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Impact of Physical Activity and Exercise Modalities on Individual Components of Metabolic Syndrome: A Narrative Review

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Abstract

Background: Metabolic syndrome (MetS) is an increasingly prevalent global health condition that increases the risk of developing type 2 diabetes mellitus and cardiovascular disease. Regular physical activity is recognized as one of the most important modifiable factors in both prevention and management of MetS.

Aim: This narrative review evaluated the effect of physical activity on each of the major elements of metabolic syndrome.

Material and methods: A narrative review was conducted using a structured search of the PubMed/MEDLINE database. The following keywords were applied: “metabolic syndrome”, “physical activity”, “exercise”, “insulin resistance”, “cardiovascular risk”, “obesity”, “lipid profile”, “blood pressure”, and “inflammation. Only peer-reviewed studies published between 2016 and 2025 were included. Eligible articles comprised randomized controlled trials,

systematic reviews, and meta-analyses. Additionally, reference lists of selected studies were screened to identify further relevant publications.

Results: The data indicate that regular physical activity results in improvements in multiple aspects of MetS. Most included studies and meta-analyses demonstrated approximately 10-17% declines in visceral fat, improved insulin sensitivity (up to 20-25%), reduced triglycerides (approximately 10-15%) and reduced systolic blood pressure (approximately 7 mmHg). Regular physical activity also resulted in decreased levels of inflammatory biomarkers including C-reactive protein.

Conclusions: Physical activity should be incorporated into all prevention and management programs for individuals with metabolic syndrome. When prescribing exercise for individuals with metabolic syndrome, consideration should be given to their initial level of fitness, existing comorbid conditions, potential risks and their likelihood of adhering to the program over time.

Key words: metabolic syndrome, physical activity, exercise, insulin resistance, cardiovascular risk, obesity

Introduction

Metabolic syndrome (MetS) is described as a multifactorial condition, where the presence of central obesity, dyslipidemia, hypertension, and impaired glucose regulation occur together and substantially increases an individual's risk of developing type 2 diabetes mellitus and cardiovascular disease [1]. Data collected through epidemiologic studies suggest that MetS affects approximately 20-30 % of the adult population worldwide. However, there are high risk populations such as obese individuals and those who live sedentary lifestyles that have prevalence rates over 40 % [2].

The pathophysiology of MetS is complex and includes many mechanisms working together to create MetS. Insulin resistance is generally regarded as the primary mechanism responsible for creating MetS, although the resulting impaired glucose uptake and increased hepatic glucose production also affect dysregulated lipid metabolism [3]. Chronic low-grade inflammation and endothelial dysfunction both contribute to development of cardiometabolic complications as

well [4]. Additionally, visceral adipose tissue is particularly involved in the process because it secretes pro-inflammatory cytokines and adipokines that enhance insulin resistance [5].

Because of the multifactorial nature of MetS, management must be comprehensive including multiple risk factors simultaneously. As such, lifestyle interventions should be the first line strategy for managing MetS with emphasis on increasing physical activity and improving diet habits [6]. Systematic reviews and meta-analyses have demonstrated that structured lifestyle programs can significantly reduce individual components of MetS, such as waist circumference, fasting glucose, blood pressure [6, 7].

Additionally, physical activity has been shown to have broad beneficial effects on metabolic health. Recent reviews also highlight its role as a central non-pharmacological intervention in metabolic syndrome [7]. Meta-analyses suggest that regular exercise may reduce systolic blood pressure (approximately 5-7 mmHg), improve insulin sensitivity (up to 20-25%), and decrease in visceral fat (approximately 10-17%) [8]. These results are clinically relevant and may be used in conjunction with pharmacological interventions when necessary.

Finally, studies have demonstrated that exercise training is associated with improved clinical outcomes in patients with MetS. A systematic review reported that structured exercise interventions significantly reduced overall cardiometabolic risk and improved functional capacity in affected individuals [9]. Furthermore, the benefits of exercise were observed across different types of exercises including aerobic, resistance and combined.

In conclusion despite strong evidence supporting the use of physical activity, global levels of physical inactivity remain high and there is often poor adherence to recommendations for physical activity. Therefore, it is important to understand how different types of physical activities influence specific components of metabolic syndrome.

Methods

A narrative review approach was taken to provide a comprehensive and clinically relevant synthesis of all available data regarding the potential benefits of physical activity in preventing and managing metabolic syndrome.

To conduct the literature search, the PubMed/MEDLINE database was used. To ensure that the literature searched represented the most contemporary and clinically relevant evidence, only publications from the past decade (2016-2025) were considered. The following keywords and their combinations were used: “metabolic syndrome”, “physical activity”, “exercise”, “insulin resistance”, “obesity”, “cardiometabolic risk”, “lipid profile”, “blood pressure”, and “inflammation”. In addition to the general search strategy, additional targeted searches were conducted for each type of exercise modality, including aerobic training, resistance training, combined training, and high-intensity interval training.

In addition to database searches, reference lists of relevant articles and review papers were manually screened to identify additional eligible studies. This approach allowed for a broader and more comprehensive inclusion of relevant literature.

Peer-reviewed articles that examined the effect of physical activity on at least one component of metabolic syndrome were reviewed. All types of studies that included RCTs, observational studies, systematic reviews and meta-analysis were included. High priority was assigned to studies that had better quality methods (including RCTs and meta-analysis) and large sample sizes with clinically relevant outcomes. Articles focused upon adults diagnosed with metabolic syndrome, obesity, and/or related cardiometabolic disorders were included.

By taking this critical appraisal process into consideration when selecting studies, a structured summary of clinically relevant findings may have been produced which can account for the variability in study design and intervention strategies reported throughout the literature. Therefore, these findings are best understood as a narrative synthesis of selected high-quality evidence rather than a quantitative estimate of pooled treatment effects.

Results

Body composition and adiposity parameters

Excess adiposity, particularly visceral fat, is strongly associated with an increased risk of metabolic syndrome and a key determinant of insulin resistance and cardiometabolic risk. Therefore, reducing visceral adipose tissue is considered a key therapeutic target in individuals with metabolic syndrome. Substantial evidence indicates that physical activity contributes to reductions in both total and abdominal fat mass [10].

There are numerous studies focusing on high-intensity interval training (HIIT), as it relates to effects on body composition. A meta-analysis consisting of several randomized controlled trials revealed that HIIT has been shown to reduce total body fat and visceral adipose tissue. Visceral fat loss ranged from about 10% to 17%, based upon pre-exercise levels of visceral fat [10]. As such, given that visceral fat is more directly related to adverse metabolic consequences, than subcutaneous fat, the potential positive impacts of this type of training appear to be clinically applicable.

In addition to HIIT there have been numerous investigations into the effects of moderate-intensity continuous training (MICT). For example, comparative analyses suggest that both types of training result in statistically significant decreases in fat mass. Additionally, there were no statistical differences observed regarding the amount of total fat lost between the two forms of training [11]. However, HIIT achieves the same effects as MICT in less time which could increase compliance among those in clinical settings.

Comparative analyses have also investigated whether various types of exercise interventions produce better or worse effects than diet-based interventions. Greater reductions in total body weight are usually observed with caloric restriction; however, exercise interventions may be particularly effective in reducing visceral adipose tissue, a key determinant of cardiometabolic risk [12]. Conversely, reductions in visceral adipose tissue were observed when subjects underwent some form of exercise intervention. As such, since the greatest improvement in insulin sensitivity occurs with a decrease in visceral adipose tissue, rather than with general weight loss, this finding supports the rationale for exercise as a first line treatment option for many patients suffering from metabolic syndrome.

A recent network meta-analysis investigating the impact of differing forms of exercise on adiposity included 84 randomized controlled trials. The findings indicated that both aerobic and resistance training combination represented the best approach for reducing visceral fat mass [13]. This provides support for maximizing the efficacy of each modality used to optimize metabolic benefits.

Additionally, randomized controlled trials, has also confirmed that combining exercise interventions is superior to using single-modality interventions. For example, the CardioRACE study demonstrated that combined aerobic and resistance training improved body composition and cardiovascular risk factors, however, the magnitude of these effects varied across exercise modalities [14]. Subjects receiving the combined training regimen exhibited significant reductions in fat mass along improvements in metabolic parameter values. Therefore, they emphasize the utility of employing multi-modal exercise regimens in order to maximize therapeutic benefits.

Therefore, it is evident that there is considerable evidence supporting the use of physical activity to promote reductions in both total and visceral adiposity in individuals with metabolic syndrome. It should be noted that the degree of benefit afforded from exercise is contingent on the level of intensity/total volume of training performed, the length/duration of each training session, and subject's baseline adiposity status/adherence to prescribed training protocols. Thus, to achieve maximum benefit, individualized prescription of exercise programs is required.

Glucose metabolism and insulin resistance

Impaired glucose metabolism and insulin resistance are central features of metabolic syndrome and play a key role in the development of type 2 diabetes and cardiovascular disease. Consistently, the improvement of glucose metabolism and insulin sensitivity through physical activity has been shown in numerous studies of various population types.

Both moderate intensity continuous training (MICT) and high-intensity interval training (HIIT) have been shown to improve insulin sensitivity in obese adults, as determined from randomized controlled trials. An increase in insulin sensitivity was found to be around 20-25% following structured exercise interventions, with no significant differences observed between HIIT and

MICT groups [15]. As such, these findings suggest that overall training volume and regularity may be more important than exercise intensity alone.

Physiological mechanisms through which improvements occur include increased glucose uptake into skeletal muscle cells, as well as enhanced insulin signaling. Exercise stimulates the translocation of GLUT4 transporters to the muscle cell membrane, thereby facilitating glucose uptake independently of insulin. Clinical guidelines recommend regular physical activity as a primary method for management of impaired glucose metabolism and type 2 diabetes mellitus [16].

Meta-analytic evidence further supports the effectiveness of combined exercise interventions. Programs that included aerobic and resistance training resulted in significant reductions in fasting glucose and improved insulin sensitivity. Combined, the data suggests that structured exercise programs result in a decrease in fasting glucose levels of 0.3-0.6 mmol/l [17]. Such improvements are clinically relevant and contribute to overall risk reduction.

Comparative analyses of HIIT and MICT show both modalities produce similar improvements in insulin sensitivity and body composition. However, HIIT may allow for comparable benefits in shorter training durations. For individuals with limited availability this could be an important factor in adherence to recommended amounts of physical activity [18].

Exercise interventions have produced greater benefit in populations with more advanced degrees of metabolic dysfunction. A recent meta-analysis showed that HIIT resulted in improved indices of insulin resistance and glycemic control in patients with diabesity, with consistent improvements observed across randomized controlled trials [19]. Such findings support the potential for use of high-intensity exercise as an effective therapeutic strategy in high-risk populations.

In conclusion, the available evidence suggests that physical activity plays an important role in improvement of glucose metabolism and reducing insulin resistance. Both aerobic and resistance training, as well as their combination, have been shown to be effectively used. Ultimately, the optimal approach should be tailored based on individual patient characteristics and clinical context.

Lipid profile and dyslipidemia

Metabolic syndrome includes dyslipidemia; which is defined as an abnormal lipid profile. It contains three main components: hypertriglyceridemia, lower than normal levels of HDL cholesterol and increased atherogenic risk. Abnormal lipid levels are a major cause of cardiovascular disease.

Structured high-intensity interval training (HIIT) has several positive effects on lipid metabolism. One recent meta-analysis of randomized controlled trials indicated that there was

a reduction in serum triglyceride level of approximately 10-15 % following structured HIIT intervention in patients with metabolic syndrome [20]. Additionally, structured HIIT was found to be associated with improved levels of HDL cholesterol. As such, this would lead to a decrease in cardiovascular risk.

Regular aerobic exercise has also been shown to have positive effects on lipid parameter values. Network meta-analyses have indicated that different forms of aerobic activity will lower serum triglyceride levels and moderately raise HDL-cholesterol. The degree of these effects depends upon the length and intensity of the aerobic activity [21]. This highlights the importance of sustained and adequate dosing of physical activity.

There are dose-response relationships established between physical activity and lipid outcome. For example, it appears that higher volumes and intensities of exercise will be associated with larger decreases in low-density lipoprotein (LDL)-cholesterol and triglycerides. For instance, decreases in LDL-cholesterol of approximately 5-10% have been documented in response to structured exercise programs [22]. These decreases in LDL-cholesterol represent clinically meaningful changes in lipid profile values that are comparable to those produced by some lifestyle-based intervention.

The evidence regarding combined exercise modalities (a combination of aerobic and resistance training) indicates that they produce the largest number of statistically significant improvements across multiple lipid parameters. For example, several systematic reviews indicate that combining aerobic and resistance training produces simultaneous reduces in serum levels of triglycerides and LDL-cholesterol, along with increases in serum levels of HDL-cholesterol [23]. These findings support the idea that multimodal exercise interventions will produce superior cardiometabolic benefits.

Finally, further support for the role of exercise in reducing overall cardiovascular risk in patients with metabolic syndrome is provided by additional meta-analyses. While both aerobic training and resistance training have been shown to improve lipid profile values in individuals with metabolic syndrome; the combination of aerobic and resistance training appears to produce greater overall effects [24].

In summary, current research supports a role for regular physical activity in producing improved lipid profiles and reduced dyslipidemia in individuals with metabolic syndrome. The magnitude of these effects is dependent upon the level of intensity and duration of physical activity, modality of exercise, baseline lipid parameter values, and adherence to the prescribed physical activity program.

Blood pressure and vascular function

Hypertension is a key component of metabolic syndrome and represents a major factor for cardiovascular disease. Research studies consistently show that the effects of exercise result in

lowering blood pressure levels. A recent study used a pairwise and network meta-analysis of randomized control trials to investigate how different forms of exercise affected resting blood pressure; results indicated that both aerobic- and isometric-based types of exercises were the most effective means of reducing resting blood pressure [25].

There is evidence suggesting that aerobic exercise can reduce blood pressure levels in a dose dependent manner. A systematic review article and dose response meta-analysis of randomized clinical trials investigated the relationship of aerobic exercise to blood pressure in patients diagnosed with hypertension. Results demonstrated that the highest level of improvement occurred when participants engaged in 150 minutes per week (mean reduction of -7.23 mmHg in systolic BP and -5.58 mmHg in diastolic blood pressure which provides a clinically relevant reduction in cardiovascular disease risk [26].

In addition to aerobic based methods of reducing blood pressure, resistance training is beneficial to individuals diagnosed with metabolic syndrome. A systematic review and meta-analysis of randomized control trials concluded that resistance training resulted in significant decreases in systolic blood pressure in these populations [27]. This suggests that resistance exercise should not be viewed only as a strategy for improving muscle strength, but also as an important component of cardiometabolic risk reduction.

In addition to the influence on resting blood pressure, research indicates that exercise improves vascular structure and function. Studies indicate that an intensive six months aerobic interval training program resulted in decreased arterial stiffness and improved microvascular functioning [28]. Changes to vascular structure are important due to their association with the development of cardiovascular disease.

Collectively, existing literature supports the integration of regular physical activity into preventing and treating hypertension secondary to metabolic syndrome [29]. Data from these studies indicate that aerobic-based exercises completed at recommended volumes (i.e., approximately 150 minutes/week), will likely produce significant reductions in blood pressure [26]. Additionally, resistance training and other forms of high intensity interval training may add additional benefits to vascular health and thus could be used in conjunction with aerobic exercise to create personalized exercise prescriptions for individuals with hypertension secondary to metabolic syndrome [27].

Inflammatory markers and cardiometabolic risk

Chronic low-grade inflammation is a fundamental feature of metabolic syndrome and plays a key role in the development of insulin resistance, endothelial dysfunction, and atherosclerosis. Elevated levels of inflammatory markers, particularly C-reactive protein (CRP) and pro-inflammatory cytokines, are commonly observed in individuals with metabolic syndrome.

Research has consistently demonstrated that exercise training reduces inflammation. A recent meta-analysis of studies conducted on people with metabolic syndrome found that participants who were assigned to a structured exercise program experienced a reduction in their level of inflammation (measured by circulating C-reactive protein, and the inflammatory cytokine IL-6) when compared to those in the control group [30]. The anti-inflammatory effects of exercise are likely to lead to clinical benefits, since even relatively modest changes in systemic inflammation have been linked to better cardiometabolic profiles.

In a meta-analysis of randomized and non-randomized trials examining the relationship between exercise and inflammation, the average decrease in CRP was -0.7 mg/l. Additionally, it appeared that the larger the difference in CRP levels at baseline, the greater the average reduction due to the intervention [31]. Therefore, one could conclude that individuals with elevated levels of inflammation would be expected to experience the greatest benefits from physical activity.

Resistance training has also been studied as a potential mechanism through which to impact inflammatory status. A meta-analysis of randomized controlled trials studying resistance training in older adults demonstrated that these interventions resulted in lower levels of circulating CRP and inflammatory cytokines. These findings suggest that resistance training results in anti-inflammatory effects [32].

Exercise intensity appears to play an important role in modulating inflammatory responses. A systematic review comparing different training intensities found that both moderate- and high-intensity exercise reduce inflammatory markers, although the amount of change depends on the characteristics of each individual and his/her baseline health status [33]. There is some evidence suggesting that aerobic exercise may also serve as a means of reducing inflammation in both clinical and healthy populations. A meta-analysis showed that there are statistically-significant reductions in CRP and other inflammatory mediators resulting from routine aerobic exercise [34].

Overall, the available evidence indicates that physical activity plays a critical role in reducing chronic inflammation associated with metabolic syndrome. These anti-inflammatory effects contribute to improvements in insulin sensitivity, vascular function, and overall cardiometabolic risk, highlighting the importance of regular exercise as part of comprehensive management strategies.

Discussion

The results from this narrative review clearly demonstrate that physical activity plays an important role in both the prevention and treatment of metabolic syndrome. Physical activity was found to positively affect all of the five main features of metabolic syndrome; body composition/weight/fatness, glucose/insulin metabolism, lipid profiles (cholesterol), hypertension, and systemic inflammatory processes. The positive impact on these many

different aspects of metabolic syndrome reflects the complex nature of the disease process in which both insulin resistance and chronic low-grade inflammation play a central role [3].

Another of the notable findings of this review was the consistent reduction in visceral adipose tissue seen in those who regularly engage in physical activity. Visceral fat is highly correlated with both insulin resistance and cardiometabolic risk and several studies have noted that high intensity training has resulted in approximately 10-17% reductions in visceral adipose tissue [10]. These changes are particularly relevant because improvements in metabolic health are more closely related to reductions in visceral fat than to overall weight loss [11].

Improvements in glucose metabolism were identified as another primary method through which exercise produces positive effects. Clinical trials have indicated that participants in structured exercise programs experience an increase in insulin sensitivity of approximately 20-25% [15]. Other studies have reported average decreases in fasting glucose of up to 0.6 mmol/l among participants in combination training programs [17]. Thus, these findings indicate that regular participation in physical activity should be viewed as a vital component of any strategy used to prevent type 2 diabetes in people with metabolic syndrome.

Further contributing to the reduction of cardiovascular disease risk through improved lipid profiles were the reductions in triglyceride levels (approximately 10-15%) and LDL cholesterol (up to 10%) seen in response to various forms of physical activity [20]. As such, physical activity is recognized as a viable option for managing hypertriglyceridemia and hyperlipidemia within the context of metabolic syndrome.

Additionally, there is considerable evidence indicating that physical activity is beneficial for lowering blood pressure. The magnitude of reductions in systolic blood pressure (average 7 mmHg) and diastolic blood pressure (average 5 mmHg) resulting from aerobic exercise performed at guideline-recommended volumes [26]. These reductions in blood pressure are associated with a substantial reduction in cardiovascular disease risk and are comparable to the effects of some pharmacological therapies.

As previously stated, the benefits of physical activity extend far beyond improvements in metabolic function. In addition to the effects described above, physical activity elicits profound anti-inflammatory responses. Studies examining the effects of exercise on C-reactive protein levels have consistently demonstrated reductions ranging by approximately 0.7 mg/l, with greater effects observed in individuals with higher baseline inflammation [31]. Given the critical role that chronic low-grade inflammation plays in promoting metabolic dysfunction and accelerating the progression of cardiovascular disease, the anti-inflammatory properties of physical activity are likely to play a pivotal role in mitigating these risks [5].

Importantly, the benefits of physical activity extend beyond individual metabolic parameters. Lifestyle intervention programs that include structured exercise have been shown to improve overall clinical outcomes in individuals with metabolic syndrome, including reductions in

cardiometabolic risk and improvements in functional capacity [35]. Furthermore, such interventions are associated with significant improvements in health-related quality of life [36].

While evidence supports the importance of incorporating physical activity into daily routines to help manage metabolic syndrome, sustaining engagement over time continues to pose challenges. Several barriers exist that impede continued involvement, including lack of motivation, limited time available to devote to physical activity and psychological factors that inhibit adherence. Incorporation of behavior modification techniques into physical activity plans has been demonstrated to enhance compliance with physical activity recommendations among individuals with metabolic syndrome [37]. Therefore, development and implementation of interventions that incorporate both psychological and behavioral elements are warranted.

Finally, inadequate physical activity represents one of the greatest global health problems today. Sedentary lifestyles characterized by low levels of cardiorespiratory fitness are strongly correlated with increased risk for metabolic syndrome and cardiovascular disease [38]. Consequently, public health initiatives focused on increasing rates of physical activity are needed to address the global burden of metabolic diseases.

The evidence reviewed herein supports the inclusion of physically active lifestyles into the treatment plans for individuals diagnosed with metabolic syndrome. A moderate-intensity aerobic program lasting about 150 minutes/week is a reasonable goal for improving both blood pressure and reducing overall cardiometabolic risk, with additional benefits observed at higher volumes [26].

Additionally, strength training programs contribute to improved insulin sensitivity, inflammation status and other metabolic parameters. Combined aerobic-resistance training programs offer a reliable mechanism to achieve improvement in several metabolic parameters [23]. High-intensity interval training provides a time efficient form of exercise providing similar if not superior metabolic benefit in select populations. However, due to its high energy expenditure requirements, HIIT may not be suitable for individuals who have low initial levels of cardiorespiratory fitness, uncontrolled hypertension, advanced cardiovascular disease, musculoskeletal injuries or other health issues. Pre-exercise medical evaluation and/or screening, gradually increasing exercise intensity over time, and careful follow-up with individualized feedback regarding progress may help minimize adverse events and enhance adherence to HIIT [16].

In clinical practice, prescribing exercise should consider both maximizing the potential for long-term adherence as well as minimizing the risk of injury associated with new forms of physical activity. For example, initiating a moderately intense aerobic program may be an acceptable starting point for many patients, while introducing progressive resistance training, combined aerobic-resistance training, or HIIT may be done later in some instances.

Finally, since maintaining long term adherence to regular physical activity regimens is often problematic, incorporating behaviorally oriented techniques may be necessary to maximize the effectiveness of exercise-based interventions [37].

Conclusions

Physical activity has a critical role in the prevention and treatment of metabolic syndrome. Numerous studies have found that regular exercise can lead to significant improvement in the various components of metabolic syndrome. These include body composition, insulin sensitivity, lipid profiles, blood pressure, and inflammatory processes. Each one of these factors represent some of the key physiological pathways involved in the development of metabolic syndrome.

Aerobic, resistance and combined forms of exercise have been shown to be beneficial. However, research indicates that combining exercises may result in the greatest overall benefit. For those who do not have time to complete an entire program of physical activity due to their busy lifestyles, high intensity interval training (HIIT) is a viable alternative. Additionally, for those who find it difficult to get started or continue with a formal exercise program, moderate levels of physical activity offer a safe and easily accessible alternative.

Although there is substantial evidence demonstrating the value of physical activity as a means of preventing and managing metabolic syndrome, continued participation is a problem for many people. As such, future strategies will need to focus on developing programs that promote long term adherence to physical activity. Future recommendations could include creating and evaluating exercise prescription methods, promoting behavioral adherence to physical activity and increasing access to physical activity programs.

Therefore, it is recommended that physical activity be recognized as a foundational component of both public health strategies and clinical management strategies intended to reduce the burden of metabolic syndrome.

Disclosure

Supplementary Materials

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