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THE IMPACT OF PHYSICAL ACTIVITY ON METABOLIC SYNDROME AND CARDIOVASCULAR RISK

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ABSTRACT

Background: Metabolic syndrome (MetS) is one of the most serious public-health challenges, affecting approximately 25 % of the adult population worldwide and more than doubling the risk of cardiovascular disease (CVD). It is characterised by the coexistence of abdominal obesity, insulin resistance, dyslipidemia and arterial hypertension, which translates into markedly increased mortality risk. Physical activity (PA) has been identified as a key modifiable factor in the prevention and treatment of this cluster of disorders. The aim of this review is to discuss in detail the impact of various forms of PA on the components of MetS and on CVD risk.
Methods and Materials: A systematic review of the scientific literature was carried out, analysing randomised trials, meta-analyses and observational studies that assessed the effectiveness of aerobic, resistance and high-intensity interval training.
Conclusions: Regular PA exerts a multidirectional influence on all components of MetS, effectively reducing abdominal obesity, insulin resistance, dyslipidemia and hypertension. Aerobic training shows the greatest efficacy in improving metabolic parameters, whereas the combination of aerobic and resistance modalities provides the most favourable therapeutic outcomes. In secondary prevention of CVD, PA achieves effectiveness comparable to pharmacotherapy and significantly surpasses it in post-stroke patients. The underlying mechanisms include improvements in insulin sensitivity, enhanced glucose uptake by skeletal muscle, and beneficial modulation of adipokine and cytokine profiles. The review underlines the importance of regular PA as a public-health strategy and highlights the need for further research aimed at optimising intervention programmes.

KEYWORDS

Metabolic Syndrome, Cardiovascular Risk, Physical Activity, Aerobic Training, Resistance Training, High-Intensity Interval Training

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Introduction

Metabolic syndrome (MetS) is a cluster of metabolic abnormalities encompassing obesity, insulin resistance, dyslipidemia and arterial hypertension. According to the 2022 diagnostic criteria, MetS is diagnosed when obesity is present, defined as a waist circumference of at least 88 cm in women or 102 cm in men, or a BMI ≥ 30 kg/m², together with at least two out of three additional conditions: pre-diabetes or diabetes, elevated non-HDL cholesterol, and hypertension [1]. Approximately 25 % of all adults worldwide are affected [2]. MetS is closely associated with type-2 diabetes, CVD and premature mortality, conferring more than a two-fold increase in coronary and cerebrovascular risk and a 1.5-fold increase in all-cause mortality [3]. Its prevalence has risen over recent decades, particularly among young adults, underscoring the importance of identifying reversible risk factors and elucidating the pathophysiological mechanisms involved [4].

Cardiovascular diseases remain the leading cause of death globally, far surpassing cancer. They account for nearly one third of all deaths annually, and, together with obesity and diabetes, for almost two thirds [5]. Coronary artery disease, heart failure, atherosclerosis and cerebrovascular disease contribute the largest mortality share. Understanding risk factors is crucial in preventing CVD development and reducing associated morbidity and mortality.

The World Health Organization (WHO) emphasises the need to counteract CVD and MetS risk factors, in particular the widespread deficit of PA [6]. Robust evidence shows that aerobic training yields greater improvements in cardiorespiratory fitness and related cardiometabolic parameters, whereas resistance training predominantly increases muscular strength and mass.

This review discusses in detail the impact of different forms of PA on the individual MetS components, integrating recent findings on the molecular mechanisms responsible for the observed therapeutic benefits.

Risk Factors for Cardiovascular Disease and Metabolic Syndrome

MetS is a complex disorder with both genetic and environmental determinants, the latter being more influential. Single-nucleotide polymorphisms in genes such as *FTO, TCF7L2, APOE, MC4R* and *ADRB1* influence susceptibility to obesity, insulin resistance, dyslipidemia or hypertension [7]. Nevertheless, modifiable lifestyle factors like unhealthy diet and physical inactivity are central to pathogenesis.

Visceral obesity is the pivotal driver, inducing adipocyte hypertrophy and a chronic low-grade inflammatory state. Excess adipose tissue increases pro-inflammatory adipokines (e.g. leptin) and lowers adiponectin, reducing insulin sensitivity. Elevated plasma free fatty acids disrupt the glucose–fatty acid cycle, promoting hyperglycemia by impairing insulin-dependent glucose transport into skeletal muscle. Ectopic lipid accumulation activates PKCε, derailing insulin signalling and fostering insulin resistance [8].

Chronic stress further aggravates MetS via hypothalamic–pituitary–adrenal activation and elevated cortisol, leading to insulin resistance, dyslipidemia, hypertension and visceral fat accrual. Stress-induced high-calorie intake compounds these effects, while oxidative stress and inflammation intensify metabolic dysfunction [9].

Gut-microbiota dysbiosis also contributes: individuals with MetS exhibit a higher Firmicutes/Bacteroidetes ratio, fewer short-chain-fatty-acid-producing bacteria and more pro-inflammatory species, aggravating endotoxemia and inflammation [7]. Vitamin-D deficiency and sleep disturbances further exacerbate insulin resistance and fat accumulation [10][11].

The Impact of Physical Activity on Metabolic Syndrome Components

Regular PA is a cornerstone in MetS prevention and management, modulating cardiometabolic parameters via complex physiological and biochemical pathways [12][13][14]. Skeletal muscle functions as an endocrine organ that secretes over 300 myokines influencing lipid and glucose metabolism and inflammation [15]. Moreover, exercise strengthens endogenous antioxidant systems, reduces inflammatory markers and improves endothelial function [16].

The impact of (PA) on body composition and metabolism varies significantly depending on the type of intervention applied. While caloric restriction leads to the loss of both fat tissue and lean body mass, physical exercise allows for the preservation or even increase of muscle mass while simultaneously reducing fat tissue [17].

Abdominal Obesity

Reduced PA promotes obesity. Combining increased energy expenditure with caloric restriction effectively reduces fat mass, particularly visceral fat, which drives chronic inflammation, insulin resistance, type-2 diabetes and atherosclerosis [18]. A common pathology accompanying **visceral obesity** is **liver steatosis**, which together constitute the most dangerous obesity phenotype [19]. Exercise decreases waist circumference, waist-to-hip ratio and BMI. Weight loss through exercise preserves lean mass better than diet alone; higher muscle mass supports glucose homeostasis and raises resting energy expenditure [20]. Reductions in fat mass elevate adiponectin and improve cytokine profiles. During physical exercise, the concentration of interleukin-6 (IL-6) increases in a manner proportional to the muscle mass involved in the activity, as well as the intensity and duration of the exercise [21]. IL-6 produced by skeletal muscles plays a dual role: it acts anti-inflammatory by inhibiting the production of tumor necrosis factor alpha (TNF-α) and interleukin-1β, while simultaneously activating the IL-1 and IL-10 receptor antagonists [22].

Insulin Resistance

PA improves insulin sensitivity through insulin-dependent and –independent glucose uptake in muscle [23]. Regular exercise increases mitochondrial density, optimises substrate metabolism and stimulates myokine release [24], lowering fasting glucose and insulin and mitigating type-2 diabetes risk. Molecular mechanisms include augmented GLUT4 translocation and activation of key glucose-metabolising enzymes, alongside enhanced glycogen synthesis [25]. Physical inactivity down-regulates GLUT4 and impairs β-cell function via oxidative stress and inflammation [26].

Hypercholesterolemia

Regular PA enhances muscular fatty-acid oxidation, lowering circulating lipids. Exercise increases lipoprotein-lipase activity, hydrolysing chylomicrons and VLDL[27]. Systematic physical activity (PA) correlates with a more favorable lipid profile, characterized by reduced triglyceride levels and increased HDL cholesterol concentration. In contrast, prolonged time spent in a seated position exerts a negative effect on lipid metabolism, regardless of demographic and behavioral variables such as age, sex, or other lifestyle factors [28].

Hypertension

PA reduces blood pressure via vascular remodelling, renin–angiotensin–aldosterone modulation, decreased sympathetic activity and improved insulin sensitivity. Exercise enlarges arterial diameter, improves elasticity, stimulates angiogenesis and enhances endothelial nitric-oxide synthesis [22][29].

Physical Activity and Cardiovascular Risk

Regular physical activity (PA) confers well-documented benefits in improving both cardiovascular and metabolic parameters. Aerobic training is the most effective modality in this regard [30]. Studies comparing pharmacotherapy with exercise interventions indicate that exercise is as effective as medication in secondary prevention of pre-diabetes, cardiovascular diseases and mortality. Among post-stroke patients, PA markedly surpasses the effectiveness of pharmacotherapy [14]. A reduction of systolic blood pressure by 10 mmHg can lower the risk of cardiovascular events by 20 %, coronary heart disease by 17 %, stroke by 27 %, heart failure by 28 % and all-cause mortality by 13 % [31].

Population-based observations indicate that high cardiorespiratory fitness and muscular strength attenuate the metabolic risk associated with excess body weight. Intervention trials corroborate this relationship. A 12-week training programme in obese adolescents improved insulin sensitivity, lipid profile and inflammatory markers independently of changes in body mass [32]. Moreover, individuals who additionally reduced visceral adipose tissue experienced an even greater decrease in triglycerides, HOMA-IR and an increase in maximal fat-oxidation rate [33].

Prospective data from 2015 obtained within the Cardiovascular Health Study, involving more than 4 000 American seniors with a mean age of 72.5 years, provide compelling evidence for the importance of PA in CVD prevention later in life. Analysis revealed an association between different forms of PA and the incidence of coronary heart disease, stroke and composite CVD risk. Individuals who walked at roughly 5 km per hour exhibited a 50 % lower risk of coronary heart disease, stroke and overall cardiovascular risk compared with those walking slower than about 3 km per hour. Equally remarkable were the distance findings: participants who walked around 5 km per week experienced a 36 % reduction in coronary heart disease risk, a 54 % decrease in stroke risk and a 47 % reduction in overall cardiovascular risk relative to those covering no more than 500 m per week [34]. These observations are of practical importance because walking is the most common form of PA among older adults and it is relatively easy to integrate into everyday life.

Aerobic Training

Aerobic training (AT) is the most effective form of physical activity for treating MetS-related health problems. Regular aerobic exercise promotes weight loss, including visceral fat reduction, especially when combined with an appropriate diet. Implementing AT alone without concomitant dietary modifications yields a smaller decrease in body mass, and its effectiveness depends on a high training volume. Nevertheless, studies demonstrate that the combined application of AT and resistance training (RT) produces the best outcomes [35]. Furthermore, AT has been observed to reduce inflammation as measured by IL-18 levels, an effect not seen with RT despite a similar degree of fat-mass reduction [36].

One study showed that an eight-month AT programme at 65–80 % of maximal oxygen uptake, performed for about 120 minutes per week, led to a significant improvement in a composite MetS score and tended to be superior to RT. The most important metabolic benefits included a marked reduction in plasma triglyceride concentrations and body mass, which directly translated into an improved cardiovascular risk profile [35].

Systematic AT possesses considerable therapeutic potential for improving metabolic control in patients with type 2 diabetes and insulin resistance. Clinical studies confirm that a moderately intense endurance-training programme, carried out for eight weeks at three sessions per week, can lead to a significant reduction in insulin resistance and improved glycemic parameters. A protocol consisting of a 30-minute walk at 60 % of maximal heart rate, preceded by a warm-up and followed by stretching exercises, resulted in lowered fasting plasma glucose and insulin levels. Mechanisms responsible for these positive effects include enhanced skeletal-muscle glucose uptake, reduced central adiposity, improved insulin action in exercising organs and activation of insulin-stimulated signalling pathways [37].

In arterial hypertension therapy, AT can also constitute an important element. Regular moderate-intensity exercise can effectively lower systolic pressure by up to 8–12 mmHg and diastolic pressure by 5–6 mmHg, an effect linked to improved vascular elasticity, favourable endothelial function and attenuation of inflammatory processes in the vessel wall [38]. Notably, training efficacy is observed even in individuals with resistant hypertension, potentially allowing a reduction in the number of antihypertensive medications required [39].

AT exerts a favourable impact on biochemical blood parameters, contributing to an improved lipid profile and normalised liver-enzyme activity. It also increases the level of orexin A, a neuropeptide that plays a key role in the regulation of sleep, appetite and energy balance. It is worth emphasising that changes in lipid concentrations such as HDL, LDL and triglycerides largely depend on exercise intensity. Although moderate activity brings measurable benefits for most individuals, higher-intensity sessions may be necessary when lowering LDL and triglycerides is a priority. Regularity and appropriate adjustment of exercise to individual capabilities are crucial for achieving optimal health outcomes [40].

Additionally, regular training significantly improved cardiovascular performance parameters such as heart rate, blood pressure and resting pulse. Beneficial changes were also observed in respiratory capacity, with increases in maximal oxygen uptake (VO_2 max) and peak expiratory flow (PEF). Moreover, physical activity positively influenced pulmonary function, leading to improvements in forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) [41].

Resistance Training

Resistance training (RT) yields pronounced benefits in increasing muscle strength and mass, which is particularly important for preventing sarcopenia in older adults. Regular RT effectively improves body composition, leading to fat-mass reduction even without a caloric deficit. The increase in muscle mass is crucial for maintaining a high basal metabolic rate, especially after weight loss when resting metabolism naturally declines[42]. This advantage arises from the fact that muscle tissue consumes much more energy than adipose tissue, facilitating the maintenance of a healthy body weight and preventing weight regain. RT thus represents not only an effective strength-building method but also an important component of long-term weight-control strategies.

Clinical trials confirm the multifaceted effects of RT on cardiometabolic parameters. An eight-week intervention comprising progressive strength training (75–80 % 1RM, three sessions per week) resulted in reductions in body mass, BMI, waist circumference and fat content. A significant improvement in lipid profile was also noted, including reductions in LDL-cholesterol, triglycerides and total cholesterol with concomitant increases in HDL-cholesterol levels [43]. Simultaneously, favourable changes in glycaemic control were observed, manifested by lower fasting glucose and glycated haemoglobin (HbA1c), indicating improved insulin sensitivity. A meta-analysis covering 12 randomised controlled trials with more than 400 participants aged over 60 confirmed the efficacy of strength exercise in reducing insulin resistance measured by HOMA-IR and lowering HbA1c [44]. Subgroup analysis revealed that older adults without type 2 diabetes benefit especially from high-intensity training, which leads to a marked improvement in insulin-resistance indices, whereas in patients with confirmed type 2 diabetes, moderate-intensity RT is more effective in long-term glycemic control. The duration of intervention is also crucial: programmes exceeding 12 weeks are more effective in improving insulin resistance, whereas shorter protocols influence HbA1c control better.

In the context of arterial hypertension, RT exhibits significant hypotensive potential. A meta-analysis of five randomised controlled trials involving 201 participants confirmed that isolated strength training leads to a clinically relevant reduction in systolic pressure by 8.2 mmHg and diastolic pressure by 4.1 mmHg compared with control groups [45]. Hypotensive mechanisms include decreased peripheral vascular resistance, improved endothelial function through increased synthesis and activity of endothelial nitric-oxide synthase and reduced arterial stiffness.

Nevertheless, in a study based on an eight-month RT programme involving three weekly sessions of three sets of 8–12 repetitions for eight different muscle groups, no significant effect was found on the composite MetS score or any individual component [35]. Despite a significant increase in muscle strength, RT did not influence key metabolic parameters such as body mass, waist circumference or triglyceride levels, contrasting with the well-documented effects of this activity on body composition [46][47]. The limited efficacy of RT in the context of MetS may result from the lower energy expenditure during training sessions compared with AT, translating into smaller changes in lipid and glucose metabolism.

High-Intensity Interval Training

In recent years, high-intensity interval training (HIIT) has gained considerable popularity as an efficient and time-saving form of physical activity. Randomised trials and meta-analyses have shown that HIIT favourably modulates all key components of MetS, translating into a reduced cardiovascular risk. After only eight weeks of intervention, significant decreases in waist circumference, fat mass and BMI have been noted together with increases in lean body mass and VO_2 peak. The reduction in waist circumference and fat fraction was greater than after continuous moderate-intensity exercise [48].

Among post-menopausal women with MetS, HIIT contributed to lower triglyceride, total-cholesterol and LDL levels while simultaneously increasing HDL concentrations. A significant reduction in fasting glucose and HbA1c was also observed. Furthermore, HIIT proved more effective than RT in reducing systolic blood pressure and improving cardiorespiratory fitness [43].

A meta-analysis of randomised controlled trials showed that HIIT is the most effective of the analysed training types in improving key heart-rate-variability parameters in adults. This results in a favourable shift in autonomic balance towards parasympathetic dominance, thereby reducing the risk of arrhythmias and sudden coronary events [49]. Additionally, HIIT increases VO_2 peak and exercise capacity in cardiac populations, matching or exceeding traditional continuous training in this respect [50]. According to the literature review, these benefits emerge despite the short duration of sessions, making HIIT an efficient and economical intervention in the primary and secondary prevention of cardiovascular diseases [51].

Training Recommendations for People with Metabolic Syndrome

Contemporary guidelines on PA for CVD prevention and MetS management are based on a robust scientific foundation highlighting the multifaceted benefits of systematic training. The WHO recommends that adults engage in at least 150 minutes of moderate-intensity PA per week. Current guidelines stress that any amount of PA is better than none, and all age groups should limit sedentary time. In addition, the inclusion of muscle-strengthening exercises is advised for all ages, as they confer benefits across the lifespan [6]. These fundamental recommendations are mirrored in the guidelines of the European Society of Cardiology, which advocate 150–300 minutes of moderate-intensity or 75–150 minutes of vigorous-intensity PA per week, or an equivalent combination of both, distributed evenly over the week [52].

A key aspect of effective training interventions is the appropriate combination of different exercise modalities. Comparative studies point to a clear advantage of AT over RT regarding MetS parameter improvement; nevertheless, the best outcomes were achieved by the group combining both training modalities, showing a significant improvement in all major MetS components [35][53]. From a practical perspective, considering the time-to-benefit ratio, AT appears to be the most efficient form of PA for individuals with MetS.

Owing to its short, intense bouts interspersed with rest periods, HIIT may be particularly attractive for individuals with limited time for PA while still providing efficient improvements in cardiovascular and metabolic functions [49]. Despite these benefits, this form of training is not recommended for most patients, especially those who are clinically unstable.

An essential therapeutic element is reducing sedentary time, which, in excess, is associated with increased cardiovascular mortality risk irrespective of regular PA levels. Studies indicate that sitting for more than eight hours a day significantly increases mortality risk, particularly among individuals with the lowest PA, whereas even moderate PA can markedly reduce this risk [54]. In practical terms, it is also important to consider non-exercise activity thermogenesis (NEAT), which covers energy expenditure associated with daily activities such as walking, maintaining posture or household chores [55]. NEAT may represent a substantial component of total daily energy expenditure and be especially important for individuals unable to participate regularly in structured exercise programs.

Conclusions

Metabolic syndrome is an increasingly common global health problem, the development of which is closely linked to chronic inflammation and oxidative stress resulting from obesity. Early identification and modification of risk factors such as a sedentary lifestyle and improper diet are crucial in prevention. Based on the review of scientific literature, it can be unequivocally stated that regular PA constitutes a fundamental element in the prevention and treatment of MetS and in reducing CVD risk. Systematic PA exerts a multidirectional impact on all components of MetS, effectively modulating abdominal obesity, insulin resistance, dyslipidemia and arterial hypertension. In secondary CVD prevention, PA shows efficacy comparable to pharmacotherapy, and among post-stroke patients, it markedly exceeds pharmacological treatment.

The molecular mechanisms include improved insulin sensitivity, increased skeletal-muscle glucose uptake, favourable modulation of the adipokine profile, myokine secretion and reduction of chronic inflammation. Additionally, PA directly influences cardiac function, contributing to enhanced myocardial contractility, greater oxygen supply and stabilised electrical activity.

Comparative analysis of different forms of training indicates a clear advantage of AT regarding MetS parameter improvement. RT is distinguished by its unique ability to increase skeletal-muscle mass and maximal strength. The most favourable therapeutic effects are obtained by combining AT with RT, leading to a synergistic action. HIIT has emerged as a particularly effective and time-saving alternative for clinically stable individuals.

An optimal therapeutic strategy should take into account individual patient preferences and time availability. Patient education concerning the benefits of regular PA and support for long-term adherence to a training programme are also crucial. Unfortunately, exercise therapy remains underused, often yielding to pharmacological interventions. More research is needed to determine the optimal duration and intensity of each training type and to identify patient subgroups that may derive particular benefit from combining different training modalities.

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