The Role of Physical Activity in Insulin Resistance

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ABSTRACT

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Introduction and aim of the study. *This study aims to analyze the role of physical activity in the context of insulin resistance and its impact on metabolic health. Insulin resistance is a key risk factor for the development of metabolic diseases such as type 2 diabetes and obesity. The study focuses on identifying the health benefits of regular physical activity and the molecular mechanisms associated with improving insulin sensitivity.*

Review methods. *A literature review was conducted using databases such as PubMed and Google Scholar to identify existing scientific research on physical activity and insulin resistance. The review included peer-reviewed articles, meta-analyses, and clinical studies from recent years.*

Current knowledge. *The study discusses various forms of physical activity, such as strength training, interval training, aerobic exercise, and yoga, and their impact on insulin resistance and metabolic health. The analysis includes molecular mechanisms such as activation of insulin signaling pathways, effects on glucose metabolism, and reduction of inflammation.*

Conclusions. *The literature review confirms the key role of physical activity as an effective tool in the prevention and treatment of insulin resistance. Regular physical activity can improve insulin sensitivity, promote weight reduction, control blood glucose, and reduce the risk of metabolic diseases.*

Keywords: *insulin resistance, physical activity, type 2 diabetes, glucose metabolism disorders*

STRESZCZENIE

Rola aktywności fizycznej w insulinooporności

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Wprowadzenie i cel pracy. *Celem niniejszej pracy jest przeprowadzenie analizy roli aktywności fizycznej w kontekście insulinooporności oraz jej wpływu na zdrowie metaboliczne. Insulinooporność jest kluczowym czynnikiem ryzyka rozwoju chorób metabolicznych, takich jak cukrzyca typu 2 i otyłość. W badaniu skupiono się na określeniu korzyści zdrowotnych regularnego wykonywania aktywności fizycznej oraz mechanizmów molekularnych związanych z poprawą wrażliwości na insulinę.*

Metody przeglądu. *Przeprowadzono analizę literatury w oparciu o bazy danych, takie jak PubMed, i Google Scholar, aby zidentyfikować istniejące badania naukowe dotyczące aktywności fizycznej i insulinooporności. W przeglądzie uwzględniono artykuły recenzowane, metaanalizy oraz badania kliniczne z ostatnich lat.*

Opis stanu wiedzy. *W pracy omówiono różne formy aktywności fizycznej, takie jak trening siłowy, trening interwałowy, aerobowy i joga, oraz ich wpływ na insulinooporność i zdrowie metaboliczne. Analiza obejmuje mechanizmy molekularne, takie jak aktywacja szlaków sygnałowych związanych z insuliną, wpływ na gospodarkę glukozową oraz redukcję stanu zapalnego.*

Wnioski. *Wnioski z przeglądu literatury potwierdzają kluczową rolę aktywności fizycznej jako skutecznego narzędzia w prewencji i leczeniu insulinooporności. Regularne wykonywanie aktywności fizycznej może prowadzić do poprawy wrażliwości na insulinę, redukcji masy ciała, kontroli poziomu glukozy we krwi oraz zmniejszenia ryzyka chorób metabolicznych.*

Słowa kluczowe: *insulinooporność, aktywność fizyczna, cukrzyca typu 2, zaburzenia metabolizmu glukozy*

Introduction and Aim of the Study

The prevalence of insulin resistance, which often leads to serious health consequences such as obesity, type 2 diabetes, cardiovascular disease, and other metabolic complications, is a significant problem in modern society [1]. In 2016, the number of people affected by type 2 diabetes amounted to 366 million, representing approximately 8% of the global population [2]. By 2021, this figure had increased to 529 million, and it is estimated that the number of people with diabetes could exceed 1.31 billion by 2050 [3].

Another serious health threat is the rising rate of obesity, which increasingly affects younger populations. In adolescents with coexisting obesity and insulin resistance, beta-cell function declines by 35% each year, which is two to four times faster than in adults. This accelerates the development of type 2 diabetes and cardiovascular disease [4]. Central obesity, particularly the accumulation of visceral adipose tissue and liver fat, is associated with insulin resistance. This interdependence contributes to a heightened risk of cardiovascular incidents [5]. Given the rising incidence of diabetes and obesity and their serious health implications, the search for effective prevention and treatment of insulin resistance is crucial. Physical activity is one potentially important factor that influences the development and progression of insulin resistance [6].

The aim of this review paper is to evaluate the potential health benefits of regular physical activity in preventing and treating insulin resistance. By analyzing research studies, we aim to demonstrate how different forms of physical activity can influence the risk of insulin resistance and its complications, along with the mechanisms through which physical activity impacts this condition. To a large extent, we seek to increase understanding of the relationship between physical activity and insulin resistance and to provide up-to-date and comprehensive information on this issue.

It is also worth emphasizing that physical activity is a key element in the non-pharmacological treatment and prevention of insulin resistance, particularly given the increase in this condition's prevalence and its complications. Therefore, this work also aims to raise public awareness about the role of physical activity in combating insulin resistance.

Review Methods

This review on the role of physical activity in the context of insulin resistance was conducted based on established methodological criteria to gather up-to-date and reliable scientific data.

Empirical studies published between 2014 and 2024 were included to ensure the validity of the analyzed data. Studies encompassing different age groups were taken into account: children, adolescents, adults, and the elderly. The focus was on studies involving populations with various health conditions, such as obesity, type 2 diabetes, and insulin resistance. A primary criterion for inclusion was that physical activity served as the main intervention to reduce insulin resistance. Only studies published in English were included, while those lacking full outcome data or consisting of conference publications without full peer-reviewed content were excluded.

A systematic literature search of PubMed and Google Scholar databases was conducted to identify relevant studies. The search used keywords such as 'insulin resistance', 'physical activity', 'exercise' and 'glucose metabolism', combined with logical operators (e.g., 'AND' and 'OR') to narrow results accurately. Additional filters restricted results to studies published between 2014 and 2024 and in English.

All identified studies were pre-screened based on title and abstract. Studies meeting the inclusion criteria were then analyzed for methodological quality, including sample size, study population characteristics, intervention type, and outcome measurement methods. Qualitative analysis focused on extracting main themes and findings from the literature, while quantitative analysis was conducted where possible to estimate the effect of physical activity on insulin resistance.

The results from the selected studies were synthesized in a narrative systematic review, presenting the effects of physical activity on insulin resistance and possible mechanisms of action across different age groups and health conditions. This structure allowed for a comprehensive presentation and interpretation of the available data in the context of current knowledge on insulin resistance.

Current Knowledge

Insulin resistance is defined here as an impaired biological response of target tissues to insulin stimulation. Although all tissues with insulin receptors can develop resistance, the main contributors are skeletal muscle, liver, and adipose tissue. Under normal conditions, insulin facilitates glucose uptake into cells, where it is used as an energy source or stored as glycogen.

Insulin resistance can be classified into three types: pre-receptor, receptor, and post-receptor. Pre-receptor insulin resistance arises from abnormalities in insulin structure or the presence of antibodies that block its action, typically due to genetic factors [7]. Receptor insulin resistance involves a reduction in the number or sensitivity of insulin receptors, often associated with obesity and chronic inflammation [8]. Regular physical activity can increase the number of receptors, thereby

enhancing the body's response to insulin [9]. Post-receptor insulin resistance involves disturbances in signaling pathways following receptor activation, which is exacerbated by chronic inflammation and excess free fatty acids, especially in obese individuals [8].

Insulin resistance affects the function of multiple tissues. In the liver it leads to increased uncontrolled glucose production, contributing to hyperglycemia [10]. Adipose tissue, especially visceral adipose tissue, promotes insulin resistance by secreting pro-inflammatory adipokines, which worsen metabolic dysfunction [11]. In skeletal muscle, insulin resistance reduces glucose uptake; however, regular exercise enhances this process by activating GLUT4 transporters [12]. Insulin resistance also impairs nervous system function, increasing the risk of neurodegenerative diseases [13].

The development of insulin resistance results in impaired glucose uptake by insulin-resistant tissues. Consequently, the body compensates by producing more insulin, leading to hyperinsulinemia, which further intensifies insulin resistance. This vicious cycle continues until pancreatic beta-cell function can no longer keep up with insulin demands, resulting in hyperglycemia [8,14]. Persistent insulin deficiency leads to elevated blood glucose levels indicative of type 2 diabetes, the primary consequence of insulin resistance [8,15].

Beyond type 2 diabetes, conditions associated with insulin resistance include obesity, cardiovascular disease, non-alcoholic fatty liver disease (NAFLD), metabolic syndrome, and polycystic ovary syndrome (PCOS). The metabolic outcomes of insulin resistance are significant and include hyperglycemia, hypertension, dyslipidemia, hyperuricemia, elevated inflammatory markers, endothelial dysfunction, and a prothrombotic state [10,16].

Insulin resistance is common in the elderly but is increasingly prevalent in all age groups, including middle-aged individuals with overweight and sedentary lifestyles. Excessive fat accumulation, defined as overweight (BMI 25-30 kg/m²) and obesity (BMI ≥ 30 kg/m²), is a risk factor for type 2 diabetes development and is associated with reduced glucose uptake. The disproportionate accumulation of subcutaneous and abdominal fat impairs insulin receptor responses, resulting in inhibited glucose uptake in skeletal muscle and a reduced capacity to suppress endogenous glucose production. These physiological changes can contribute not only to hyperglycemia, but also to further fat accumulation, and chronic inflammation characterized by pro-inflammatory cytokine release [9,13]. The long-term complications of metabolic diseases, including type 2 diabetes, can be mitigated by adhering to medical advice, and by maintaining a healthy lifestyle, a balanced diet, and regular physical activity [17]. In this review, we focus primarily on the role of physical activity, as it is a vital yet often underemphasized component in the treatment of insulin resistance.

Molecular Mechanisms

Abnormalities in insulin signaling are a key factor leading to insulin resistance. The process begins with the activation of the insulin receptor (IR) through tyrosine phosphorylation of the β-subunit, which triggers further signaling cascades, including the activation of phosphoinositide kinase 3 (PI3K) and the effector Akt. Activated Akt subsequently stimulates glucose uptake via GLUT4 translocation to the cell membrane. Insulin resistance may result from defects at various stages of this process, including defects in insulin receptors (IRs), which may involve structural abnormalities, decreased receptor numbers, or impaired signaling capacity. Several factors, such as oxidative stress or hyperinsulinemia, can impair insulin signaling through various mechanisms, including protein degradation by proteasomes, dephosphorylation, or serine/threonine phosphorylation by kinases [18].

Human and animal studies have unequivocally demonstrated that regular physical activity can correct the molecular abnormalities associated with insulin resistance, restoring physiological insulin sensitivity [12]. Physical exertion significantly impacts glucose uptake and insulin signaling in the body. During exercise, glucose uptake in skeletal muscle increases, driven by the activation of AMP-activated protein kinase (AMPK). AMPK acts by phosphorylating the protein TBC1D1, leading to its inactivation. This inactivation enables Rab proteins to interact with GLUT4 vesicles, facilitating GLUT4 translocation and enhancing glucose uptake into the cell.

Furthermore, exercise has been shown to improve insulin signaling by increasing IRS-1-mediated PI3-K activation, which contributes to greater glucose uptake. Although exercise does not directly affect gene expression of components in the early stages of the insulin cascade, it improves the efficiency of the insulin pathway, suggesting it primarily influences post-receptor signaling [2,12,18].

In summary, exercise affects multiple molecular mechanisms involved in glucose uptake and insulin signaling, which may contribute to improved insulin sensitivity and overall metabolic health.

Various Forms of Physical Activity

Through an analysis of available literature, we examine different types of physical activity and their potential impact on improving insulin resistance, considering

recent studies, review articles, and meta-analyses. Aerobic exercise, characterized by repetitive and continuous movements of large muscle groups, includes activities like walking, cycling, jogging, and swimming, and primarily relies on aerobic energy production systems. Interval training involves short, alternating high-intensity exercise bouts lasting about 30 seconds, combined with lower-intensity intervals, typically lasting around 120 seconds. Flexibility exercises enhance the range of motion around the joints, while balance exercises improve gait and help prevent falls. Yoga combines flexibility, balance, and resistance exercises [18].

Yoga, with its deep roots in India and a 4,000-year evolution as a traditional form of mind-body training, is gaining recognition as a promising, cost-effective, and non-invasive therapeutic option for individuals with diabetes and insulin resistance. Research suggests that yoga, like other mind-body integrative therapies, can significantly alleviate stress-related hyperglycemia and benefit the body [19].

In a study led by Manoharan Mangala Gowri, M.D. et al., the effects of a specific yoga-based therapeutic protocol, consisting of 10 sessions held twice a week for four months, were analyzed in patients with diabetes. The findings suggest that the yoga-based intervention improved insulin sensitivity in these patients compared to a control group. A key mechanism identified was improved blood flow to organs, which is associated with increased expression of insulin receptors in muscle, enhancing glucose uptake by muscle tissue and lowering blood glucose levels. Additionally, yoga practice led to a significant decrease in body mass index (BMI), which is associated with insulin resistance and elevated blood glucose levels [17,19].

Studies by Viswanathan et al. also support the positive effects of yoga on glycemic control and insulin resistance. Significant reductions in blood glucose and HbA1c were observed in the yoga group compared to the control group [20,21].

In a study by Gorantla Shravya Keerthi et al., yoga combined with standard treatment was shown to reduce the direct effects of hyperinsulinemia on the hypothalamus, thereby decreasing sympathetic nervous system activity and enhancing parasympathetic function. This process increases the sensitivity of target tissues to insulin, improves peripheral glucose utilization, and ultimately lowers glucose levels. Therefore, by reducing the risk of diabetes and improving quality of life, yoga is believed to help delay the progression from pre-diabetes to the irreversible stages of the disease and associated complications, while improving glycemic control and enhancing both mental and physical health [22,23].

The above studies suggest that yoga is a simple and accessible therapeutic strategy that may be effective in improving diabetes control and reducing insulin resistance compared to no regular physical activity [19]. A study by Benjamin J. Ryan et al. compared metabolic responses after 12 weeks of high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT). It was discovered that the long-term adaptive responses to both types of training were very similar. A comparable increase in muscle oxidative capacity was observed, associated with an increase in the abundance of many proteins involved in mitochondrial respiration, lipid and carbohydrate metabolism, as well as similar changes in muscle lipid profile. Overall, this study indicates that despite significant differences in training intensity and volume, both HIIT and MICT lead to similar improvements in peripheral insulin sensitivity the day after exercise and induce similar long-term metabolic adaptations in skeletal muscle [24].

In another study, Jenna B. Gillen et al. compared rapid sprint interval training (SIT) with traditional moderate-intensity continuous training (MICT). They found that an SIT protocol of 3 minutes of high-intensity intermittent exercise per week, with a total time commitment of 30 minutes, was as effective as 150 minutes of continuous moderate-intensity training per week in increasing insulin sensitivity, cardiorespiratory fitness, and skeletal muscle mitochondrial content [25]. The potential mechanisms mediating the exercise-induced increase in whole-body insulin sensitivity are complex. Regarding potential changes in skeletal muscle that may partly explain improved insulin sensitivity, a similar increase in GLUT4 protein content was found after both training protocols, despite large differences in exercise volume. SIT and MICT were also shown to similarly increase skeletal muscle microvascular density, which is associated with improved glucose transport and insulin sensitivity. This effect may also be related to improved mitochondrial content or increased capacity for intramuscular triglyceride utilization [25,26].

A study by Khaled M. Badaam et al. provides further evidence that high-speed sprint training improved insulin resistance, glycemic indices, and anthropometric parameters similarly to traditional aerobic exercise. The reduction in insulin resistance led to an improvement in glycated hemoglobin levels following physical activity. Improvements in BMI and waist-to-hip ratio were also observed in both groups [27].

Given the much lower time requirements with SIT or HIIT compared to MICT, these forms of exercise can be excellent options for individuals with time constraints. An analysis by Fatemeh Kazeminasab and her team concluded that, in addition to reducing body fat, exercise – particularly aerobic exercise – induces changes in both metabolic and non-metabolic processes, leading to improvements in insulin resist-

ance and related markers. Exercise can reduce oxidative stress and inflammatory adipokines, as well as activate and increase glucose transporter 4 (GLUT4) density [11,28]. Furthermore, exercise enhances β-cell function, modulates insulin receptor substrate 1 (IRS1) phosphorylation, reduces plasma ceramide levels, and stimulates angiogenesis, which are mechanisms by which exercise reduces insulin resistance associated with overweight and obesity [29].

Variability in Response to Exercise Depending on Gender, Age and Comorbidities

The literature indicates that the metabolic response to physical activity in the context of insulin resistance can vary significantly depending on gender, age, and the presence of comorbidities. A review of various studies highlights that these factors are essential in tailoring exercise programs.

Research on the influence of gender on exercise effectiveness indicates that men and women respond differently to various forms of training. Nolan and Prentki (2019) observed that men improve insulin sensitivity more rapidly in response to aerobic training, partly due to greater muscle mass and lower visceral fat levels compared to women [8]. In contrast, Keshel and Coker (2015) noted that women tend to benefit more from resistance training, potentially due to differences in hormones and lipid metabolism [9]. Cartee (2015) confirmed that women show better improvement in insulin resistance with weight-bearing exercise, suggesting that training programs should be tailored to meet the specific metabolic needs of each gender [12].

Age is another crucial factor affecting the response to physical activity. In children and adolescents, regular exercise has been shown to have a strong preventive and therapeutic effect on insulin resistance, contributing to improved insulin sensitivity and glycemic regulation [10]. Research by Yaribeygi et al. (2019) indicates that in young adults, exercise – especially high-intensity interval training (HIIT) – is particularly effective, as it rapidly enhances insulin sensitivity through mitochondrial increases and the activation of GLUT4 transporters in muscle [11]. In older adults, however, as noted by Abdul-Ghani and DeFronzo (2021), the benefits of exercise are limited by a decrease in muscle mass and reduced elasticity of muscle tissue, which may lessen insulin sensitivity [7]. Nonetheless, research by Besse-Patin et al. (2014) suggests that even in seniors, regular high-intensity training provides significant benefits, albeit to a lesser degree than in younger individuals [13].

The presence of comorbidities, such as hypertension, dyslipidemia, or chronic inflammation, further influences the effectiveness of physical activity in managing insulin resistance. Chronic inflammation may limit the benefits of exercise, as it affects insulin receptors and impairs cellular signaling processes associated with glucose metabolism [9]. Nolan and Prentki (2019) demonstrated that obese individuals, who often exhibit increased inflammation, require higher exercise intensities to achieve metabolic effects comparable to those seen in healthy individuals [8]. Conversely, Cartee (2015) notes that patients with type 2 diabetes and cardiovascular disease may need to adjust the intensity and form of training to match their capabilities, avoiding overexertion while aiming for optimal therapeutic benefit [12].

In summary, various studies confirm that the effectiveness of physical activity in enhancing insulin sensitivity depends on factors such as gender, age, and the presence of comorbidities. These findings suggest the need to tailor exercise programs to the specific metabolic conditions of each patient.

Impact of Previously Initiated Physical Activity

This section delves into the effect of physical activity initiated early in life on the later development of insulin resistance. Reviewing the available data and recent studies provides insight into how regular physical activity can influence the risk of developing this metabolic condition.

A study by Hitomi Fujita et al. explores the connection between early-life physical activity and insulin resistance in later life. Insulin resistance, which disrupts glucose and fat metabolism, has been linked to the development of diseases such as type 2 diabetes and hypertension, as highlighted earlier. Early detection of insulin resistance is crucial for preventing lifestyle-related diseases [30]. Physical activity correlates positively with reduced insulin resistance, as skeletal muscles are the primary target organs for insulin [31]. Furthermore, physical activity induces long-term physiological changes, not just short-term effects [32]. The study noted that individuals who regularly exercised had higher BMIs than those who were physically inactive. The observed higher BMI values among those who exercised regularly may be due to increased muscle mass, which can significantly impact insulin resistance. Insulin, an anabolic hormone, not only inhibits muscle protein degradation but also facilitates new protein synthesis. The degree of insulin-mediated changes in muscle protein synthesis has been shown to be inversely related to the HOMA-IR index, a measure of insulin resistance. Physical activity also enhances the protein metabolic cycle, which helps reduce insulin resistance by increasing muscle mass

and enhancing glucose uptake by muscle cells, ultimately lowering blood glucose levels [30].

In addition, the lipid content within skeletal muscle cells significantly affects insulin resistance, and both quantity and quality of muscle lipids are regulated by physical activity. Exercise can reduce the lipid content in muscle, which subsequently decreases levels of free fatty acids that may impair glucose metabolism. Lower muscle lipid levels may improve insulin sensitivity by increasing insulin receptor expression and activating signaling pathways related to glucose metabolism. These mechanisms may collectively prevent the onset of insulin resistance [30].

In another study, S.V. Fischer and colleagues examined the effects of early physical activity on later insulin resistance development, conducting the experiment on rats. Results indicated that during exercise, tissues meet their energy demands through increased lipolysis and reduced re-esterification of fatty acids, which is followed by heightened oxidation of fatty acids by peritoneal tissues, particularly in skeletal muscle. This process results in reduced fat mass. Improved insulin sensitivity, due to decreased fat mass, may relate to changes in the immunometabolism of adipose tissue under the influence of exercise [33]. The study's findings suggest that the earlier exercise is initiated, the sooner the harmful effects of early obesity, including insulin resistance, can be mitigated or even prevented [34].

A study by Timo A. Lakka et al. examined the two-year effects of physical activity and dietary intervention on reducing the progression of insulin resistance in a general population of children. The results showed that several mainly short-term physical exercise and dietary interventions, especially when combined, were effective in reducing insulin resistance in overweight and obese children. The combined physical activity and dietary intervention reduced fasting insulin increases by 4.65 pmol/L (34%) and HOMA-IR increases by 0.18 units (37%) over two years in a population-based sample of children, 85% of whom were of normal weight at the start of the study. This observation is important from a public health perspective, suggesting that lifestyle changes can reduce the increase in insulin resistance not only in overweight and obese children but also in the general child population, where most are of normal weight [35].

Insulin resistance typically increases during puberty, but the increase can begin several years before puberty, as early as age 7. The rise in insulin resistance during pre- and post-adolescence is partly due to increased body fat and elevated serum IGF-1 levels, mainly regulated by growth hormone. There is also evidence that physical activity can reduce the natural peak of insulin resistance that occurs around ages 12-13, regardless of puberty status and body fat percentage [36]. These findings highlight the importance of preventing insulin resistance in childhood by increasing physical activity, reducing sedentary time, and improving diet in the general child population, not just in overweight and obese children [35].

Critical Analysis

The review provides a comprehensive view of the importance of physical activity in the prevention and treatment of insulin resistance, highlighting both the potential and limitations of physical interventions. The studies presented demonstrate the effectiveness of various forms of activity – such as aerobic, interval, and strength training, as well as yoga – but the results indicate that the effectiveness of these interventions depends on numerous factors, including age, gender, comorbidities, and the type and intensity of training.

The findings indicate that the response to physical activity varies among groups. For example, Nolan and Prentki (2019) and Keshel and Coker (2015) observe that men and women respond differently to various training forms, suggesting the need to individualize interventions [8,9]. Additionally, as shown by Cartee (2015) and Yaribeygi et al. (2019), training effectiveness varies with age, with younger age groups showing a stronger response, while older individuals may experience limited benefits due to physiological factors like decreased muscle mass [11,12].

Comorbidities, such as obesity or chronic inflammation, can also reduce the benefits of exercise. Chronic inflammation affects insulin receptors and insulin signaling mechanisms, as indicated by Besse-Patin et al. (2014) and Abdul-Ghani and DeFronzo (2021), suggesting that individuals with advanced insulin resistance may require more tailored exercise programs [7,13].

The review provides accurate and up-to-date inclusion criteria, ensuring that the data are both reliable and relevant. However, methodological variability across the studies reviewed – including differences in intervention intensity and type – makes it challenging to standardize the results and interpret them consistently. The review highlights that a full understanding of physical activity's role in insulin resistance requires further research involving controlled and long-term interventions.

Conclusions

This work aimed to explore the role of physical activity in insulin resistance and its impact on metabolic health. The literature review offered a thorough understanding of the molecular mechanisms involved

in insulin resistance and the health benefits of regular physical activity.

Figure 1 summarizes how physical activity can increase insulin sensitivity and indirectly reduce the risk of cardiovascular disease.

The analysis of studies showed that various forms of physical activity, including strength training, interval training, aerobic exercise, and yoga, can improve insulin sensitivity, reduce body weight, and decrease the risk of type 2 diabetes and other metabolic diseases.

The findings support the importance of promoting physical activity as an effective tool in preventing and treating insulin resistance. Regular exercise programs could provide health benefits not only for people with insulin resistance but also for the general population interested in maintaining good metabolic health.

However, further research is needed to determine optimal training strategies and the long-term effects of physical activity on metabolic health. Based on the available data, it is evident that regular physical activity is a key component of a healthy lifestyle, especially for individuals with insulin resistance and those at increased risk for metabolic diseases.

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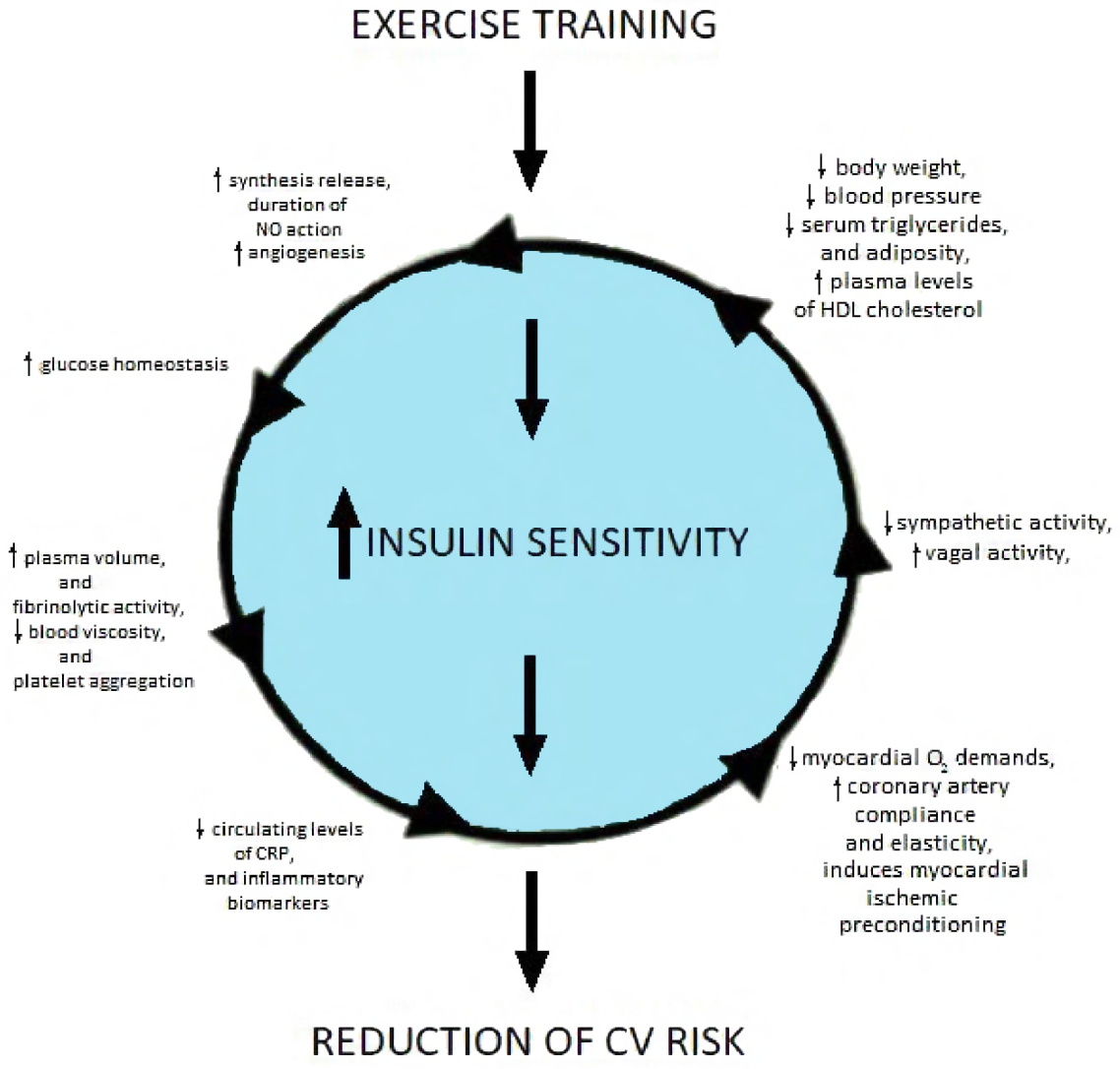

Figure 1. Indirect effects of physical activity on cardiovascular disease risk reduction
Source: Iaccarino G., Franco D., Sorriento D. et al.: Modulation of Insulin Sensitivity by Exercise Training: Implications for Cardiovascular Prevention. J Cardiovasc Transl Res 2021; 14(2): 256–270.

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The authors declare no conflict of interest.

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