International Journal of Engineering, Management and Humanities (IJEMH)
Volume 4, Issue 5, Sep.-Oct., 2023 pp: 237-243 www.ijemh.com

Exercise training and metabolic syndrome: A review

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Date of Submission: 01-10-2023 Date of Acceptance: 11-10-2023

ABSTRACT: Metabolic syndrome is a condition that poses a significant global health challenge. It consists of a cluster of interrelated metabolic disorders that raises the chance of developing cardiovascular disease, type 2 diabetes, and other chronic illnesses. Due to the epidemic of obesity and sedentary life, the metabolic syndrome and its consequences, especially diabetes, are no longer observed only in advanced age individuals. There is evidence that most instances of obesity are more connected to low energy expenditure than to excessive food consumption, with physical inactivity in modern life appearing to be the most important etiological cause for the spread of this illness in industrialised nations. Therefore, exercise training has emerged as a viable non-pharmacological option for metabolic syndrome management. The purpose of this article is to review existing research in order to provide the syndrome's definition, underlying pathogenesis, exercise treatment approaches, and the effects of exercise training on several components of the metabolic syndrome, such as obesity, insulin resistance, dyslipidemia, and hypertension.

KEYWORDS: metabolic syndrome, obesity, diabetes, insulin resistance, exercise training

I. INTRODUCTION

The simultaneous disorder of glucose and insulin metabolism, overweight and abdominal fat distribution, severe dyslipidaemia, and hypertension have led to the rise of the concept of the metabolic syndrome, also known as Syndrome X, Deadly Quartet, or insulin resistance syndrome [1-5].

Although the term metabolic syndrome included in scientific papers, it made its resurgence as the concept of Syndrome X in 1988 [1, 5], while the occurrence of hypertension, hyperglycaemia and gout have been described since 1923 [6]. Insulin resistance is considered to be the real abnormality of this syndrome. The pathogenesis of this syndrome has multiple origins, but obesity and a sedentary lifestyle, the latter associated with a high-fat diet, as well as generally unknown genetic factors, appear to interact [1-5, 7].

From the point of view of public health, metabolic syndrome is clinically one of the most important problems, because of the very high morbidity and mortality rates resulting from its component diseases, Type 2 Diabetes or cardiovascular diseases [1-5, 8, 9]. Also, patients with Type 2 Diabetes are not immune to the metabolic syndrome and its consequences, including cardiovascular and microvascular diseases [10-13]. As a result of the epidemic of obesity and sedentary life, the metabolic syndrome and its consequences, especially diabetes, are no longer observed only in advanced age individuals [14].

II. PATHOGENESIS

The pathogenesis of metabolic syndrome is little known. A distribution of fat in the abdominal area can be a particularly important problem [15-18]. Abdominal fat can be divided into visceral (of the organs) and subcutaneous fat and can be assessed by computed tomography or magnetic resonance imaging. Most experimental evidence suggests that abdominal obesity has a negative effect on carbohydrate and lipid metabolism by increasing lipolytic activity and specifically when fat drains directly into the portal venous system. According to this hypothesis, there is an increase in the concentration of non-esterified fatty acids, with an added resistance to insulin in the liver and skeletal muscles, as well as dyslipidaemia [19]. However, the pathophysiological implications are still not very clear [20-30].

The accumulation of triglycerides in the liver leads to a decrease in insulin sensitivity and an increase in the production of Very Low Density Lipoproteins (VLDL), which results in an increase in the transfer of cholesterol esters from High Density Lipoproteins (HDL) to Low Density

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Lipoproteins (LDL), and finally in VLDL [31-33]. This then leads to reduced HDL levels and smaller, denser LDL particles. Skeletal muscle is an important determinant of glucose utilization [24, 33]. Scientific evidence suggests that intramuscular lipid deposits play a very important role in reducing glucose utilization in skeletal muscle, and they do so by impairing intracellular glucose transport, initially affecting insulin receptor activity [24, 32-34].

Paradoxically, the ability to utilize fatty acids as an energy source during the resting state decreases in the presence of insulin resistance [24]. As the metabolic syndrome worsens while interacting with genetic susceptibility, insulin resistance and diet, this can lead to progressive impairment of β-cell function associated with decreased insulin secretory capacity [35-39]. As the secretory capacity of the β-cells decreases, impaired glucose tolerance (IGT) develops. IGT is common in elderly individuals, and accounts for 25% of individuals of this age in Europe. About 5-10% of these individuals become diabetic each year. Manifestation of cardiovascular risk factors such as dyslipidaemia, hypertension, endothelial dysfunction, inflammation, hyper coagulation and fibrinolysis disorder, obesity and impaired insulin and glucose metabolism predispose individuals to develop metabolic syndrome and lead to the development of severe cardiovascular conditions that can lead to death [1-5, 8, 9].

Also, adipose tissue produces hormones, cytokines and other peptides such as angiotensinogen, adipsin, acylation stimulating protein, adiponectin, retinol binding protein, leptin, resistin, tumor necrosis factor alpha, interleukin-6, plasminogen activating inhibitor-1 that may play an important role in insulin resistance, inflammation and the development of diabetes and cardiovascular disease [39-41].

The pathophysiology behind the association of obesity with insulin resistance is not very clear [42-45]. Genetic and environmental factors [46, 47] contribute to the development of overweight and the possibility of developing insulin resistance and ectopic fat deposition as well as other manifestations of the metabolic syndrome.

The World Health Organization (WHO) has classified diabetes and its complications as Metabolic Syndrome [48]. There is also a classification made by the National Cholesterol Education Program (NCEP) Expert Panel for the same syndrome.

Table 1. WHO and NCEP Classification of Metabolic Syndrome.

Classification of WHO	Classification of NCEP
Hyperinsulinemia	**Hyperinsulinemia**
Fasting plasma glucose ≤7.0 mmol l(-1)	Fasting plasma glucose >6.1 mmol· l^{-1}
AND	AND
At least two of the following indicators:	At least three of the following indicators:
Dyslipidaemia (Serum triglycerides ≤1.70 mmol·l-1 or HDL cholesterol <0.90 mmol·l-1)	Serum triglycerides ≤1.70 mmol· l-1
	HDL cholesterol <1.0 mmol· l-1
Hypertension (blood pressure ≥140/90 mmHg or being treated)	Blood pressure ≥130/85 mmHg or being treated
Abdominal obesity	**Abdominal obesity**
Definition 1 – Waist-to-hip Ratio (WHR) >0.90 or Body Mass Index >30 kg· m-2	Definition 1 - Waist circumference >102 cm
Definition 2 – Waist circumference >94 cm	Definition 2 - Waist circumference >94 cm

III. EFFECTS OF ENDURANCE TRAINING AND RESISTANCE TRAINING ON METABOLIC SYNDROME

There are evidences suggesting that most cases of obesity are more related to the low energy expenditure than to the high food ingestion, where the physical inactivity of the modern life seems to be the highest etiological factor for the growth of this disease in industrialized societies [49].

Systematic reviews [50-53] have concluded that both, endurance training (walking, jogging, or cycling) or resistance training (weight training) lowers absolute haemoglobin A1c by about 0.6%. The haemoglobin A1c value reflects the average plasma glucose concentration of the last 2 to 3 months. A 1% reduction in absolute A1c is

associated with a 15% to 20% reduction in major cardiovascular events [54] and a 37% reduction in microvascular complications [55].

The only study that compared the effects of combined endurance and resistance training with the effects of endurance training found no differences in haemoglobin A1c values between groups, but the small number of individuals who were tested and the low haemoglobin A1c values of both groups (the control and the experiment groups) did not allow to make an accurate assessment of the difference [56].

Absolute haemoglobin A1c values, suited for body weight, were statistically significantly lower in the endurance training group compared to the control group (difference in percentage -0.51; P = 0.007) and in the resistance training compared to the control group (difference in percentage -0.38; P = 0.038). In the group that had combined resistance and endurance training, haemoglobin A1c values changed by an additional percentage of -0.46 compared with the endurance training group (P = 0.014) and by a percentage of -0.59 compared with the group resistance training (P = 0.001).

Participants with an A1c level of or above 7.5% had a greater decrease in haemoglobin A1c than those with lower than median A1c values (P = 0.001), whereas among those with below than average haemoglobin A1c values, only the group that had a combination of endurance and resistance training experienced positive changes. Changes in blood pressure; total cholesterol, HDL, LDL, and triglyceride levels and the ratio of HDL cholesterol to total cholesterol did not differ significantly between groups [57]. However, as the physiological effects of endurance training [58] differ from those of resistance training [59, 60], these differences are not solely due to the additional time required to perform the necessary physical load.

Endurance training involves continuous activities of large muscle groups, while resistance training affects small muscle groups with short time span actions. The need for rest between sets in the case of resistance training is more than half the time of a training session including the active muscle contraction itself, while endurance training is continuous [57].

If the findings of Sigal et al. [57] would be explained by the duration of physical exercise, the effect of resistance training on haemoglobin A1c should be expected to be half that of endurance training, and the effects of resistance training combined with endurance training should be as 1.5 times less than endurance training alone. While the effects of endurance and resistance training were more or less similar on haemoglobin A1c, in the case of combined resistance and endurance training the effect was twice that of endurance training alone [57].

Even if the effect was only related to the duration of training, it can still be said that combined training is more liked by individuals because it is not repetitive. Many people would experience feelings of monotony of training if they were to do the same thing over and over, whereas in the case of resistance training there is a continuous change of the physical exercise performed. The effect of resistance training and that of endurance training are complementary: endurance training increases cardiorespiratory fitness, while resistance training increases muscle mass, strength and endurance [57].

The effect of resistance training on haemoglobin A1c values found by Sigal et al. [57] was smaller than those reported by Dunstan et al [61] and Castaneda et al. [62]. There are many reasons for this difference. The individuals tested in the study of Sigal et al. [57] were younger than those in the other two studies. Older individuals benefit more from resistance training than younger individuals because they lose muscle mass as a result of inactivity [63, 64].

The mean haemoglobin A1c value prior to the start of the other 2 studies was higher than in the case of Sigal et al. (2007). Thus, the effect of exercise was greater when the haemoglobin A1c value was higher at the beginning of the study. Dunstan et al. [61] did not assess the treatment effect of exercise, and as a consequence there may be an overestimation of the effectiveness of exercise.

When it comes to changes in blood pressure, none of the exercise programs had a statistically significant effect on arterial blood pressure compared to the control group, and the effects of exercise on plasma lipid levels were modest. A meta-analytic study found no significant exercise-induced changes in these variables [53]. To achieve greater changes, a higher training volume and intensity should be achieved [65].

Both endurance and resistance training alone led to improved glycaemic control, and when combined these training sessions had a greater effect than either type of training alone. These effects were stronger in those with poorer muscle mass and less efficient initial glycaemic control at the start of the study [57].

Studies in the last decades have shown that circuit resistance training can lead to improvements in vascular endothelial function within 8 to 12 weeks, even in the absence of changes in blood lipid profile, arterial pressure, and glycaemic control [66, 67].

Trained muscles oxidize more fatty acids (while conserving limited glycogen stores) at the same absolute weight load resulting in protection against hypoglycaemia-induced fatigue and prolongation of the time required to reach full fatigue [68, 69]. Endurance training of skeletal muscle increases the function of β-oxidation enzymes and this leads to greater oxidation of fatty acids at a given absolute load [70].

Creatine phosphate concentrations are higher while inorganic phosphate concentrations of ADP, AMP, and lactate are lower in the muscles of trained rats compared with untrained rats during the same contractile activity [71, 72]. Constable et al. described this adaptation as an aspect of the minor disruption of homeostasis that occurs in trained muscles compared to those of the untrained ones when the same activity is performed [71]. Therefore, muscles that have not performed physical activity suffer a greater homeostatic disorder under the same absolute load and work intensity. Eaton et al. [73] relates this fact to the discordance between "Stone Age" genes and the need for their expression in the context of the "Space Age", resulting in the destruction of older complex homeostatic systems. "Increased cross-sectional area in the muscle of at the mid-thigh level is statistically greater in the endurance and resistance training groups compared to the control group (respectively, P =0.003 and P =0.001) [57].

V.CONCLUSION

Exercise training is essential for the prevention and management of metabolic syndrome. Regular physical exercise tackles each component of metabolic syndrome, providing several advantages ranging from weight reduction and improved lipid profiles to enhanced insulin sensitivity and lower inflammation. Exercise prescription should be included as part of the treatment strategy for persons with metabolic syndrome by healthcare practitioners. Individualising exercise programmes to meet individual requirements and preferences is critical to long-term effectiveness in combating this frequent health condition. As research reveals the good effects of exercise training, it emphasises the need of leading an active lifestyle in the goal of metabolic health and general well-being.

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