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# The Role of Physical Activity in Improving Metabolic Syndrome Components: A Literature Review

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**ABSTRACT**

**Introduction:** Metabolic syndrome represents a worldwide cardiometabolic challenge linked with excess adiposity, insulin insensitivity, type 2 diabetes mellitus, elevated blood pressure, lipid metabolism disorders, and cardiovascular disease. Structured physical activity has been recommended as a non-pharmacological strategy to improve metabolic syndrome components. **Methods:** This literature review analyzed experimental studies published between January 2021 and April 2026. Articles were searched through PubMed, ScienceDirect, and Google Scholar using the keywords "physical activity," "exercise," and "metabolic syndrome" with the Boolean operator "AND." Research articles were chosen according to specific inclusion and exclusion parameters, subjected to rigorous evaluation utilizing the JBI Critical Appraisal Tool, and synthesized narratively. Eight experimental studies met the eligibility criteria. **Results:** Physical activity interventions improved waist circumference, body mass index, body weight, blood pressure, lipid profile, cardiorespiratory fitness, fasting glucose, and insulin resistance. Aerobic exercise and the integration of aerobic and resistance training exhibited the most reliable advantages in comparison to interventions that utilized a single modality or were less systematically organized. **Conclusion:** Structured physical activity is clinically relevant for physiotherapy management of metabolic syndrome. Exercise prescription should prioritize aerobic and combined training with individualized intensity, duration, and progression to optimize cardiometabolic outcomes.

**Keywords:** *Physical Activity, Metabolic Syndrome, Aerobic Exercise, Resistance Training, Combined Exercise*

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## INTRODUCTION

Metabolic syndrome constitutes a growing global public health concern driven by sedentary lifestyles, central obesity, unhealthy dietary patterns, and insufficient physical activity (Chomiuk et al., 2024; Jannah et al., 2023). Recent global evidence shows that the burden of metabolic syndrome has continued to increase substantially. A comprehensive examination and analytical modeling reported that the global prevalence of metabolic syndrome increased from 11.9% in 2000 to 28.4% in 2023, with an estimated 1.54 billion adults affected worldwide. The prevalence reached 31.0% among women and 25.7% among men in 2023, signifying that metabolic syndrome has emerged as a significant worldwide issue concerning cardiometabolic health (Noubiap et al., 2026). This condition is clinically important because it elevates the probability of manifesting cardiovascular diseases, type 2 diabetes mellitus, insulin resistance, and extended metabolic consequences (Myers et al., 2019; Roberts et al., 2012).

Metabolic syndrome is commonly defined based on consensus criteria from leading health organizations, including the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III), International Diabetes Federation (IDF), and the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) (Kassi et al., 2011; Saklayen, 2018; Vari et al., 2007). Diagnosis generally requires the existence of a minimum of three out of five established benchmarks: augmented abdominal girth, heightened blood pressure, elevated triglyceride levels, diminished



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HDL cholesterol, and increased fasting blood glucose levels (Lorenzo et al., 2006; Saely et al., 2006; Saklayen, 2018). These components are closely related to insulin resistance, visceral adiposity, oxidative stress, persistent subclinical inflammation, endothelial impairment, and compromised lipid metabolism (Mulyani et al., 2023; Niu et al., 2023; Roberts et al., 2012).

Engagement in physical exercise has been extensively advocated as a non-pharmacotherapeutic approach for the prevention and control of metabolic syndrome. Contemporary guidelines advocate that adults engage in 150–300 minutes of aerobic exercise at a moderate intensity exercise weekly, or alternatively, 75–150 minutes of high-intensity activity exercise weekly, in conjunction through the implementation of muscular fortification exercises at least biweekly. (Chomiuk et al., 2024; Myers et al., 2019). From a physiological perspective, consistent physical activity enhances glucose absorption via the translocation of GLUT4 and facilitates the process of fatty acid oxidation, enhances insulin sensitivity, reduces visceral fat accumulation, improves endothelial function, and contributes to better blood pressure and lipid profile regulation (Chomiuk et al., 2024; Ekelund et al., 2009; Roberts et al., 2012).

The state of the art shows that different exercise modalities have been investigated for metabolic syndrome, including aerobic exercise, resistance training, Pilates, combined aerobic–resistance training, and technology-based interventions. Prior meta-analyses and systematic reviews have consistently indicated that exercise training improves cardiometabolic determinants of risk, encompassing arterial tension, corporeal composition, glycemic control, and lipid profile analysis, inflammatory markers, and cardiovascular fitness (Das et al., 2021; Liang et al., 2021; Ostman et al., 2017; Pattyn et al., 2012). However, the evidence is not entirely uniform. Some studies suggest that aerobic exercise produces stronger effects on cardiorespiratory fitness and visceral fat reduction, whereas resistance training may be more relevant for increasing muscle mass and supporting glucose utilization (Ismail et al., 2011; Myers et al., 2019). Other evidence indicates that combined exercise may provide broader benefits, but the magnitude of its superiority varies depending on exercise intensity, duration, frequency, participant characteristics, and adherence (Liang et al., 2021; Silva et al., 2024).

Despite these findings, several gaps remain in the literature. First, many previous reviews have focused on general exercise effects without clearly distinguishing the contribution of different exercise modalities to specific metabolic syndrome components. Second, earlier reviews often emphasized clinical outcomes, such as body mass index, lipid profile, or blood pressure, but provided limited integration between clinical findings and physiological mechanisms such as GLUT4 translocation, insulin sensitivity, visceral fat oxidation, and inflammatory regulation. Third, evidence regarding exercise timing, intensity, and technology-based delivery remains relatively fragmented. Fourth, previous reviews have not consistently translated the evidence into practical physiotherapy recommendations based on exercise prescription principles, especially frequency, intensity, time, and type.

Based on these gaps, the novelty of this literature review lies in its attempt to synthesize recent experimental evidence on physical activity interventions for metabolic syndrome by integrating three aspects: clinical outcomes, physiological mechanisms, and physiotherapy-based exercise prescription implications. Unlike previous reviews that mainly describe the general benefits of exercise, this review specifically highlights the comparative role of aerobic, resistance, Pilates, combined training, virtual exercise, and mobile application-based interventions in improving metabolic syndrome components. This review also emphasizes how exercise-related improvements may be explained through insulin sensitivity mechanisms, particularly GLUT4-mediated glucose uptake, and how these findings can inform evidence-based physiotherapy practice.

Consequently, this comprehensive review of the literature seeks to examine the significance of physical exercise in improving metabolic syndrome components, synthesize recent experimental findings across different exercise modalities, explain relevant physiological



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mechanisms, and provide a theoretical basis for developing targeted, evidence-based preventive, promotive, and rehabilitative exercise interventions for individuals with metabolic syndrome.

## METHODS

This comprehensive literature review was undertaken to evaluate the effects of exercise interventions on adults diagnosed with metabolic syndrome. Articles were retrieved from Google Scholar, PubMed, and ScienceDirect using the keywords "physical activity," "exercise," and "metabolic syndrome," with the Boolean operator "AND" (Ramdhani et al., 2014), covering publications from January 2021 to April 2026. Both randomized and quasi-experimental studies were considered. Inclusion criteria included adult participants diagnosed with metabolic syndrome and studies reporting outcomes on anthropometric measures, cardiorespiratory fitness, metabolic markers, or functional capacity, published in English. Exclusion criteria included studies published before 2021, review articles, abstracts only, and studies lacking sufficient outcome data. The populations in the included studies primarily consisted of adults aged 40–65 years, both males and females, from regions including Europe, Asia, and North America, with participants commonly presenting with excessive body weight, diminished insulin sensitivity, and various other metabolic hazard indicators.

The included studies involved heterogeneous participant characteristics in terms of age, sex, clinical condition, and intervention setting. Most studies recruited adults with metabolic syndrome, while several focused on specific subgroups, including elderly individuals, pre-menopausal women, women with obesity-related anthropometric risk, and males with metabolic syndrome. The recognition of metabolic syndrome was predicated upon the established criteria reported in each included study. The intervention settings also varied, including supervised exercise programs, lifestyle interventions, virtual therapeutic exercise, and mobile application-based programs. These variations were considered in the narrative synthesis because differences in age, sex, baseline metabolic risk, and intervention setting may influence the response to physical activity interventions.

Critical appraisal was conducted employing the JBI Critical Appraisal Instrument for Experimental Research Studies, suitable for both randomized and quasi-experimental designs and enabling structured evaluation of methodological quality. The process of data extraction was conducted autonomously by two evaluators, encompassing the design of the study, sample size, intervention type, duration, frequency, intensity, and reported outcomes, with disagreements resolved by consensus. Data were synthesized narratively and presented in tables to compare intervention modalities, outcomes, and effect sizes, including virtual and app-based interventions. All procedures were conducted to ensure the integrity of the review, including accurate reporting, avoidance of duplication, and transparent analysis. This enhanced methodology improves transparency and reproducibility, supporting a rigorous synthesis of evidence on physical activity interventions for metabolic syndrome.



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Table 1. Characteristics of Participants in the Included Studies

| Study | Age Category | Sex | Population/Clinical Characteristics | Metabolic Syndrome Diagnosis/Criteria | Setting/Intervention Context |
|---|---|---|---|---|---|
| Mascaro et al., (2022) | Adults | Male and Female | Adults diagnosed with Non-Alcoholic Fatty Liver Disease (NAFLD) and exhibiting features of metabolic syndrome. | Participants diagnosed with metabolic syndrome and NAFLD or metabolic risk factors as reported in the study | Intervention strategies focusing on lifestyle modifications incorporating the Mediterranean dietary pattern and organized physical exercise routines. |
| Morales Palomo et al., (2023) | Adults | Male and Female | Adults with metabolic syndrome, randomized based on sex, age, and BMI | Participants identified as having metabolic syndrome based on the established study parameters | Supervised aerobic exercise intervention comparing morning and afternoon training |
| Thabet et al. (2026) | Adult pre-menopausal women | Female | Pre-menopausal women with metabolic dysregulation | Individuals identified with metabolic syndrome | Pilates and aerobic exercise intervention combined with Mediterranean diet |
| Meryska et al. (2025) | Elderly | Male and female | Elderly individuals with metabolic syndrome | Individuals identified as having metabolic syndrome | Aerobic and resistance exercise intervention setting |
| Carrera Valdés et al. (2025) | Adults | Female | Women with metabolic syndrome and obesity-related anthropometric risk | Participants diagnosed with metabolic syndrome | Virtual therapeutic exercise delivered through an online platform |
| Wong et al. (2021) | Adults | Male and female | Adults with metabolic syndrome participating in a lifestyle intervention program | Individuals categorized as having metabolic syndrome | Mobile application-based lifestyle intervention compared with booklet-based education |
| Szczepanowski et al. (2023) | Adults | Male | Males with involving metabolic dysregulation | Participants diagnosed with metabolic syndrome | Aerobic and combined aerobic–resistance exercise intervention |
| Jastrzębska et al. (2023) | Adults | Male | Males with metabolic syndrome and carbohydrate metabolism indicators | Participants diagnosed with metabolic syndrome | Aerobic and resistance exercise intervention setting |



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Critical appraisal was conducted employing the JBI Critical Appraisal Instrument for Experimental Research Studies, suitable for both randomized and quasi-experimental designs and enabling structured evaluation of methodological quality. The process of data extraction was conducted autonomously by two evaluators, encompassing the design of the study, sample size, intervention type, duration, frequency, intensity, and reported outcomes, with disagreements resolved by consensus. Data were synthesized narratively and presented in tables to compare intervention modalities, outcomes, and effect sizes, including virtual and app-based interventions. All procedures were conducted to ensure the integrity of the review, including accurate reporting, avoidance of duplication, and transparent analysis. This enhanced methodology improves transparency and reproducibility, supporting a rigorous synthesis of evidence on physical activity interventions for metabolic syndrome.

## RESULTS

### Data Analysis

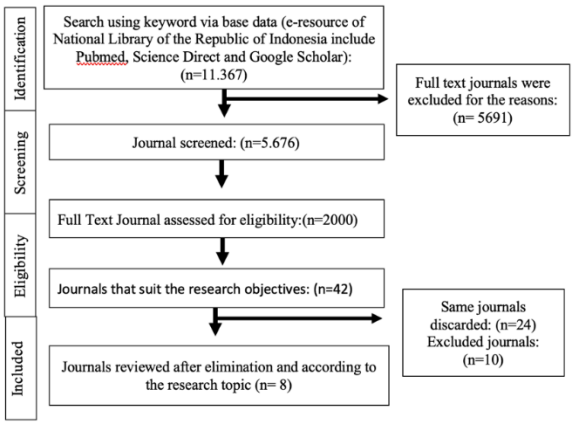


Figure 1. PRISMA study flow diagram

The study selection process is summarized in the PRISMA flow diagram shown in Figure 1. The diagram illustrates the stages of article identification, screening, eligibility assessment, and final inclusion, resulting in eight experimental studies selected for this literature review.



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Table 2. Data analysis matrix in articles used in the literature review

| Author, Title, Journal | Method Design | Result |
|---|---|---|
| Mascaro et al., 2022, Effect of a Six-Month Lifestyle Intervention on the Physical Activity and Fitness Status of Adults with NAFLD and Metabolic Syndrome, Nutrients. | Prospective cohort analysis conducted within a parallel-group randomized trial | The study found significant changes:<br>1. Muscle Strength and Endurance<br>o Standing handgrip: The CD the cohort exhibited a noteworthy enhancement characterized by a mean variance of 1.1 kg and the MD-PA group improved by 1.3 kg ($p < 0.05$). The MD-HMF group showed a slight decrease of −0.2 kg.<br>o Sitting handgrip: Significant improvement in CD (1.4 kg) and MD-PA (1.9 kg) groups ($p < 0.05$), while MD-HMF decreased slightly (−0.4 kg).<br>o Modified push-ups: MD-HMF increased 1.8 reps and MD-PA increased 0.8 reps, while the CD group only increased 0.1 reps.<br>2. Aerobic Capacity ($VO_2$ max)<br>o The MD-PA group significantly increased $VO_2$ max by 2.7 mL $O_2$/kg/min ($p < 0.05$), compared to a slight decrease in CD (−0.2) and a larger decrease in MD-HMF (−1.9).<br>3. Physical Activity Intensity<br>o Light-intensity PA: CD increased 25.1 min/day, MD-HMF increased 7.3 min/day, MD-PA decreased −19.3 min/day.<br>o Moderate-intensity PA: MD-PA increased 7.5 min/day, CD and MD-HMF decreased −20.5 and −9.3 min/day, respectively.<br>4. BMI<br>o All groups showed reductions: MD-HMF −3.0 kg/m², CD −2.2 kg/m², MD-PA −2.0 kg/m².<br>Between-Group Comparisons<br>• MD-PA had higher improvements in $VO_2$ max and moderate-intensity PA than both CD and MD-HMF groups.<br>• CD group increased light-intensity physical activity more than MD-PA and MD-HMF groups.<br>• The MD-PA group showed greater improvements in $VO_2$max and moderate-intensity physical activity compared with the CD and MD-HMF groups. |
| Morales-Palomo, et al., 2024, Efficacy of Morning versus Afternoon | Randomized Controlled Trial (RCT), parallel- | 1. Body Composition and Fat Mass<br>o AMEX (morning exercise group): Fat mass decreased by 0.8 kg (95% CI: −1.45 to −0.21, P = 0.009).<br>o PMEX (afternoon exercise group): Fat mass decreased by 0.6 kg (95% CI: −1.17 to −0.13, P = 0.015).<br>o Control group: Fat mass slightly increased 0.6 kg (95% CI: 0.03–1.37, P = 0.04). |



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| Author, Title, Journal | Method Design | Result |
|---|---|---|
| Aerobic Exercise Training on Reducing Metabolic Syndrome Components: A Randomized Controlled Trial, The Journal of Physiology | group design with block randomization based on sex, age, and BMI. | ○ Both exercise groups showed significant reductions in fat mass compared to control (AMEX P = 0.004; PMEX P = 0.006).<br>2. Cardiorespiratory Fitness (CRF) and Exercise Performance<br>○ V˙O2max: Increased significantly in both exercise groups (AMEX +16%; PMEX +11%; both P < 0.001). Control group slightly decreased (−3%, P = 0.039).<br>○ Maximal power output (Wmax): AMEX +21%, PMEX +15%, both P < 0.001; no change in control.<br>○ Maximal fat oxidation (FOmax): Improved in both AMEX and PMEX (P = 0.002 and 0.01, respectively).<br>3. Metabolic Syndrome Components and Z Score<br>○ Waist circumference: AMEX −2.3 cm; PMEX −1.9 cm (both P < 0.001 vs. control).<br>○ Mean arterial pressure: AMEX −4.9 mmHg; PMEX −2.3 mmHg (AMEX vs. control P = 0.004).<br>○ Systolic blood pressure: Significant reduction only in AMEX (−5.5 mmHg; P = 0.006).<br>○ Fasting insulin: Reduced in AMEX by 1.3 µU/mL (P = 0.002); PMEX unchanged.<br>○ HOMA-IR: Reduced in AMEX −0.40 (P = 0.001); no improvement in PMEX.<br>○ MetS Z-score: Reduced in AMEX −0.24 and PMEX −0.11; both significantly better than control, AMEX also significantly better than PMEX (P = 0.021).<br>4. Between-Group Comparisons<br>○ AMEX group showed greater improvements in systolic BP, fasting insulin, HOMA-IR, and MetS Z-score compared to PMEX and control.<br>○ Both AMEX and PMEX improved fat mass, waist circumference, V˙O2max, Wmax, and FOmax compared to control.<br>○ Control group showed no meaningful improvements in MetS components or CRF.<br><br>Both morning and afternoon vigorous aerobic workouts significantly improved body composition, cardiorespiratory fitness, and MetS components. Morning training showed greater reductions in insulin resistance, systolic blood pressure, and MetS Z-score than afternoon training. |
| Thabet et al., 2026, Effect of Pilates Exercise versus Aerobic Exercise on Metabolic Syndrome in | Randomized Controlled Trial (RCT) comparing three groups | Anthropometric Measures<br>1. BMI:<br>• Pilates group decreased by 3.05 kg/m² (p = 0.001)<br>• Aerobic group diminished by 3.96 kg/m² (p = 0.001)<br>• Control group diminished by 2.46 kg/m² (p = 0.001)<br>• Abdominal Girth: |



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| Author, Title, Journal | Method Design | Result |
|---|---|---|
| Pre-menopausal Women, Health, Sport, Rehabilitation. | | • Pilates −5.10 cm, Aerobic −8.30 cm, Control −3.75 cm (all p = 0.001)<br>2. Arterial Pressure<br>• Mean Arterial Pressure (MAP):<br>• Pilates −4.75 mmHg, Aerobic −7.58 mmHg, Control −4.25 mmHg (all p = 0.001)<br>3. Lipid Profile<br>• Total Cholesterol (TC): Pilates −20.01 mg/dL, Aerobic −28.07 mg/dL, Control −13.52 mg/dL (all p = 0.001)<br>• Triglycerides (TG): Pilates −17.75 mg/dL, Aerobic −27.28 mg/dL, Control −7.10 mg/dL (all p = 0.001)<br>• HDL-C: Pilates +6.15 mg/dL, Aerobic +6.63 mg/dL, Control +4.56 mg/dL (all p = 0.001)<br>• LDL-C: Pilates −21.68 mg/dL, Aerobic −28.30 mg/dL, Control −16.02 mg/dL (all p = 0.001)<br>4. Between-Group Comparisons<br>• Aerobic exercise produced greater improvements than Pilates in all metabolic parameters (BMI, WC, MAP, TC, TG, LDL-C) while HDL-C increased more in aerobic group compared to Pilates.<br>• Both exercise groups were significantly better than control across all outcomes (p < 0.001).<br>Main Findings:<br>• Both Pilates and aerobic exercise combined with a Mediterranean diet significantly improved anthropometric measures, blood pressure, and lipid profile in pre-menopausal women with metabolic syndrome.<br>• Aerobic exercise showed greater improvements than Pilates in Body Mass Index, waist circumference, average arterial pressure, overall cholesterol levels, triglyceride concentrations, and low-density lipoprotein cholesterol. |
| Meryska, R., Khotimah, S., & Wulandari, R., 2025, Differences in the Effect of Aerobic Exercise and Resistance Exercise on | Quasi-experimental study with pretest-posttest two-group design | 1. Aerobic Exercise Group (Group 1)<br>• Cardiovascular endurance (6-minute walking test): Increased from 3.34 ± 0.57 METs pre-test to 6.00 ± 1.18 METs post-test (p < 0.001).<br>2. Resistance Exercise Group (Group 2)<br>• Cardiovascular endurance (6-minute walking test): Increased from 3.38 ± 0.67 METs pre-test to 5.46 ± 1.14 METs post-test (p < 0.001).<br>3. Between-Group Comparison<br>• Post-test cardiovascular endurance was significantly higher in the aerobic exercise group than in the resistance exercise group.<br>Main Findings: |



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| Author, Title, Journal | Method Design | Result |
|---|---|---|
| Cardiovascular Endurance in Metabolic Syndrome, Fisio MU. | | • Both aerobic and resistance exercise groups showed significant increases in cardiovascular endurance after the intervention. The aerobic exercise group had higher post-test cardiovascular endurance than the resistance exercise group. |
| Carrera Valdes et al., 2025, Virtual Therapeutic Exercise System for the Treatment of Metabolic Syndrome, RECyT. | Pre-experimental, analytical, minimal control study was conducted, incorporating a pre-test and post-test for a single control group | 1. Body Weight<br>• Participants decreased their average body weight from 100.16 kg to 95.53 kg over the 6-month virtual exercise program ($p < 0.001$).<br>2. Body Mass Index (BMI)<br>• BMI decreased from 37.09 to 35.37 kg/m² after completing the virtual therapeutic exercises ($p < 0.001$).<br>3. Waist-Hip Index (WHI)<br>• WHI significantly decreased from 97.44 to 88.61 ($p < 0.001$).<br>4. Virtual Delivery Outcomes<br>• The Facebook-based system allowed participants to perform aerobic, strength (Body Pump), and flexibility (Yoga) exercises from home.<br>• Descriptive statistics and expert evaluation confirmed significant improvement in anthropometric measures despite participants remaining in obesity grade II.<br>Main Findings:<br>• The virtual therapeutic exercise program reduced body weight, BMI, and waist-hip index after six months. |
| Wong et al., 2021, The Effect of a Lifestyle Intervention Program Using a Mobile Application for Adults with Metabolic Syndrome | Pilot Randomized Controlled Trial | The study found significant changes:<br>1. Body Weight<br>o The cohort utilizing the application demonstrated a decrease in body mass from 72.47 ± 2.60 kg to 71.20 ± 2.53 kg at three months ($\beta = -1.069$, $p = 0.012$). The booklet group showed minimal change from 70.14 ± 2.15 kg to 69.91 ± 2.11 kg.<br>2. Body Mass Index (BMI)<br>o The cohort utilizing the application exhibited a decline in BMI from 27.62 ± 0.92 to 27.19 ± 0.90 at three months ($\beta = -0.371$, $p = 0.026$). The booklet group showed minimal change from 27.64 ± 0.76 to 27.59 ± 0.75.<br>3. Total Exercise Time |



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|---|---|---|
| versus a Program Using a Booklet: A Pilot Randomized Controlled Trial, Clinical Interventions in Aging. | | ○ The app group showed a significant increase in total exercise time at one month (β = 54.476, p = 0.003). The booklet group showed no significant change.<br>4. Total Amount<br>○ The app group showed an increase in total exercise amount at one month (β = 5.933, p = 0.029) and three months (β = 8.584, p = 0.032). The booklet group showed no significant improvement.<br>5. Exercise Self-Efficacy<br>○ The cohort utilizing the application exhibited notable advancements in their self-efficacy regarding exercise after a duration of one month (β = 7.919, p = 0.002) and three months (β = 10.62, p = 0.001). The booklet group showed no significant change.<br>6. Other Outcomes<br>○ No significant between-group differences were found in blood pressure, lipid profile, and fasting glucose at three months.<br>Main Findings:<br>• The mobile application group showed improvements in body weight, BMI, total exercise time, total exercise amount, and exercise self-efficacy compared with the booklet group. |
| Szczepanowski, R., Pasiak, K., & Zieliński, J., 2023, Exercise-Induced Alternations of Adiponectin, Interleukin-8 and Indicators of Carbohydrate Metabolism in Males with Metabolic Syndrome, Biomolecules. | Randomized controlled trial | 1. Body Composition<br>○ Combined aerobic–resistance group (EG2):<br>▪ Fat-free mass (FFM) increased by 5.8% after 16 weeks (p < 0.001).<br>▪ Gynoid body fat (GYNOID) decreased significantly after 6 weeks (p = 0.02) and 16 weeks (p < 0.001).<br>▪ Waist circumference (WC) decreased by 3.8 cm after 12 weeks (p = 0.01).<br>○ Aerobic-only group (EG1):<br>▪ FFM showed small non-significant increases.<br>▪ GYNOID decreased after 6 weeks (p = 0.03).<br>▪ WC changes were not significant.<br>○ Control group (CG): No significant changes.<br>2. Insulin Resistance Indices<br>○ EG2:<br>▪ HOMA-AD decreased by 46% after 16 weeks (p = 0.02).<br>▪ HOMA-TG decreased by 39% (p = 0.03).<br>○ EG1: HOMA-TG decreased (p = 0.04), HOMA-AD unchanged.<br>○ CG: No significant changes.<br>3. Adiponectin (ADIPO) and ADIPO/LEP Ratio |



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| | | ○ ADIPO: No significant changes in either EG1 or EG2.<br>○ ADIPO/LEP ratio:<br>▪ EG1 showed significant changes after 6 weeks ($p = 0.01$) and 16 weeks ($p < 0.001$).<br>▪ EG2 and CG did not show significant changes.<br>4. Interleukin-8 (IL-8)<br>○ EG1: IL-8 decreased after 6 weeks ($p = 0.04$) and remained lower throughout.<br>○ EG2: No significant changes in IL-8.<br>○ CG: IL-8 increased by 36% over 16 weeks ($p = 0.01$).<br>○ At week 16, IL-8 in EG1 was significantly lower than CG ($p = 0.03$).<br>Main Findings:<br>• Aerobic–resistance training (EG2) enhanced physiological composition, diminished abdominal girth, and alleviated insulin resistance.<br>• Aerobic-only training (EG1) decreased IL-8 and improved ADIPO/LEP ratio and some insulin resistance indices.<br>• Control group showed no improvements; in fact, IL-8 increased over time.<br>• Both exercise cohorts exhibited enhancements in specific indices of body composition, inflammation, and insulin resistance when contrasted with the control cohort. |
| Jastrzębska, M., Żebrowska, A., & Stańczyk, J., 2023, Effect of Exercise Interventions on Irisin and Interleukin-6 Concentrations and Indicators of Carbohydrate Metabolism in Males with Metabolic Syndrome, Journal of | Prospective, randomized, controlled trial | 1. Fasting Glucose (FG)<br>○ Aerobic exercise group: Decreased from $115.6 \pm 12.3$ mg/dL to $104.3 \pm 10.7$ mg/dL ($p < 0.001$).<br>○ Resistance exercise group: Decreased from $114.8 \pm 11.9$ mg/dL to $106.5 \pm 11.2$ mg/dL ($p < 0.001$).<br>○ Control group: No significant change.<br>2. HbA1c<br>○ Aerobic group: Reduced from $6.7 \pm 0.4\%$ to $6.1 \pm 0.3\%$ ($p < 0.001$).<br>○ Resistance group: Reduced from $6.6 \pm 0.3\%$ to $6.2 \pm 0.3\%$ ($p < 0.001$).<br>○ Control group: No significant change.<br>3. Lipid Profile<br>○ Total Cholesterol (TC): Aerobic −15.3 mg/dL, Resistance −12.8 mg/dL ($p < 0.05$).<br>○ Triglycerides (TG): Aerobic −20.5 mg/dL, Resistance −18.3 mg/dL ($p < 0.05$).<br>○ HDL-C: Increased significantly in both exercise groups (Aerobic +4.2 mg/dL, Resistance +3.8 mg/dL).<br>○ LDL-C: Decreased significantly (Aerobic −12.1 mg/dL, Resistance −10.7 mg/dL).<br>4. Between-Group Comparisons |



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| Clinical Medicine. | | ○ Both aerobic and resistance exercise groups showed significantly greater improvements than control for FG, HbA1c, and lipid parameters ($p < 0.01$).<br>○ Aerobic exercise showed slightly greater reductions in fasting glucose and TG compared to resistance exercise, though differences were not statistically significant.<br>Main Findings:<br>• Both aerobic and resistance exercise significantly improved glycemic control and lipid profile in adults with metabolic syndrome.<br>• Both aerobic and resistance exercise groups showed significant improvements in glycemic control and lipid profile compared with the control group. |



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**Literature Review Result**

The literature review included eight experimental studies evaluating physical activity interventions in adults with metabolic syndrome. The study designs consisted of randomized controlled trials, quasi-experimental studies, prospective randomized controlled trials, pilot randomized controlled trials, and pre-experimental studies. The interventions examined included aerobic exercise, resistance exercise, Pilates exercise, combined aerobic–resistance training, lifestyle intervention programs, virtual therapeutic exercise, and mobile application-based lifestyle interventions.

The included studies reported improvements in anthropometric, cardiovascular, metabolic, inflammatory, and functional outcomes following physical activity interventions. Reported anthropometric improvements included reductions in body mass index, waist circumference, body weight, adipose tissue, and waist-hip index. Cardiovascular and functional outcomes included improvements in blood pressure, $VO_2$max, maximal power output, cardiovascular endurance, physical activity level, muscle strength, and functional capacity. Metabolic outcomes included improvements in fasting glucose, fasting insulin, HOMA-IR, HbA1c, total cholesterol, triglycerides, LDL-C, and HDL-C (Mascaró et al., 2022; Morales-Palomo et al., 2023; Thabet et al., 2026; Meryska et al., 2025).

Mascaró et al. (2022) reported that a a six-month lifestyle modification program incorporating a Mediterranean dietary regimen and organized physical exercise improved $VO_2$max, moderate-intensity physical activity, handgrip strength, and body mass index in adults with NAFLD and metabolic syndrome. Morales-Palomo et al. (2023) found that both morning and afternoon aerobic exercise improved fat mass, waist circumference, $VO_2$max, maximal power output, and MetS Z-score, while morning exercise produced substantial decreases in systolic blood pressure, fasting insulin levels, HOMA-IR, and Metabolic Syndrome Z-score.. Thabet et al. (2026) reported that both Pilates and aerobic exercise combined with a Mediterranean diet reduced BMI, waist circumference, mean arterial pressure, total cholesterol, triglycerides, and LDL cholesterol, while enhancing HDL cholesterol levels in pre-menopausal women diagnosed with metabolic syndrome.

Meryska et al. (2025) discovered that both aerobic and resistance training enhanced cardiovascular stamina in senior individuals afflicted with metabolic syndrome., with aerobic exercise producing higher post-test MET values than resistance exercise. Carrera Valdés et al. (2025) reported that virtual therapeutic exercise reduced body weight, body Mass Index, alongside the waist-to-hip ratio, index in women with metabolic syndrome. Wong et al. (2021) found that a mobile application-based lifestyle intervention reduced body weight and BMI and increased weekly the duration of physical activity, cumulative quantity of exercise, and individual confidence in exercising relative to education delivered through printed materials.

Szczepanowski et al. (2023) reported that combined aerobic–resistance exercise increased fat-free mass, reduced waist circumference, and improved insulin resistance indicators, while aerobic exercise decreased interleukin-8 and improved the adiponectin/leptin ratio in males with metabolic syndrome. Jastrzębska et al. (2023) discovered that both aerobic and resistance training led to a decrease in fasting glucose levels, HbA1c, total cholesterol, triglycerides, and LDL-C, concurrently elevating HDL-C in comparison to the control group.

Overall, the reviewed studies showed that physical activity interventions were associated with measurable improvements in several components of metabolic syndrome. Aerobic exercise and the integration of aerobic and resistance training modalities was observed to be the most prevalent reported interventions associated with improvements across anthropometric, cardiovascular, metabolic, and functional outcomes.

**DISCUSSION**

This literature review indicates that structured physical activity contributes to improvements in several components of metabolic syndrome, particularly body composition, abdominal girth, arterial tension,



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lipid composition, cardiorespiratory fitness, glucose metabolism, insulin resistance, and functional capacity. However, the magnitude of these improvements varied across the included studies. This variation suggests that the response to exercise is influenced not only by the type of physical activity, but also by study design, participant characteristics, baseline metabolic risk, exercise intensity, intervention duration, adherence, dietary co-interventions, and delivery methods.

Aerobic exercise showed the most consistent benefits for cardiorespiratory fitness, fat mass, abdominal girth, arterial pressure, and insulin sensitivity. Morales-Palomo et al. (2023), Meryska et al. (2025), and Thabet et al. (2026) reported improvements in $VO_2max$, cardiovascular endurance, anthropometric measures, and metabolic parameters after aerobic exercise interventions. These results corroborate earlier research that aerobic exercise is effective in improving cardiovascular capacity, visceral fat reduction, and factors associated with cardiometabolic risk (Ismail et al., 2011; Myers et al., 2019; Chen et al., 2023). Nevertheless, the superiority of aerobic exercise should be interpreted carefully because resistance exercise and Pilates also produced clinically meaningful improvements in selected outcomes, particularly blood pressure, lipid profile, glycemic control, and functional capacity.

Combined aerobic–resistance exercise appears to provide broader benefits because it targets both cardiovascular and musculoskeletal systems. Aerobic exercise mainly improves energy expenditure, fat oxidation, and cardiorespiratory fitness, whereas resistance exercise supports muscle mass, strength, and glucose utilization. This is clinically relevant due to the fact that skeletal muscle serves as the principal location for glucose absorption stimulated by insulin. The findings of Szczepanowski et al. (2023) support this interpretation, showing improvements in fat-free mass, waist circumference, and insulin resistance indicators following combined exercise. These results align with earlier research indicating that combined exercise may improve parameters associated with metabolic syndrome and factors contributing to cardiovascular risk more comprehensively than single-modality exercise (AbouAssi et al., 2015; Liang et al., 2021; Silva et al., 2024).

Despite these benefits, the evidence across studies was heterogeneous. The included articles used different research designs, including randomized controlled trials, quasi-experimental studies, pre-experimental studies, and pilot randomized controlled trials. This methodological variation affects the strength of evidence. Randomized controlled trials provide stronger internal validity, whereas quasi-experimental and pre-experimental studies are more vulnerable to selection bias, uncontrolled confounding, and limited causal inference. Therefore, although the findings generally support the beneficial influence of physical exercise, the degree of certainty differs across studies.

Participant characteristics also contributed to heterogeneity. Some studies included adult men, some involved pre-menopausal women, some focused on elderly individuals, and others included women with obesity-related anthropometric risk or adults with NAFLD and metabolic syndrome. These differences are important because age, sex, hormonal status, obesity severity, muscle mass, baseline insulin resistance, and comorbid conditions can influence physiological adaptation to exercise. For example, elderly participants may respond differently to resistance or aerobic exercise due to lower baseline muscle mass and cardiorespiratory capacity, while pre-menopausal women may have different metabolic and hormonal profiles compared with male participants. Therefore, the findings should not be generalized without considering participant characteristics.

Several potential confounding factors should also be considered. Some interventions combined exercise with dietary modification, particularly Mediterranean diet, making it difficult to isolate the independent effect of physical activity. Improvements in BMI, waist circumference, lipid profile, and insulin resistance may reflect the combined influence of exercise, dietary intake, caloric control, and adherence to lifestyle modification. Similarly,



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technology-based interventions such as mobile applications and virtual exercise platforms may improve outcomes not only through exercise, but also through self-monitoring, motivation, feedback, accessibility, and behavioral engagement. Therefore, the observed benefits in these studies may represent the impact of a more comprehensive lifestyle modification as opposed to exercise exclusively.The reviewed studies also showed differences in outcome responses across exercise modalities. Aerobic exercise generally produced stronger improvements in $VO_2max$, cardiovascular endurance, fat mass, and waist circumference, while resistance exercise contributed to improvements in muscle strength, fat-free mass, and glucose utilization capacity. Pilates improved anthropometric measures, blood pressure, and lipid profile, but aerobic exercise produced greater changes in several metabolic parameters. Morning aerobic exercise appeared more effective than afternoon exercise for the purpose of diminishing systolic blood pressure, fasting insulin levels, HOMA-IR index, and MetS Z-score, although both morning and afternoon exercise improved adipose tissue, abdominal girth, maximal oxygen uptake, and peak power output (Morales-Palomo et al., 2023). These findings indicate that exercise timing may influence some metabolic responses, but it should be considered as a supporting factor rather than the main determinant of intervention success.

From a physiological perspective, the effect of exercise on metabolic syndrome can be partly explained by enhanced insulin sensitivity via the translocation of glucose transporter type 4 (GLUT4). In metabolic syndrome, insulin resistance diminishes insulin's efficacy in promoting glucose absorption within skeletal muscle tissues. Physical activity enhances the translocation of GLUT4 to the muscle cell membrane via both insulin-mediated and insulin-independent mechanisms, allowing glucose uptake to increase even when insulin action is impaired. Repeated exercise sessions may improve skeletal muscle glucose transport, reduce fasting insulin, lower HOMA-IR, and improve glycemic control (Roberts et al., 2012; Chomiuk et al., 2024; Ekelund et al., 2009). This mechanism helps explain why several included studies reported enhancements in plasma glucose levels, glycated hemoglobin (HbA1c), fasting insulin concentrations, and insulin sensitivity indicators.

In addition to GLUT4-mediated glucose uptake, exercise may improve metabolic syndrome through reductions in visceral adiposity, enhanced fatty acid oxidation, improved lipid metabolism, endothelial function, and modulation of inflammatory markers. Reductions in waist circumference, triglycerides, LDL-C, and blood pressure are clinically important because these variables are central components of metabolic syndrome and major contributors to cardiovascular risk. However, inflammatory outcomes were not reported consistently across all included studies. Some studies showed improvements in interleukin-8 and adiponectin/leptin ratio, while others emphasized anthropometric and metabolic changes. This indicates that future research should include more standardized inflammatory and adipokine markers to clarify the biological pathways linking exercise with metabolic syndrome improvement (Das et al., 2021; Szczepanowski et al., 2023).

The conclusions drawn from this analysis bear significant ramifications for evidence-based physiotherapy practice. Exercise prescription for individuals with metabolic syndrome should be individualized using the FITT principle. Based on the reviewed evidence and current recommendations, aerobic exercise may be prescribed engaging in physical activity three to five occasions weekly at a moderate level of intensity or adjusted progressively according to tolerance, with a target duration of 150–300 minutes per week. Resistance exercise may be added at least two times per week to improve muscle strength, fat-free mass, and glucose utilization. Combined aerobic–resistance exercise may be prioritized for patients who need comprehensive improvement in the distribution of body constituents, responsiveness to insulin, lipid composition, and overall functional ability. Pilates or lower-impact exercise may be considered for individuals with low fitness levels, obesity, musculoskeletal limitations, or low tolerance to vigorous exercise.



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Technology based exercise interventions may be useful as supportive strategies in physiotherapy management. Mobile applications and virtual exercise platforms can improve accessibility, self-monitoring, motivation, and exercise self-efficacy. However, these approaches should not replace individualized assessment and professional supervision, especially for individuals with multiple metabolic risk factors. Physiotherapists should consider patient safety, baseline cardiovascular risk, exercise tolerance, musculoskeletal limitations, and adherence barriers when designing exercise programs.

Overall, this review contributes to evidence-based physiotherapy by integrating clinical outcomes, physiological mechanisms, and practical exercise prescription implications. Aerobic exercise and combined aerobic–resistance training appear to be the most consistently beneficial interventions for improving metabolic syndrome components. However, heterogeneity in the formulation of research design, attributes of participants, specifications of intervention methods, accompanying interventions, and metrics for outcomes. limits the ability to determine a single optimal exercise program for all patients. Future studies should use expanded randomized controlled experiments, extended observation intervals, uniform methodologies metabolic syndrome criteria, clearer reporting of exercise intensity and adherence, and direct comparison of FITT-based exercise prescriptions to strengthen clinical recommendations for physiotherapy practice.

## CONCLUSION

This literature review concludes that structured physical activity is effective in improving key components of metabolic syndrome, including body mass index, abdominal girth, arterial pressure, lipid composition, cardiovascular endurance, glucose homeostasis, and insulin responsiveness. Aerobic exercise and the integration of aerobic and resistance training exhibited the most reliable advantages. and should be prioritized in physiotherapy-based exercise prescription. Clinically, exercise programs for individuals with metabolic syndrome should be individualized using the FITT framework, involving aerobic activities conducted three to five times weekly, at a moderate level of intensity. adjusted to patient tolerance, a total duration of 150–300 minutes per week, and resistance training added at least two times per week to improve muscle strength and glucose utilization. This review contributes to evidence-based physiotherapy by integrating clinical outcomes, physiological mechanisms, and practical exercise prescription recommendations. However, the evidence remains limited by heterogeneity in study design, participant characteristics, intervention protocols, co-interventions, and follow-up duration; therefore, future studies should use standardized FITT-based protocols and longer follow-up to strengthen clinical recommendations.

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