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Effectiveness of High-Intensity Interval Training Protocols in Reducing Visceral Fat Mass and Improving Body Composition

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Abstract

Visceral obesity is a global health challenge requiring effective and time-efficient exercise interventions. This thematic review critically analyzes High-Intensity Interval Training (HIIT) protocols for reducing visceral fat and improving body composition in obese populations across ages. From 187 initially identified records in PubMed, Scopus, and Sinta (2015–2025), 20 original experimental studies met inclusion criteria. Data were thematically coded and synthesized. Results showed that HIIT consistently reduces visceral adipose tissue (VAT) more than Moderate-Intensity Continuous Training (MICT), with VAT reduction ranging 1.5–2.8% in adults and increased fat-free mass (0.5–1.2 kg) in adolescents. The 2:1 work-to-rest ratio (e.g., 60s work/30s rest) emerged as the most effective pattern for enhancing fat oxidation and insulin sensitivity, mediated by irisin and PGC-1α pathways. Quality assessment (PEDro scores: 5–8) indicated moderate-to-good study quality. HIIT is an effective, time-efficient modality for body composition management. Practitioners are advised to implement the 2:1 protocol, though heterogeneity in measurement tools (BIA vs. MRI) warrants cautious interpretation.

Keywords: HIIT, visceral fat, body composition, obesity, thematic review

Introduction

The increase in obesity prevalence has become a significant global health challenge, and Indonesia is no exception. This condition is closely related to food intake and nutritional status, which directly affect an individual's physical fitness level and increase the risk of cardiometabolic diseases from an early age (Meng et al., 2022). This issue is not merely an aesthetic concern but a primary risk factor for various non-communicable diseases due to glucose metabolism disorders and increased systemic inflammatory markers (Allen et al., 2017). One of the most crucial indicators in this metabolic risk is the accumulation of visceral fat, which is biologically more active and pro-inflammatory compared to subcutaneous fat (Andonian et al., 2021). Efforts to counter obesity through physical activity have become a national priority to improve public health status through the utilization of sport science (Finze et al., 2025).

Although physical activity is widely recognized as a primary strategy, the main constraint often faced by the public is time limitation. Busy schedules result in people having less time to exercise regularly, thus requiring more efficient exercise methods (Arad et al., 2020). Traditionally, Moderate-Intensity Continuous Training (MICT) has been considered the standard in weight management; however, this protocol requires a long duration which often leads to low compliance rates (Ramírez-vélez et al., 2016). In this context, High-Intensity Interval Training (HIIT) emerges as a promising alternative. HIIT is not only proven to significantly increase aerobic capacity and vascular function in a short time (Rafiei et al., 2019), but it is also considered more enjoyable and has better compliance rates for inactive individuals (Reljic et al., 2018).

Biomolecularly, the effectiveness of HIIT in reducing visceral fat is associated with the activation of complex metabolic signaling pathways. High intensity in HIIT triggers increased expression of signaling pathways that play a vital role in mitochondrial biogenesis and fatty acid oxidation (Fereshte et al., 2024). Additionally, muscle contractions during HIIT trigger the secretion of myokines such as Irisin, which can induce the browning phenomenon in white adipose tissue (Herrera et al., 2017). These adaptations also include improvements in heart rate variability and cardiac mechanical function, which are often impaired in obese populations (Jalaludeen et al., 2020) and (Navarro et al., 2022). However, to obtain consistent results, clear protocol standardization is required to ensure the effectiveness and safety of the intervention (Finze et al., 2025).

Uncertainty regarding the optimal work-to-rest ratio remains a critical gap in current literature. Shorter recovery durations in HIIT protocols are known to trigger higher body fat loss compared to long recovery periods (Javad et al., 2019). Nonetheless, there is significant variation in total workload and the power output produced between obese and non-obese individuals during interval training (Colpitts et al., 2021). Most previous studies tend to focus on final total body weight results without deeply dissecting how protocol variations affect metabolic profiles through a critical analysis of research methodology quality.

Therefore, this article aims to critically analyze various HIIT protocols through a thematic review approach of current literature. The novelty of this review lies in the identification of patterns or central themes that integrate article quality analysis to provide evidence-based protocol recommendations. The analytical focus is directed toward thematic categorization regarding the effectiveness of intervention ratios on metabolic adaptation mechanisms, which is expected to serve as a strategic guide for coaches and sports practitioners in designing precise exercise programs to optimally address obesity issues.

This review addresses two primary questions: (1) Which HIIT protocol (work-to-rest ratio) is most effective for reducing visceral fat mass? (2) What are the underlying molecular mechanisms? A thematic review approach was chosen to identify patterns across heterogeneous protocols, as meta-analysis was not feasible due to variability in outcome measures and intervention designs.

Methods

Research Design

This study employed a thematic literature review approach to synthesize evidence regarding the effectiveness of High-Intensity Interval Training (HIIT) protocols on visceral fat reduction and hemostatic profile improvements. A thematic review was selected because it enables the identification, analysis, and synthesis of recurring patterns and themes across studies, thereby providing a comprehensive understanding of the mechanisms and outcomes associated with HIIT interventions.

Literature Search Strategy

The literature search was conducted systematically on three databases: PubMed, Scopus, and Sinta, using a combination of Boolean operators. The search string used was: ('HIIT' OR 'high-intensity interval training') AND ('visceral fat' OR 'body composition') AND ('obesity' OR 'overweight'). The publication timeframe was limited to the last ten years (2015–2025) to align with current sports biotechnology standards. Two

Table 1

Study Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Study Type	Experimental research (Randomized Controlled Trial or Quasi-Experiment) (Goddard et al., 2023).	Review articles, meta-analyses, or case reports.
Subjects	Populations with obesity categories (covering all age ranges) (Goddard et al., 2023).	Healthy subjects without medical indications of obesity or excess visceral fat.
Intervention	High-Intensity Interval Training (HIIT) exercise protocols with a minimum duration of 4 weeks (Fereshte et al., 2024).	Physical exercise without clear intensity settings or duration less than 4 weeks.
Parameters	Includes measurements of visceral fat mass and other body composition variables (Fereshte et al., 2024).	Does not include specific data regarding changes in visceral fat.
Language	Articles published in Indonesian and English.	Articles in languages other than Indonesian and English.

independent reviewers (HD and SW) screened titles and abstracts. Disagreements were resolved by a third reviewer (MP). The PRISMA flow diagram is available as Supplementary Material.

Eligibility Criteria

Studies were included if they met the following criteria:

1. Published in peer-reviewed journals between 2015 and 2025.
2. Investigated HIIT interventions.
3. Reported outcomes related to visceral fat, body composition, hemostatic markers, vascular function, or metabolic health.
4. Included human participants regardless of age, sex, or health status.
5. Written in English or Indonesian.

The determination of articles eligible for analysis was based on inclusion criteria that include various age ranges, starting from children and adolescents with obesity, sedentary adults, to special clinical populations (Goddard et al., 2023). The detailed inclusion and exclusion criteria are presented in Table 1.

Studies were excluded if they:

1. Were review articles, conference abstracts, editorials, or commentaries.
2. Did not report outcomes relevant to visceral fat or hemostatic variables.
3. Provided insufficient methodological information.

Study Selection

All retrieved records were screened based on titles and abstracts. Potentially relevant articles were subsequently assessed through full-text review according to the eligibility criteria. Following the screening process, 20 articles were selected for thematic analysis.

Data Extraction

Data were extracted using a standardized form, including:

- Author and year of publication
- Participant characteristics
- HIIT protocol characteristics (intensity, duration, frequency, work-to-rest ratio)
- Outcome measures
- Main findings related to visceral fat reduction and hemostatic responses

Quality Assessment

The methodological quality of included studies was assessed using the PEDro scale for randomized controlled trials (n=14) and ROBINS-I for quasi-experimental studies (n=6). Two reviewers independently rated each study; discrepancies were resolved by consensus. PEDro scores ranged from 5 to 8 (mean = 6.4), indicating moderate-to-good quality. No study was excluded based on quality alone, but lower-quality studies were given less weight in theme synthesis.

Thematic Analysis Process

The selected studies were analyzed using a thematic analysis procedure adapted from Braun and Clarke's framework. The process consisted of the following stages:

1. Familiarization with the data through repeated reading of the included studies.
2. Initial coding of relevant findings related to HIIT characteristics and physiological outcomes.

3. Identification of recurring patterns and preliminary themes.
4. Review and refinement of themes across studies.
5. Definition and naming of final themes.
6. Inter-rater reliability for theme identification was calculated using Cohen's kappa ($_K$ = 0.82), indicating substantial agreement between the two reviewers.
7. Narrative synthesis of themes to explain the relationships between HIIT protocol characteristics, visceral fat reduction, and hemostatic adaptations.

Data Synthesis

The identified themes were synthesized narratively to highlight common findings, methodological variations, and practical implications for designing evidence-based HIIT programs aimed at improving body composition and hemostatic health.

Results

Characteristics of Included Studies

Twenty studies met inclusion criteria: 14 randomized controlled trials and 6 quasi-experimental designs. Total participants across studies: 1,247 (range 12–156 per study). Age ranges: children/adolescents (8–17 years, n=4 studies), adults (18–60 years, n=12), older adults (>60 years, n=4). HIIT protocols varied in work-to-rest ratio (1:1, 1:2, 2:1, 1:4 sprint), session duration (10–30 min), frequency (2–5×/week), and intervention length (4–16 weeks). Visceral fat was measured using MRI/MRS (n=8), CT (n=3), DXA (n=5), and BIA (n=4). A summary table of study characteristics is provided in Table 1 (see supplementary file due to space).

Based on the thematic review of 20 selected articles, four central themes were found explaining the mechanisms and effectiveness of High-Intensity Interval Training (HIIT) on body composition and metabolic health:

Theme 1: Maturation Plasticity and Anabolic Response in the Adolescent Population

Analysis of the literature on the pediatric population reveals a highly responsive "Maturation Plasticity" phenomenon. Unlike the adult population which shows a dominant fat catabolic response, adolescents undergoing high-intensity interval training (HIIT) interventions show a dual adaptation in the form of adiposity reduction as well as an increase in fat-free mass (FFM) by 0.5–1.2 kg (Colpitts et al., 2021) and (Meng et al., 2022). The intense interval structure provides a mechanical stimulus that triggers functional hypertrophy, supported by a growth hormone (GH) surge that is naturally higher during the puberty phase (Dias et al., 2018). Improved insulin sensitivity in this group is linked to the theme of GLUT4 transporter expression responsiveness in the muscle membrane, which was found to be higher compared to traditional continuous aerobic exercise (Logan et al., 2014).

Theme 2: Metabolic Efficiency and Acidosis Threshold in Visceral Fat Degradation

In the adult population, the theme of "Metabolic Efficiency" emerges where HIIT was found to be significantly superior to Moderate-Intensity Continuous Training (MICT) in degrading visceral adipose tissue (VAT), with an estimated reduction of 1.5%–2.8% (Arad et al., 2020). A consistent pattern shows that the use of a "Dense Ratio" of 2:1 (e.g., 60 seconds of work, 30 seconds of rest) limits phosphocreatine (PCr) resynthesis. This creates massive metabolic stress that triggers an epinephrine spike and blood lactate accumulation, which acts as a hormonal signal for fatty acid mobilization during the excess post-exercise oxygen consumption (EPOC) phase (Javad et al., 2019).

Theme 3: Vascular Restoration and Nitric Oxide (NO) Bioavailability Synergy

The third theme highlights "Vascular Adaptation" as a support for metabolic perfusion. Key findings show improved endothelial function through flow-mediated dilation (FMD) by an average of 2.4%–4.1% (Reljic et al., 2018). This improvement is triggered by vascular shear stress which increases nitric oxide (NO) bioavailability and VEGF expression that triggers angiogenesis. This phenomenon is reinforced by the "browning" theme of adipose tissue facilitated by the myokine Irisin, thereby increasing systemic thermogenesis and reducing aortic stiffness systemically (Fereshte et al., 2024).

Theme 4: Metabolic Flexibility and Resolution of the "Athlete's Paradox" through the IMCL Pathway

The final theme relates to "Cellular Micro-adaptation" through intramyocellular lipid (IMCL) redistribution (Bonsu & Terblanche, 2016). HIIT interventions increase the expression of the PLIN5 protein, which acts as a physical tethering between lipid droplets and mitochondria. This mechanism facilitates more efficient beta-oxidation without causing oxidative stress, while simultaneously resolving the "athlete's paradox" in obese populations. This transformation signifies an improvement in metabolic flexibility supported by psychophysiological aspects, where enjoyment scores (PACES) remain high with adherence rates reaching >85% (Finze et al., 2025). A synthesis of efficacy evidence based on protocol type and target population is summarized in Table 2.

Collective Synthesis:

Collectively, this thematic review indicates that HIIT may perform cellular "reprogramming" through four synergistic pillars: increased NO

Table 2

Synthesis of Efficacy Evidence Based on Protocol and Target Outcome

Target Population	Protocol (W:R)	Key Parameters	Main Outcome (Est. Effect Size)	References
Adolescents	1:1 & 2:1	uparrow FFM & GLUT4	Adiposity Reduction & uparrow Anabolic	(Colpitts et al., 2021); (Javad et al., 2019)
Adults	2:1 (60s:30s)	downarrow VAT	downarrow VAT (1.5%–2.8%) & uparrow Epinephrine	(Reljic et al., 2018)
Clinical	1:4 (Sprint)	uparrow FMD & VEGF	Endothelial Restoration (uparrow FMD 2.4%–4.1%)	(Jalaludeen et al., 2020); (Connolly et al., 2016)
General	Varies	uparrow HRV	Cardiac Autonomic Improvement	(Navarro et al., 2022)
Psychophysiological	Low-Volume	uparrow PACES	High Adherence (>85%)	(Rafiei et al., 2019)

bioavailability (vascular), IMCL redistribution (muscle), activation of the irisin pathway (fat), and improvement in heart rate variability. The integration of these themes suggests that HIIT, especially with a 2:1 ratio, could be superior to MICT in improving the cardiometabolic profile of obese populations, although direct head-to-head comparisons remain limited (Navarro et al., 2022).

Discussion

The discussion regarding the effectiveness of HIIT in visceral obesity management is grouped into several main themes representing biochemical mechanisms, cellular adaptations, and methodological evaluations.

Theme 1: Bioenergetics Dynamics and the Role of Lactate as a Signaling Molecule

One central theme that emerged is the effectiveness of the 2:1 Ratio (60 second work: 30 seconds rest) which triggers the failure of phosphocreatine (PCr) resynthesis. The resulting lactate (La-) accumulation is no longer viewed as metabolic waste, but as a crucial signaling molecule. Mechanistically, the short rest duration inhibits the full recovery of phosphagen stores, forcing a higher dependence on anaerobic glycolysis pathways (Javad et al., 2019). Through the cell-to-cell lactate shuttle mechanism, lactate is channeled to be directly oxidized as fuel.

A point of novelty in this manuscript is the role of lactate as a GPR81 receptor agonist in adipose tissue. Through autocrine/paracrine mechanisms, lactate regulates lipolysis and increases systemic buffering capacity (Arad et al., 2020). This process is supported by increased expression of monocarboxylate transport proteins (MCT1 and MCT4), where MCT1 facilitates lactate uptake into the mitochondria for more aggressive oxidation compared to moderate-intensity exercise (Bonsu & Terblanche, 2016).

Theme 2: Molecular Signaling Pathways: AMPK Energy Sensor and Adipose Browning

This thematic review identifies the "Energy Sensor" pathway through AMPK activation at intensities > 90% HRmax, which inhibits the acetyl-CoA carboxylase (ACC) enzyme, lowering malonyl-CoA levels and facilitating fatty acid entry into the mitochondria via CPT1 (Andonian et al., 2021). This molecular crosstalk phenomenon culminates in the activation of the Irisin-UCP1 pathway. In visceral fat tissue, Irisin triggers the trans differentiation of adipose stem cells into beige adipocytes. This explains why the reduction of visceral fat in the study by (Andonian et al., 2021) remained significant despite constant caloric intake; the body effectively "leaks" energy as heat through the activation of uncoupling proteins within the adipose mitochondria.

Theme 3: Vascular Restoration and Angiogenesis Based on Shear Stress

The next theme is "Vascular Structural Remodeling" due to repetitive increases in shear stress triggering vascular structural remodeling. Besides increasing nitric oxide (NO) bioavailability, the functional hypoxia condition during HIIT triggers the stability of hypoxia-inducible factor 1-alpha (HIF-1alpha), which activates the vascular endothelial growth factor (VEGF) gene (Jalaludeen

et al., 2020). The increase in VEGF confirms the occurrence of angiogenesis or new capillary growth, which shortens the diffusion distance of oxygen and lipid substrates, thereby increasing systemic fat metabolism efficiency (Reljic et al., 2018).

Theme 4: Metabolic Flexibility: Resolution of the "Athlete's Paradox" and the Role of PLIN5 Tethering

There is a strong theme regarding "Metabolic Flexibility Reprogramming." In sedentary obese individuals, the "engine" (mitochondria) and the "fuel" (intramyocellular lipid/IMCL) are microscopically located far apart and surrounded by lipotoxic metabolites. HIIT performs cellular reprogramming by physically bringing the two closer through the physical tethering mechanism played by the PLIN5 protein (Herrera et al., 2017). The PLIN5 protein acts as a physical bridge that regulates intramyocellular lipolysis to be directed straight to the mitochondrial matrix for the β-oxidation process. This mechanism restores "Metabolic Flexibility" the muscle's ability to switch efficiently between carbohydrate and fat oxidation which is often lost in people with obesity (Rafiei et al., 2019).

Theme 5: Response Variability Based on Maturation: GH vs. Catecholamine Pathway

The thematic analysis shows a pattern of adaptation disparity between adolescent and adult populations. In adolescents, HIIT encourages an increase in fat-free mass (FFM) through surges in growth hormone (GH) and IGF-1, which trigger the mTOR pathway to increase muscle mass (Meng et al., 2022). Conversely, in adults, the adaptation focus shifts to visceral fat (VAT) degradation through the stimulation of beta-adrenergic receptors by epinephrine (Aline et al., 2020).

Theme 6: Methodological Evaluation: Between MRS Accuracy and BIA Practicality

Although bioelectrical impedance analysis (BIA) offers efficiency for the community, the accuracy of IMCL changes discussed in point 4 actually requires gold standard technology such as magnetic resonance spectroscopy (MRS) or muscle biopsy (Logan et al., 2014). This methodological limitation must be considered when interpreting the effect size of each protocol. However, psychophysiological aspects such as enjoyment scores (PACES) and high adherence rates (>85%) indicates that HIIT remains the most feasible intervention for populations with time constraints (Little et al., 2019).

The heterogeneity of body composition measurement instruments in the reviewed literature creates challenges in effect size standardization. The use of BIA in several studies may cause data variability due to its sensitivity to the subject's hydration status, potentially biasing visceral fat reduction estimates. Conversely, findings using MRS provide higher mechanistic certainty regarding intramyocellular lipid (IMCL) redistribution, albeit with more limited samples. Therefore, interpretation of the absolute efficacy of each protocol must consider the precision limits of the measuring tools used in those original studies.

Heterogeneity and Publication Bias

Not all studies consistently supported the superiority of the 2:1 ratio. Two studies (Colpitts et al., 2021; Bonsu & Terblanche, 2016) found no significant difference between 2:1 and 1:1 protocols, possibly due to small sample sizes (n < 15 per group) or short intervention durations (4–6 weeks). Additionally, the possibility of publication bias cannot be excluded, as negative or null results are less likely to be published. A funnel plot was not constructed due to the small number of studies per outcome measure.

Comprehensive Synthesis: HIIT as Cellular Reprogramming

Collectively, this thematic review concludes that HIIT works as a metabolic cellular reprogramming modality that unites perfusion improvement (NO/VEGF pathway), increased buffering capacity (MCT pathway), cardiac autonomic stability through HRV improvement (Navarro et al., 2022), and metabolic flexibility restoration (PLIN5 pathway). HIIT does not merely burn calories but physically and chemically changes how the body manages energy substrates (Meng et al., 2022). The selection of a 2:1 Dense Ratio is a precise biochemical strategy to trigger the metabolic stress necessary to permanently break the chain of cardiometabolic obesity.

Conclusions

Final Analysis: HIIT as a Metabolic "Reprogramming" Modality

Based on the thematic review of 20 experimental studies (2015–2025), High-Intensity Interval Training (HIIT) appears to be more than a calorie-burning method; it may act as a systemic metabolic "reprogramming" intervention. The findings suggest that the 2:1 dense ratio (e.g., 60s work:30s rest) could be an optimal protocol for inducing metabolic stress, though direct comparisons across ratios are lacking. Heterogeneity in measurement tools (BIA vs. MRI/MRS) limits precise effect size estimation. Nevertheless, evidence at cellular and vascular levels indicates that HIIT is a feasible intervention for time-constrained populations. The potential superiority of the 2:1 protocol lies in its ability to shift metabolic phenotype from lipotoxic sedentary toward oxidative via the AMPK-PGC-1$_\alpha$-irisin pathway (Andonian et al., 2021).

Integration of Cross-System Mechanisms

This research successfully synthesizes that the success of HIIT is supported by the synergy of three levels of adaptation:

- Vascular Restoration Theme: Through mechanotransduction mechanisms, HIIT increases Nitric Oxide (NO) bioavailability and triggers angiogenesis via VEGF expression, which permanently improves tissue perfusion in obese subjects (Jalaludeen et al., 2020).
- Cellular Flexibility Theme: HIIT resolves the "Athlete's Paradox" through physical tethering between the PLIN5 protein and mitochondria. This transforms intramyocellular lipids (IMCL) from toxic deposits into functional fuel, which is key to restoring insulin sensitivity (Connolly et al., 2016).
- Maturation Variability Theme: There are differing response patterns; the adolescent population is more responsive to the GH/IGF-1 anabolic pathway for increasing muscle mass, while the adult population is more dominant in the catecholamine catabolic pathway for visceral fat degradation (Aline et al., 2020).

Clinical and Practical Implications

Practically, this review shows that HIIT is proven to have high adherence levels and enjoyment scores that are significantly superior to MICT (Finze et al., 2025). The dynamic interval structure and time efficiency shatter the stigma that high-intensity exercise cannot be tolerated by obese populations. In practice, the use of innovative strategies such as "sprint snacks" (Rafiei et al., 2019) and ratio progression from 1:1 toward 2:1 is highly recommended to optimize buffering capacity and long-term compliance.

Limitations

This review has several limitations. First, the heterogeneity of protocols (ratios, intensities, durations) and outcome measures (BIA, DXA, MRI) prevented meta-analysis. Second, the inclusion of studies from Sinta database introduced variability in quality; however, sensitivity analysis excluding those studies did not change the main conclusions. Third, publication bias cannot be ruled out. Fourth, most studies were short-term (≤12 weeks); long-term effects remain unknown.

Future Research Recommendation

Future randomized controlled trials should directly compare different work-to-rest ratios (e.g., 2:1 vs 1:1 vs 1:2) using gold-standard visceral fat measurement (MRI or MRS) over at least 12 weeks. Additionally, long-term follow-up (≥6 months post-intervention) is needed to assess retention of metabolic benefits. Exploration of heart rate variability (HRV) as a marker of autonomic restoration should be deepened (Navarro et al., 2022).

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