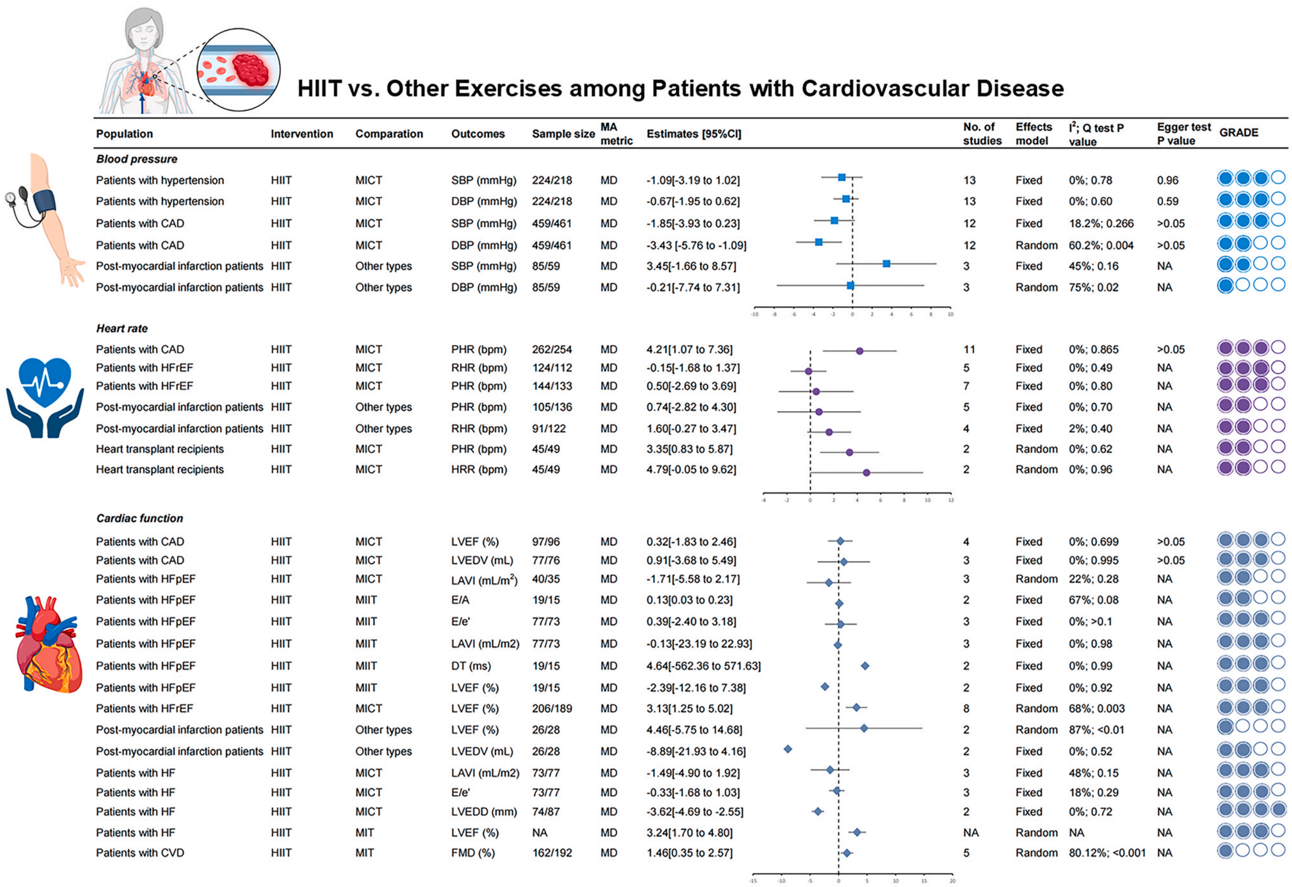

Fig. 3. Forest plot comparing HIIT versus other exercises among patients with cardiovascular disease. Panel A (MD) and Panel B (SMD). CAD, coronary artery disease; HFrEF, heart failure with reduced ejection fraction; HFpEF, heart failure with preserved ejection fraction; HF, heart failure; MIIT; moderate-intensity interval training; MIT, moderate intensity training; HRR, heart rate reserve; E/E′, early diastolic mitral inflow velocity/early diastolic mitral annular tissue velocity; E/A, early diastolic mitral inflow velocity/late diastolic mitral inflow velocity; DT, deceleration time; NA, not available. Effect sizes of HRR, PHR, LVEF, FMD, E/A, and DT on the right side of the central axis indicate support for HIIT; effect sizes of SBP, DBP, RHR, LAVI, and E/E′ on the left side of the central axis indicate support for HIIT. LVEDV and LVEDD require comprehensive evaluation based on disease characteristics and other indicators.

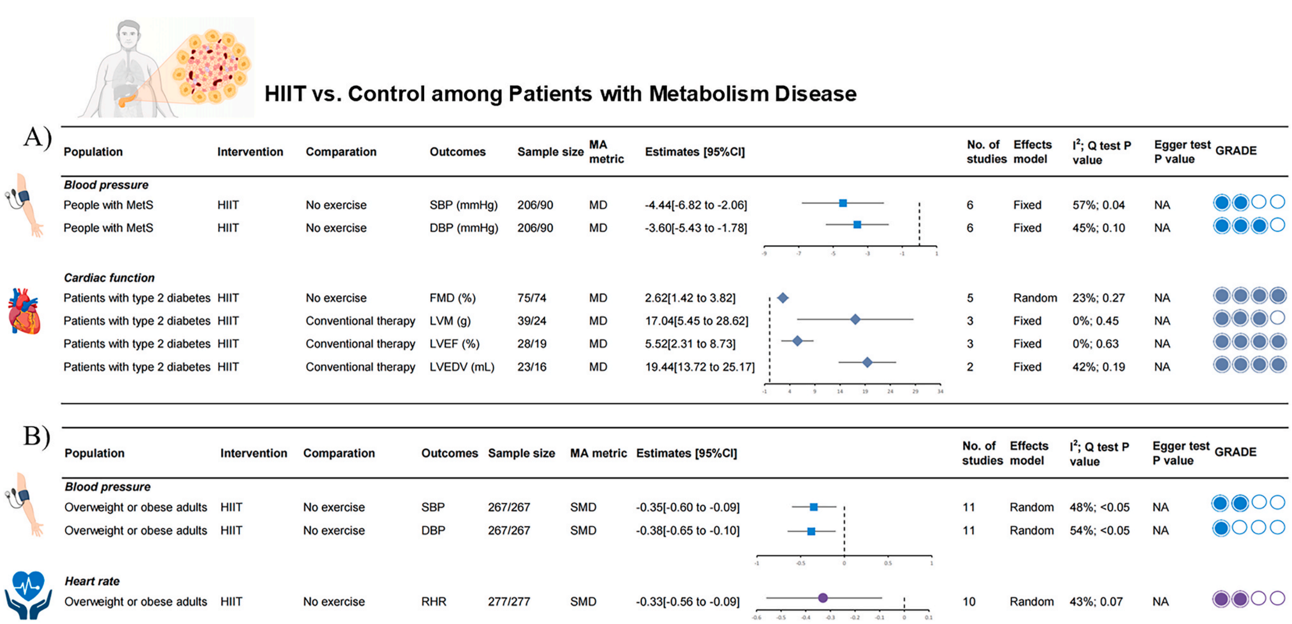

Fig. 4. Forest plot comparing HIIT versus no exercise or conventional therapy among patients with metabolism disease. Panel A (MD) and Panel B (SMD). LVM, left ventricular mass, NA, not available. Effect sizes of LVEF, LVM, and FMD on the right side of the central axis indicate support for HIIT; effect sizes of SBP, DBP, and RHR on the left side of the central axis indicate support for HIIT. LVEDV require comprehensive evaluation based on disease characteristics.

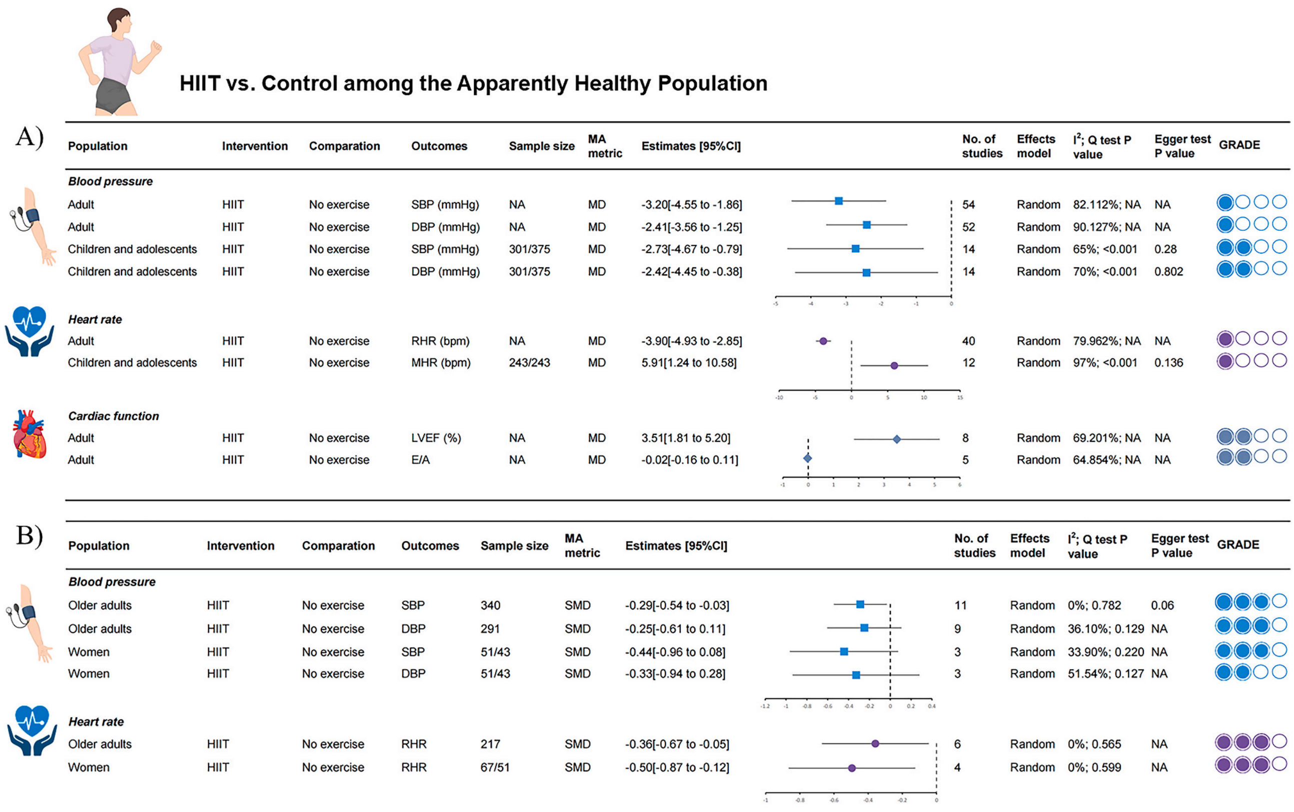

Fig. 5. Forest plot comparing HIIT versus no exercise or conventional therapy in apparently healthy population. Panel A (MD) and Panel B (SMD). MHR, maximum heart rate; NA, not available. Effect sizes of LVEF, MHR and E/A on the right side of the central axis indicate support for HIIT; effect sizes of SBP, DBP, and RHR on the left side of the central axis indicate support for HIIT.

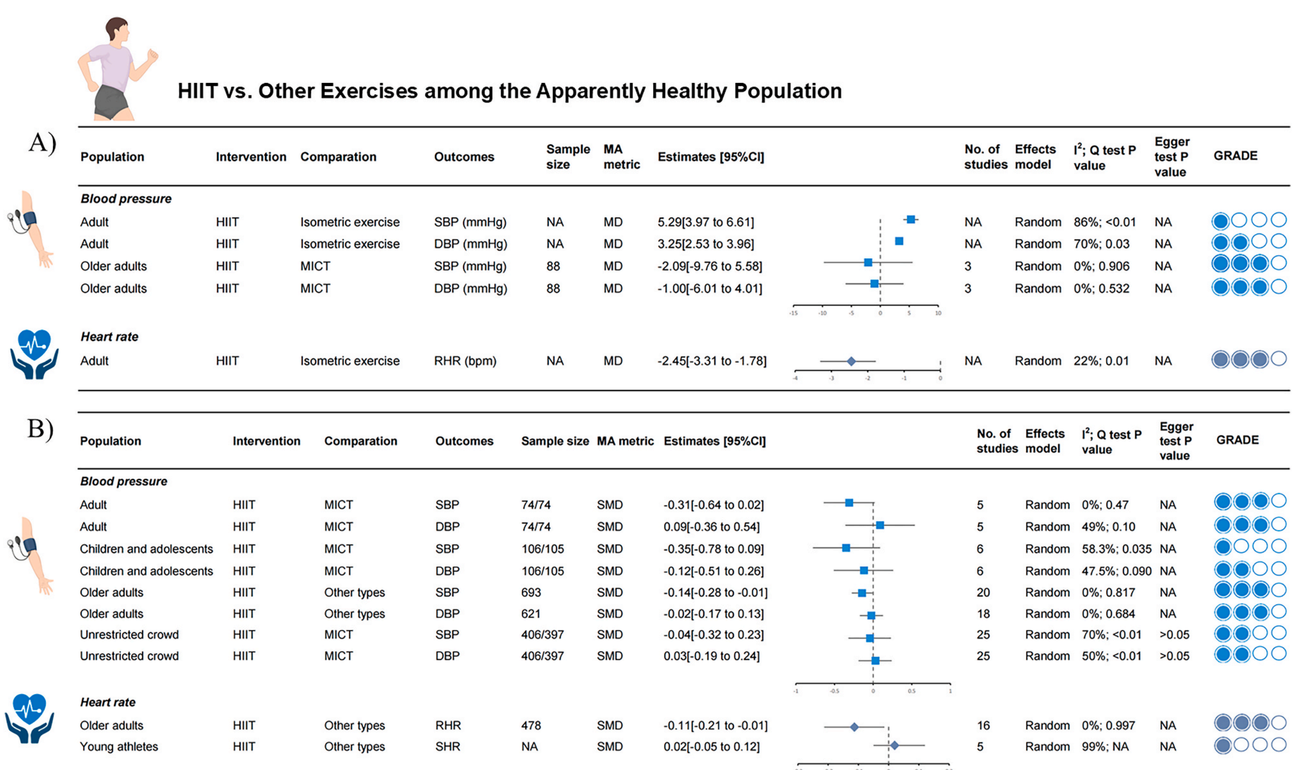

Fig. 6. Forest plot comparing HIIT versus other exercises in apparently healthy population. Panel A (MD) and Panel B (SMD). SHR, submaximal heart rate; NA, not available. Effect sizes of SHR on the right side of the central axis indicate support for HIIT; effect sizes of SBP, DBP, and RHR on the left side of the central axis indicate support for HIIT.

−0.12, 95% CI = −0.51 to 0.26, I^2 = 47.5%)[48] as compared to MICT.

In older adults, HIIT did not significantly reduce SBP (MD = −2.09 mmHg, 95% CI = −9.76 to 5.58, I^2 = 0%)[49] or DBP (MD = −1.00 mmHg, 95% CI = −6.01 to 4.01, I^2 = 0%)[49] as compared to MICT. Compared with other exercise, HIIT significantly reduced SBP (SMD = −0.14, 95% CI = −0.28 to −0.01, I^2 = 0%) [44] and RHR (SMD = −0.11, 95% CI = −0.21 to −0.01, I^2 = 0%),[44] but did not significantly reduce DBP (SMD = −0.02, 95% CI = −0.17 to 0.13, I^2 = 0%).[44]

In young athletes, HIIT did not significantly raise submaximal HR (SMD = 0.02, 95% CI = −0.05 to 0.12, I^2 = 99%)[50] compared with other exercise.

In any population (unrestricted crowd), HIIT did not significantly decrease SBP (SMD = −0.04, 95% CI = −0.32 to 0.23, I^2 = 70%)[51] or DBP (SMD = 0.03, 95% CI = −0.19 to 0.24, I^2 = 50%)[51] compared with MICT.

4. Discussion

This is the first UR of the effects of HIIT on CV health, including 54 systematic reviews and meta-analyses, yielding 88 distinct pooled effect sizes. The results revealed that HIIT was generally more effective than no exercise or conventional therapy in improving BP, HR, and cardiac structure and function. However, compared with other exercise (especially MICT), HIIT showed advantages only in improving LVEF, LVEDD, E/A, and FMD, and the effectiveness of different HIIT prescriptions may vary. Therefore, HIIT prescriptions should be individually designed based on the specific characteristics and needs of different populations. Nevertheless, due to inherent limitations of exercise intervention research (e.g., lack of blinding, high protocol heterogeneity), the GRADE ratings of the included evidence were generally low to moderate. Therefore, our findings should be interpreted with caution and considered as provisional guidance until higher-quality evidence becomes available.

4.1. *Efficacy of HIIT vs. No exercise or conventional therapy*

This UR showed that HIIT generally more effective than no exercise or conventional therapy in improving SBP (−5.43 to −2.73 mmHg), DBP (−4.35 to −2.41 mmHg), RHR (−4.35 to −2.17 bpm), LVEF (3.51%-5.52%), and LVM (5.45-28.62 g). The ability of HIIT to improve vascular endothelial function and modulate the autonomic nervous system[52,53] has been verified previously, which induces changes in BP and HR.[54] Moreover, HIIT can cause physiological cardiac remodeling, induce myocardial thickening, increase the capillary density, and raise the blood pumping efficiency, thereby affecting the parameters of cardiac structure and function.[55,56] This UR corroborated the relevant findings of included studies in real-world applications. However, clear guidelines for HIIT prescriptions across populations are still lacking in existing studies. The use of HIIT is hindered by safety concerns of acute CV events,[57,58] and physiological tolerance, dependence, and mental stress in specific groups.[59,60]

This UR further offered evidence support for the use of HIIT in specific disease groups. Specifically, the positive effects of HIIT on patients with CVD (hypertension, coronary artery disease, post-percutaneous coronary intervention, heart transplant, carotid atherosclerosis, and in heart failure with reduced ejection fraction) were fully verified by the available evidence. Notably, in addition to significantly lowering BP in hypertensive patients and modulating HR in patients with hypertension and heart transplant, HIIT significantly decreased CIMT in patients with carotid atherosclerosis and significantly elevated LVEF in heart failure with reduced ejection fraction patients, without significantly altering LVEDV. These findings demonstrate that HIIT not only meets the intended goals in the treatment for specific groups such as HF, but also may offer specific advantages, such as significant improvement in cardiac systolic function through short-term high-intensity training while avoiding the possible pathological ventricular remodeling due to long-term volume overload.[61–63].

The available evidence suggested that in patients with metabolic disease, HIIT effectively reduced BP in adults with MetS, overweight, or obesity, modulated HR in overweight or obese adults, and significantly improved vascular endothelial function, LVM, LVEF, and LVEDV in T2DM patients. Different from previous studies that focused on the improving effect of HIIT on blood metabolic indicators (e.g., HDL, glycated hemoglobin, insulin),[4,36] we analyzed indicators of CV structure and function (e.g., LVEF, LVM, LVEDV), which could effectively reflect and predict the risk of CV deterioration and pathological remodeling in patients with metabolic disease due to metabolic function decline.[64,65] The findings will provide more comprehensive and detailed evidence for the development of exercise prescriptions for patients with metabolic disease.

HIIT failed to significantly improve HR and BP in MSD populations, which was possibly attributed to the comparisons. Specifically, the comparator conditions in the included studies included routine care, small-scale interventions, or no exercise.[41] These comparators were not true inactive controls and may themselves have provided some physiological benefits, potentially attenuating the additional effect of HIIT. Despite the limited effect, HIIT with high time-efficiency reduces the risk of musculoskeletal fatigue and rapidly stimulates muscle adaptability to improve function,[66,67] which may still be an important intervention for metabolic and CV dysfunction resulting from lack of exercise in MSD patients.[68]

This UR also synthesized evidence in apparently healthy populations. Except for DBP in the elderly and SBP and DBP in females, BP and HR were significantly regulated by HIIT across populations. We found that females of higher age, mainly elderly females, were included in the original studies in meta-analyses on SBP and DBP,[45] which may account for the above non-significant result. In adults, HIIT increased LVEF but did not significantly affect E/A, indicating that HIIT may preferentially enhance cardiac systolic function, but it is less effective or takes longer to improve diastolic function.[69,70] Overall, HIIT achieves stronger efficacy than no exercise or conventional therapy.

4.2. *Efficacy of HIIT vs. other exercise*

This UR revealed that HIIT showed advantages over other exercise (e.g., MICT, MIIT) only in improving LVEF, LVEDD, E/A, and FMD. In terms of exercise characteristics, HIIT is more intense, and thus more significantly stimulates myocardial contraction and induces stronger physiological adaptability than moderate-intensity exercise.[67,71] In contrast, moderate-intensity exercise, especially MICT, produces less stimulation on myocardial contraction, but it can persistently accumulate the improvement effect. To sum up, HIIT with high-intensity acute stimulation may be more advantageous in improving physiological remodeling of cardiac structure and volume,[72,73] while the effects of HIIT and MICT on the indicators that require long-term adaptive stimulation such as BP and HR[74,75] are likely to be more influenced by overall volume of exercise.[76] No clear guidelines are yet available for the selection of HIIT versus MICT in clinical treatment and public health,[71] and this UR offered evidence-based support for the use of HIIT and other exercise across applications.

In patients with CVD, HIIT was more effective in improving BP and HR only in patients with coronary artery disease and heart transplant patients, and it had no advantage over other exercise in most groups (HF, post-MI, and hypertension). HIIT significantly improved FMD as compared to MIT in patients with CVD, and HIIT was better than MICT and MIIT in improving E/A, LVEF, and LVEDD in HF patients. This evidence suggests that transient hemodynamic changes triggered by HIIT are more likely to induce changes in cardiac structure and volume, facilitate adaptive cardiomyocyte hypertrophy and elevation of ejection fraction, and reverse ventricular dilatation compared with moderate-intensity exercise.[77,78] HIIT and moderate-intensity exercise may exert similar regulatory effects on BP, i.e., they may both modulate BP through common mechanisms such as improving endothelial function[52] and relieving systemic inflammation.[51] Due to similarities in the total energy expenditure or vasodilatory effects, HIIT and other exercise produced comparable effects in the included studies. To sum up, HIIT may be considered a preferred option for HF and ischemic cardiomyopathy patients who undergo treatment mainly to improve cardiac structure and volume, while exercise prescriptions should be developed taking into account the intensity, volume, and time efficiency of different exercise for patients who undergo treatment mainly to improve BP and HR. In the UR, the cardiac structure and function of some groups such as post-MI patients did not benefit significantly from HIIT, which may be attributed to the limited number of original studies and great heterogeneity.[11] In addition, patient adherence to HIIT and therapists' effective supervision and control of exercise intensity and volume may also be important influencing factors for the results.[57,79] Therefore, despite the lack of evidence supporting the benefits of HIIT in individual CVD populations, HIIT remains a potentially more valuable and advocated intervention in the CVD rehabilitation.

In metabolic disease populations (overweight or obese adolescents and children, and T2DM patients), HIIT far outperformed MICT only in improving SBP in overweight or obese adolescents and children. HIIT shares the same or similar mechanisms with MICT in improving BP and regulating HR, and BP is more dependent on long-term cumulative energy expenditure and chronic adaptations of the autonomic nervous system.[80] It is possible that overweight or obese adolescents and children without severe CVD have milder metabolic disorders, which might allow for better adherence to HIIT. However, this potential explanation requires further investigation.

In the apparently healthy adults, adolescents, and children, HIIT exhibited no prominent advantage in lowering BP and modulating HR. However, HIIT displayed a non-negligible advantage in time in this population, especially in adults. HIIT consumes more energy per unit of time[81] and can maintain an increasing oxygen consumption rate 24-48 h post-exercise,[82] which, as short-duration, high-intensity exercise, is more in line with the rapid pace of modern life.[83] To sum up, we obtained sufficient evidence that HIIT outperformed no exercise or conventional therapy in improving the indicators of CV structure and function (e.g., LVEF, LVEDV) in populations with metabolic disease and apparently healthy individuals, but a comparison of the benefits of HIIT versus MICT is lacking in these populations.

4.3. *Safety considerations and prescription caution*

When discussing the cardiovascular benefits of HIIT, attention must also be paid to its safety. The high-intensity stimulation of HIIT induces rapid fluctuations in heart rate and blood pressure. The double product (heart rate × systolic blood pressure), a key indicator of myocardial oxygen consumption,[84] reaches high levels during HIIT. For patients with cardiovascular disease or individuals with occult cardiovascular risk, such acute hemodynamic changes may precipitate myocardial ischemia or arrhythmias.[85] Of note, the meta-analyses included in this umbrella review generally lacked systematic reporting of adverse events, yet safety is a critical aspect that cannot be overlooked in clinical practice. Therefore, adequate medical screening should be conducted before HIIT implementation, and real-time monitoring of heart rate and perceived exertion is required during exercise,[86] with clear termination criteria such as chest pain, dizziness, or sharp fluctuations in blood pressure.[86,87] The risk-benefit ratio of HIIT needs to be individualized: for clinically stable patients, the improvements in cardiac structure and function may outweigh the potential risks; however, for individuals with unstable conditions, recent acute events, or severe comorbidities, moderate-intensity continuous training may be a safer alternative. HIIT should not be considered a one-size-fits-all protocol but should be individually designed based on the patient's age, underlying disease status, cardiorespiratory fitness, and exercise history. These findings may be generalizable to similar populations, but differences in facility settings, health status, and supervision should be considered when applying HIIT in practice.

4.4. *Limitations of this review*

This is the first UR of the evidence on the effects of HIIT on CV health, and it acts as a preliminary guide for the use of HIIT in clinical and public health settings. However, some methodological limitations are worth noting. First, we categorized the included studies based on the study population and comparisons using the UR methods of Poole et al.[20] and Huang et al.[21] to minimize overlapping of evidence, and prioritized studies that were more up-to-date and of higher quality. However, minor omission of evidence was inevitable. Second, the quality of a UR depends to some extent on the quality of the included studies. Methodological biases in the included studies may affect the quality assessment and the accuracy of results, and publication bias cannot be fully ruled out despite Egger's tests showing no significant bias in some comparisons. Third, most of the included meta-analyses did not differentiate between different HIIT protocols, such as long-interval versus short-interval HIIT. As a result, the synthesized evidence in this umbrella review supports the overall effectiveness of HIIT but does not permit protocol-level comparisons or recommendations. Future studies directly comparing different HIIT protocols are needed. Fourth, considerable heterogeneity ($I^2 > 75\%$) was observed in some comparisons, which may reduce the reliability of those specific findings and warrants cautious interpretation. This heterogeneity may stem from several factors, such as the pooling of different comparator conditions (e.g., no exercise versus conventional therapy), variations in HIIT protocols (e.g., intensity, interval duration, and frequency)[88,89], and differences in participant characteristics across studies. In addition, the comparator category "no exercise or conventional therapy" combined two distinct control conditions that may have different effects on cardiovascular outcomes. This pooling may have introduced heterogeneity and should be considered when interpreting the findings. Finally, although this umbrella review covered four major population categories (cardiovascular disease, metabolic disease, musculoskeletal disease, and apparently healthy individuals), the number of available meta-analyses for some specific subpopulations (e.g., specific types of cardiovascular disease) was limited[90]. Consequently, the evidence within these subcategories remains less comprehensive, and further studies are needed to strengthen the conclusions. In the future, the sample size should be expanded to cover more diverse populations, and the specific effects and mechanisms of HIIT in different health conditions[91] should be further investigated.

5. Conclusions

HIIT demonstrates clear cardiovascular benefits compared with no exercise across most populations. Its advantages over other exercise modalities are specific to cardiac structure and volume (e.g., LVEF, LVEDD), with comparable effects on blood pressure and heart rate. These benefits were observed across patients with cardiovascular diseases, metabolic disorders, and apparently healthy individuals. However, the current evidence does not support protocol-specific recommendations, and direct comparisons of different HIIT protocols are needed.

Prospero

Registration number: CRD420251027905.

Ethics approval and consent to participate

Not applicable.

Consent for publication

This manuscript is a systematic review and meta-analysis that synthesizes data from previously published studies. All data utilized are aggregate and anonymized, with no personally identifiable information included. Therefore, individual consent for publication was not required.

Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

All authors contributed to the study conception and design. Writing - original draft preparation: [Minghui Du]; Writing - review and editing: [Mingyue Yin, Bopeng Qiu, Kai Xu]; Conceptualization: [Minghui Du, Mingyue Yin]; Methodology: [Minghui Du, Mingyue Yin, Bopeng Qiu, Liang Xia, Enyi Ma]; Formal analysis and investigation: [Minghui Du, Ying Bai, Xinyu Zeng, Enyi Ma, Liang Xia, Wei Zhang]; Supervision: [Mingyu Yin],and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding statement

This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Figs. 2–6, S1-S2, and the Graphical Abstract were created using BioRender (https://biorender.com) under an academic open-access publication license. The corresponding citations are:

Fig. 2: Created in BioRender. Du, M. (2026) https://BioRender.com/ix00pad.

Fig. 3: Created in BioRender. Du, M. (2026) https://BioRender.com/4mqenp0.

Fig. 4: Created in BioRender. Du, M. (2026) https://BioRender.com/p4d0o7j.

Fig. 5: Created in BioRender. Du, M. (2026) https://BioRender.com/boijle3.

Fig. 6: Created in BioRender. Du, M. (2026) https://BioRender.com/79v1xx6.

Fig. S1: Created in BioRender. Du, M. (2026) https://BioRender.com/q6uj8d6.

Fig. S2: Created in BioRender. Du, M. (2026) https://BioRender.com/c266nbb.

Graphical Abstract: Created in BioRender. Du, M. (2026) https://BioRender.com/6hth3j8.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jesf.2026.200495.

References

1. Coates AM, Joyner MJ, Little JP, et al. A perspective on high-intensity interval training for performance and health. *Sports Med*. Dec 2023;53(Suppl 1):85–96.
2. Buchheit M, Laursen PB. High-intensity interval training, solutions to the programming puzzle: part I: cardiopulmonary emphasis. *Sports Med*. May 2013;43(5):313–338.
3. Poon ET, Li HY, Gibala MJ, et al. High-intensity interval training and cardiorespiratory fitness in adults: an umbrella review of systematic reviews and meta-analyses. *Scand J Med Sci Sports*. May 2024;34(5), e14652.
4. Poon ET, Li HY, Kong APS, et al. Efficacy of high-intensity interval training in individuals with type 2 diabetes mellitus: an umbrella review of systematic reviews and meta-analyses. *Diabetes Obes Metabol*. Apr 2025;27(4):1719–1734.
5. Poon ET, Sum WM, Lubans D, et al. High-intensity interval training for improving cardiometabolic health in children and adolescents: an umbrella review of systematic reviews. *J Sports Sci*. Dec 2024;42(23):2199–2215.
6. Scott J. Pathophysiology and biochemistry of cardiovascular disease. *Curr Opin Genet Dev*. Jun 2004;14(3):271–279.
7. Lin CC, Li CI, Liu CS, et al. Association of echocardiographic parameters with all-cause and cardiovascular mortality in patients with type 2 diabetes. *Int J Cardiol*. Aug 1 2024;408, 132136.
8. Carberry J, Petrie MC, Lee MMY, et al. Empagliflozin to prevent worsening of left ventricular volumes and systolic function after myocardial infarction (EMPRESS-MI). *Eur J Heart Fail*. Mar 2025;27(3):566–576.
9. Duprez DA, Duval S, Hoke L, et al. Early cardiovascular structural and functional abnormalities as a guide to future morbid events. *Eur J Prev Cardiol*. Sep 20 2021;28(11):1214–1221.
10. Yang C, Zhang L, Cheng Y, et al. High intensity interval training vs. moderate intensity continuous training on aerobic capacity and functional capacity in patients with heart failure: a systematic review and meta-analysis. *Front Cardiovasc Med*. 2024;11, 1302109.
11. Qin Y, Kumar Bundhun P, Yuan ZL, et al. The effect of high-intensity interval training on exercise capacity in post-myocardial infarction patients: a systematic review and meta-analysis. *Eur J Prev Cardiol*. Mar 25 2022;29(3):475–484.
12. Tucker WJ, Beaudry RI, Liang Y, et al. Meta-analysis of exercise training on left ventricular ejection fraction in heart failure with reduced ejection fraction: a 10-year update. *Prog Cardiovasc Dis*. Mar-Apr 2019;62(2):163–171.
13. Jianghua H, Feier M, Dong Z, et al. Meta-analysis of the effects of different exercise modes on cardiac function and peak oxygen uptake in patients with type 2 diabetes mellitus. *Front Physiol*. 2024;15, 1448385.
14. Fernandez R, Sharifnia AM, Khalil H. Umbrella reviews: a methodological guide. *Eur J Cardiovasc Nurs*. Jan 23 2025;24(6):996–1002.
15. Guy Faulkner MJF, Lee Jacqueline. Umbrella reviews (systematic review of reviews). *Int Rev Sport Exerc Psychol*. 2021;15(1):73–90.
16. Fusar-Poli P, Radua J. Ten simple rules for conducting umbrella reviews. *Evid Base Ment Health*. Aug 2018;21(3):95–100.
17. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ*. 2017;358:j4008.
18. Guyatt G, Oxman AD, Akl EA, et al. GRADE guidelines: 1. Introduction-GRADE evidence profiles and summary of findings tables. *J Clin Epidemiol*. Apr 2011;64(4):383–394.
19. Balshem H, Helfand M, Schünemann HJ, et al. GRADE guidelines: 3. Rating the quality of evidence. *J Clin Epidemiol*. Apr 2011;64(4):401–406.
20. Poole R, Kennedy OJ, Roderick P, et al. Coffee consumption and health: umbrella review of meta-analyses of multiple health outcomes. *Br Med J*. Nov 22 2017;359, j5024.
21. Huang Y, Chen Z, Chen B, et al. Dietary sugar consumption and health: umbrella review. *Br Med J*. Apr 5 2023;381, e071609.
22. DerSimonian R, Laird N. Meta-analysis in clinical trials revisited. *Contemp Clin Trials*. Nov 2015;45(Pt A):139–145.
23. de Souza Mesquita FO, Gambassi BB, de Oliveira Silva M, et al. Effect of high-intensity interval training on exercise capacity, blood pressure, and autonomic responses in patients with hypertension: a systematic review and meta-analysis. *Sports Health*. Jul-Aug 2023;15(4):571–578.
24. Conceição LSR, Gois CO, Fernandes RES, et al. Effect of high-intensity interval training on aerobic capacity and heart rate control of heart transplant recipients: a systematic review with meta-analysis. *Braz J Cardiovasc Surg*. Feb 1 2021;36(1):86–93.
25. Gao P, Zhang X, Yin S, et al. Meta-analysis of the effect of different exercise mode on carotid atherosclerosis. *Int J Environ Res Public Health*. Jan 25 2023;20(3):2189.
26. Zhang X, Xu D, Sun G, et al. Effects of high-intensity interval training in patients with coronary artery disease after percutaneous coronary intervention: a systematic review and meta-analysis. *Nurs Open*. May 2021;8(3):1424–1435.
27. Luo P, Wu R, Gao W, et al. Effects of high-intensity interval exercise on arterial stiffness in individuals at risk for cardiovascular disease: a meta-analysis. *Front Cardiovasc Med*. 2024;11, 1376861.
28. Li L, Liu X, Shen F, et al. Effects of high-intensity interval training versus moderate-intensity continuous training on blood pressure in patients with hypertension: a meta-analysis. *Medicine (Baltim)*. Dec 16 2022;101(50), e32246.
29. Gao C, Yue Y, Wu D, et al. Effects of high-intensity interval training versus moderate-intensity continuous training on cardiorespiratory and exercise capacity in patients with coronary artery disease: a systematic review and meta-analysis. *PLoS One*. 2025;20(2), e0314134.
30. Siddiqi TJ, Rashid AM, Javaid SS, et al. High-intensity interval training versus moderate continuous training in patients with heart failure with preserved ejection fraction: a systematic review and meta-analysis. *Curr Probl Cardiol*. Aug 2023;48(8), 101720.

31. Lai P, Xue JH, Xie MJ, et al. High-intensity and moderate-intensity interval training in heart failure with preserved ejection fraction: a meta-analysis of randomized controlled trials. *Medicine (Baltim)*. Feb 22 2023;102(8), e33010.
32. Qi Z, Zheng Y, Chan JSK, et al. Exercise-based cardiac rehabilitation for left ventricular function in patients with heart failure: a systematic review and meta-analysis. *Curr Probl Cardiol*. Feb 2024;49(2), 102210.
33. Edwards J, Shanmugam N, Ray R, et al. Exercise mode in heart failure: a systematic review and meta-analysis. *Sports Med Open*. Jan 9 2023;9(1):3.
34. Fuertes-Kenneally L, Blasco-Peris C, Casanova-Lizón A, et al. Effects of high-intensity interval training on vascular function in patients with cardiovascular disease: a systematic review and meta-analysis. *Front Physiol*. 2023;14, 1196665.
35. Qiu B, Zhou Y, Tao X, et al. The effect of exercise on flow-mediated dilation in people with type 2 diabetes mellitus: a systematic review and meta-analysis of randomized controlled trials. *Front Endocrinol (Lausanne)*. 2024;15, 1347399.
36. Serrablo-Torrejon I, Lopez-Valenciano A, Ayuso M, et al. High intensity interval training exercise-induced physiological changes and their potential influence on metabolic syndrome clinical biomarkers: a meta-analysis. *BMC Endocr Disord*. Nov 10 2020;20(1):167.
37. Batacan Jr RB, Duncan MJ, Dalbo VJ, et al. Effects of high-intensity interval training on cardiometabolic health: a systematic review and meta-analysis of intervention studies. *Br J Sports Med*. Mar 2017;51(6):494–503.
38. Qiu S, Cai X, Yin H, et al. Exercise training and endothelial function in patients with type 2 diabetes: a meta-analysis. *Cardiovasc Diabetol*. May 2 2018;17(1):64.
39. Cao M, Tang Y, Li S, et al. Effects of high-intensity interval training and moderate-intensity continuous training on cardiometabolic risk factors in overweight and obesity children and adolescents: a meta-analysis of randomized controlled trials. *Int J Environ Res Public Health*. Nov 12 2021;18(22), 11905.
40. García-Hermoso A, Cerrillo-Urbina AJ, Herrera-Valenzuela T, et al. Is high-intensity interval training more effective on improving cardiometabolic risk and aerobic capacity than other forms of exercise in overweight and obese youth? A meta-analysis. *Obes Rev*. Jun 2016;17(6):531–540.
41. Casaña J, Varangot-Reille C, Calatayud J, et al. High-intensity interval training (HIIT) on biological and body composition variables in patients with musculoskeletal disorders: a systematic review and meta-analysis. *J Clin Med*. Nov 24 2022;11(23):6937.
42. Edwards JJ, Griffiths M, Deenmamode AHP, et al. High-intensity interval training and cardiometabolic health in the general population: a systematic review and meta-analysis of randomised controlled trials. *Sports Med*. Sep 2023;53(9):1753–1763.
43. Men J, Zou S, Ma J, et al. Effects of high-intensity interval training on physical morphology, cardiorespiratory fitness and metabolic risk factors of cardiovascular disease in children and adolescents: a systematic review and meta-analysis. *PLoS One*. 2023;18(5), e0271845.
44. Liang W, Wang X, Cheng S, et al. Effects of high-intensity interval training on the parameters related to physical fitness and health of older adults: a systematic review and meta-analysis. *Sports Med Open*. Sep 12 2024;10(1):98.
45. Kwok MMY, Ng SSM, Man SS, et al. The effect of aquatic high intensity interval training on cardiometabolic and physical health markers in women: a systematic review and meta-analysis. *J Exerc Sci Fit*. Apr 2022;20(2):113–127.
46. Edwards J, De Caux A, Donaldson J, et al. Isometric exercise versus high-intensity interval training for the management of blood pressure: a systematic review and meta-analysis. *Br J Sports Med*. May 2022;56(9):506–514.
47. Yin M, Li H, Bai M, et al. Is low-volume high-intensity interval training a time-efficient strategy to improve cardiometabolic health and body composition? A meta-analysis. *Appl Physiol Nutr Metab*. Mar 1 2024;49(3):273–292.
48. Wang Y, Wang S, Meng X, et al. Effect of high-intensity interval training and moderate-intensity continuous training on cardiovascular risk factors in adolescents: systematic review and meta-analysis of randomized controlled trials. *Physiol Behav*. Mar 1 2024;275, 114459.
49. Carpes L, Costa R, Schaarschmidt B, et al. High-intensity interval training reduces blood pressure in older adults: a systematic review and meta-analysis. *Exp Gerontol*. Feb 2022;158, 111657.
50. Engel FA, Ackermann A, Chtourou H, et al. High-intensity interval training performed by young athletes: a systematic review and meta-analysis. *Front Physiol*. 2018;9:1012.
51. Mattioni Maturana F, Martus P, Zipfel S, et al. Effectiveness of HIIE versus MICT in improving cardiometabolic risk factors in health and disease: a meta-analysis. *Med Sci Sports Exerc*. Mar 1 2021;53(3):559–573.
52. Schmederer Z, Rolim N, Bowen TS, et al. Endothelial function is disturbed in a hypertensive diabetic animal model of HFpEF: moderate continuous vs. high intensity interval training. *Int J Cardiol*. Dec 15 2018;273:147–154.
53. Soori R, Amini AA, Choobineh S, et al. Exercise attenuates myocardial fibrosis and increases angiogenesis-related molecules in the myocardium of aged rats. *Arch Physiol Biochem*. Feb 2022;128(1):1–6.
54. Nakao K, Kuwahara K, Nishikimi T, et al. Endothelium-derived C-Type natriuretic peptide contributes to blood pressure regulation by maintaining endothelial integrity. *Hypertension*. Feb 2017;69(2):286–296.
55. Wang B, Zhou R, Wang Y, et al. Effect of high-intensity interval training on cardiac structure and function in rats with acute myocardial infarct. *Biomed Pharmacother*. Nov 2020;131, 110690.
56. Bo B, Nguyen T, Nakada Y, et al. Abstract 4141348: high-intensity interval training improves cardiac function and increases expression of genes promoting cardiomyocyte proliferation in myocardial-infarcted mice. *Circulation*. 2024;150 (suppl l_1). A4141348-A4141348.
57. Quindry JC, Franklin BA, Chapman M, et al. Benefits and risks of high-intensity interval training in patients with coronary artery disease. *Am J Cardiol*. Apr 15 2019; 123(8):1370–1377.
58. Keech A, Holgate K, Fildes J, et al. High-intensity interval training for patients with coronary artery disease: finding the optimal balance. *Int J Cardiol*. Jan 1 2020;298: 8–14.
59. Ellingsen Ø, Halle M, Conraads V, et al. High-intensity interval training in patients with heart failure with reduced ejection fraction. *Circulation*. Feb 28 2017;135(9): 839–849.
60. Taylor JL, Holland DJ, Keating SE, et al. Short-term and long-term feasibility, safety, and efficacy of high-intensity interval training in cardiac rehabilitation: the FITR heart study randomized clinical trial. *JAMA Cardiol*. Dec 1 2020;5(12):1382–1389.
61. O'Driscoll JM, Wright SM, Taylor KA, et al. Cardiac autonomic and left ventricular mechanics following high intensity interval training: a randomized crossover controlled study. *J Appl Physiol*. Oct 1 2018;125(4):1030–1040, 1985.
62. Maleki F, Mehrabani J. Right ventricular remodeling induced by prolonged excessive endurance exercise is mediated by upregulating Wnt/β-catenin signaling in rats. *Int J Cardiol*. Oct 15 2024;413, 132316.
63. Mahanty A, Xi L. Utility of cardiac biomarkers in sports medicine: focusing on troponin, natriuretic peptides, and hypoxanthine. *Sports Med Health Sci*. Jun 2020;2 (2):65–71.
64. Peterzan MA, Lygate CA, Neubauer S, et al. Metabolic remodeling in hypertrophied and failing myocardium: a review. *Am J Physiol Heart Circ Physiol*. Sep 1 2017;313 (3):H597–h616.
65. Dhalla NS, Shah AK, Tappia PS. Role of oxidative stress in metabolic and subcellular abnormalities in diabetic cardiomyopathy. *Int J Mol Sci*. Mar 31 2020;21(7):2413.
66. Seo M-Wl Jung-Min, Jung Hyun Chul, Kim Joon Young, Song Jong-Kook. Identification of the optimal hiit protocol for fatigue resistance in adolescent athletes: a randomized controlled trial. *Kinesiology*. 2022;54(2):256–267.
67. Martinez-Valdes E, Farina D, Negro F, et al. Early motor unit conduction velocity changes to high-intensity interval training versus continuous training. *Med Sci Sports Exerc*. Nov 2018;50(11):2339–2350.
68. Bowden Davies KA, Pickles S, Sprung VS, et al. Reduced physical activity in young and older adults: metabolic and musculoskeletal implications. *Ther Adv Endocrinol Metab*. 2019;10, 2042018819888824.
69. Suarez PZ, Natali AJ, Mill JG, et al. Effects of moderate-continuous and high-intensity interval aerobic training on cardiac function of spontaneously hypertensive rats. *Exp Biol Med (Maywood)*. Sep 2022;247(18):1691–1700.
70. Rasmussen IE, Løk M, Durrer CG, et al. Impact of high-intensity interval training on cardiac structure and function after COVID-19: an investigator-blinded randomized controlled trial. *J Appl Physiol*. Aug 1 2023;135(2):421–435, 1985.
71. Taylor JL, Holland DJ, Spathis JG, et al. Guidelines for the delivery and monitoring of high intensity interval training in clinical populations. *Prog Cardiovasc Dis*. Mar-Apr 2019;62(2):140–146.
72. Cavalcante PAP, Mauro, Silva Ariana, et al. Cardiac remodeling and physical exercise: a brief review about concepts and adaptations. *Int J Sports Sci*. 2016:52–61.
73. Stanton KM, Wylie L, Kotchetkova I, et al. Soldiers' heart: a prospective study of cardiac remodeling in soldiers undergoing progressive intensity exercise training. *Med Sci Sports Exerc*. Dec 1 2022;54(12):2011–2019.
74. Domingos-Souza G, Santos-Almeida FM, Meschiari CA, et al. Electrical stimulation of the carotid sinus lowers arterial pressure and improves heart rate variability in L-NAME hypertensive conscious rats. *Hypertens Res*. Oct 2020;43(10):1057–1067.
75. Barton T, Low DA, Thijssen DHJ, et al. Twelve-week daily gluteal and hamstring electrical stimulation improves vascular structure and function, limb volume, and sitting pressure in spinal cord injury: a pilot feasibility study. *Am J Phys Med Rehabil*. Oct 1 2022;101(10):913–919.
76. Jabbarzadeh Ganjeh B, Zeraattalab-Motlagh S, Jayedi A, et al. Effects of aerobic exercise on blood pressure in patients with hypertension: a systematic review and dose-response meta-analysis of randomized trials. *Hypertens Res*. Feb 2024;47(2): 385–398.
77. Krzesiak A, Cognard C, Sebille S, et al. High-intensity intermittent training is as effective as moderate continuous training, and not deleterious, in cardiomyocyte remodeling of hypertensive rats. *J Appl Physiol*. Apr 1 2019;126(4):903–915, 1985.
78. Batista DF, Polegato BF, da Silva RC, et al. Impact of modality and intensity of early exercise training on ventricular remodeling after myocardial infarction. *Oxid Med Cell Longev*. 2020;2020, 5041791.
79. Yu H, Santos-Rocha R, Radzimiński Ł, et al. Effects of 8-Week online, supervised high-intensity interval training on the parameters related to the anaerobic threshold, body weight, and body composition during pregnancy: a randomized controlled trial. *Nutrients*. Dec 11 2022;14(24):5279.
80. Valensi P. Autonomic nervous system activity changes in patients with hypertension and overweight: role and therapeutic implications. *Cardiovasc Diabetol*. Aug 19 2021;20(1):170.
81. Jiang L, Zhang Y, Wang Z, et al. Acute interval running induces greater excess post-exercise oxygen consumption and lipid oxidation than isocaloric continuous running in men with obesity. *Sci Rep*. Apr 22 2024;14(1):9178.
82. Moniz SC, Islam H, Hazell TJ. Mechanistic and methodological perspectives on the impact of intense interval training on post-exercise metabolism. *Scand J Med Sci Sports*. Apr 2020;30(4):638–651.
83. JaJ Plizga, Arkadiusz, Grajnert Filip, et al. High-intensity interval training - health benefits and risks - literature review. *Quality in Sport*. 2024;18, 53359.
84. Gobel FL, Norstrom LA, Nelson RR, et al. The rate-pressure product as an index of myocardial oxygen consumption during exercise in patients with angina pectoris. *Circulation*. Mar 1978;57(3):549–556.
85. Kim YJ, Park KM. Possible mechanisms for adverse cardiac events caused by exercise-induced hypertension in long-distance middle-aged runners: a review. *J Clin Med*. Apr 10 2024;13(8):2184.

86. Price KJ, Gordon BA, Bird SR, et al. A review of guidelines for cardiac rehabilitation exercise programmes: is there an international consensus? *Eur J Prev Cardiol*. Nov 2016;23(16):1715–1733.
87. Ikäheimo TM, Länsitie M, Valtonen R, et al. Good safety practice in a randomized controlled trial (CadColdEx) involving increased cardiac workload in patients with coronary artery disease. *BMC Cardiovasc Disord*. Mar 25 2019;19(1):69.
88. Yin M, Li Y, Aziz AR, et al. Short bouts of accumulated exercise: Review and consensus statement on definition, efficacy, feasibility, practical applications, and future directions. *J Sport Health Sci*. 2025. Published online September 18, 2025.
89. Yin M, Deng S, Deng J, et al. Physiological adaptations and performance enhancement with combined blood flow restricted and interval training: A systematic review with meta-analysis. *J Sport Health Sci*. 2025;14:101030.
90. Wang B, Zeng X, Deng H, et al. High-intensity interval training and moderate-intensity continuous training are effective, feasible, and safe for patients with metabolic dysfunction-associated steatotic liver disease (MASLD): A systematic review and meta-analysis. Metabolism. Published online June 15, 2026.
91. Yang T, Bi S, Zhang X, Yin M, Feng S, Li H. The Impact of Different Intensities of Physical Activity on Serum Urate and Gout: A Mendelian Randomization Study. Metabolites. 2024;14(1):66. Published 2024 Jan 19.