Effects of Exercise Therapy on Type 2 Diabetes Mellitus

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Abstract. Type 2 diabetes (T2DM) is a chronic metabolic disorder in which people are insulin resistant and β-cell dysfunction. Drug treatment and dietary control are conventional measures that are considered the main methods of treatment. Although they are effective in short term, they still have some side effects, like low compliance and significant individual differences. In contrast, exercising intervention is a safe, effective and non-drug strategy. An increasing number of people are taking an interest in this strategy, which is known as 'public policy' nowadays. This article systematically and briefly examines the function and effect of aerobic exercise, resistance exercise and combined exercise prevention and treatment exercise in the case of T2DM. Aerobic exercise also has a significant effect on reducing fasting blood glucose and glycated hemoglobin by promoting glucose uptakes in skeletal muscle. It lowers glucose production by the liver, improving fat utilization and lipid metabolism. Resistance training can also control the blood glucose, strengthen muscles and physical fitness. By increasing muscle mass, upregulating GLUT-4 expression, and enhancing muscle sensitivity. Combined training is able to obtain complementary mechanisms and insulin sensitivity, which is more effective in improving metabolism. Based on the current evidence, exercise interventions are considered safe and effective for elderly and T2DM patients. However, clinical promotions still has some limitations, such as lack of awareness and individualized plans. Further studies should investigate the deepen mechanisms and explore opportunities to promote the standardized application of exercise therapy in diabetes management.

Keywords: Type 2 diabetes mellitus, blood glucose, exercise.

1. Introduction

Diabetes mellitus (DM) is a chronic metabolic disorder with a complex pathogenesis, primarily due to impaired glucose utilization, causing hyperglycemia due to inadequate insulin production or the inability of the insulin that is produced to work effectively. In recent years, the continued rise in prevalence of diabetes is attributed to population ageing, urbanization and widespread unhealthy lifestyles. In China, the rate of diabetes is 11.2% according to World Health Organization (WHO) criteria [1]. If long-term glycemic control is inadequate, it can result in a number of serious complications which impose a considerable public health problem, and interventions are urgently needed to address the problem effectively. At present, both drug use and dietary control play a role in the management of diabetes and are associated with significant drawbacks. Drugs can have side effects such as hypoglycaemia [2]. As far as dietary control is concerned, these patients may not have good long-term compliance, and it requires a high level of self-management skills. Work schedules, social activities and eating habits are all factors that can keep patients from following their diet consistently in real life. Furthermore, there are significant differences in the metabolism, insulin sensitivity and gut flora among individuals that affect their responses to the same diet treatment. In addition, diets alone are not very effective in improving insulin resistance. The right nutrition regimen can help to keep blood glucose levels stable, but nutrition can also influence the fluctuations in blood glucose levels. The beneficial effects may be small. By contrast, exercise programs (e.g. aerobic and resistance exercise) can more directly improve the metabolism by promoting the uptake of glucose in skeletal muscle. This article will systematically review the developments in exercise-based interventions for diabetes and provide important theoretical guidance to clinical management. In terms of etiology and pathogenesis, diabetes can be mainly divided into type 1 diabetes and type 2 diabetes.

2. Classification of Diabetes

Diabetes is classified into Type 1 Diabetes Mellitus (T1DM) and Type 2 Diabetes Mellitus (T2DM).

Among them, T1DM is caused by an autoimmune error that attacks the pancreatic beta cells, resulting in an absolute lack of insulin. Its occurrence is closely related to genetic susceptibility, especially with HLA genes (such as HLA-DR3, DR4), but usually requires environmental factors (such as viral infections or chemical toxins) as triggering factors. T1DM is more common in adolescents and requires lifelong insulin injections.

T2DM accounts for more than 90% of diabetes patients. Its pathogenesis is complex and is mainly related to insulin resistance and the gradual decline of pancreatic beta cell function. On the one hand, insulin resistance is a key link in the occurrence of T2DM, and its occurrence is closely related to obesity, lack of physical activity, and high-calorie diets and other lifestyles. These factors can reduce the body's sensitivity to insulin, thereby affecting normal glucose metabolism. On the other hand, as the disease progresses, pancreatic beta cell function fails. Long-term high blood sugar status and lipid toxicity effects cause the beta cells to gradually lose compensatory ability or metabolic capacity, ultimately leading to insufficient insulin secretion. In addition, chronic low-grade inflammation related to obesity also plays an important role in the occurrence of T2DM. The fat tissue secretes various inflammatory factors such as TNF-α, IL-6, which further aggravates insulin resistance, forming a vicious cycle.

3. Risk factors for diabetes

The risk factors for diabetes can be classified into two main categories: uncontrollable risk factors and controllable risk factors.

Among the uncontrollable factors, the main ones include genetic factors and the aging process. Studies have shown that individuals with a family history of diabetes have a significantly increased risk of developing the disease. For example, type 1 diabetes (T1DM) is closely associated with human leukocyte antigen (HLA) genes, while type 2 diabetes (T2DM) is more influenced by genetic inheritance, possibly through genetic effects on insulin secretion or utilization, thereby increasing the risk of developing the disease. Additionally, research indicates that as people age, their metabolic capacity gradually declines, muscle mass decreases, and insulin sensitivity decreases, leading to an increasing incidence of type 2 diabetes among those over 40 years old [3].

In contrast, controllable factors are more crucial in the prevention and management of T2DM. Firstly, the accumulation of visceral fat is an important driving factor for insulin resistance. Excessive visceral fat is not only a form of energy storage but also actively secretes various inflammatory factors (such as tumor necrosis factor-α, interleukin-6, etc.), which interfere with the insulin signaling pathway and weaken the response of tissues such as muscles and the liver to insulin, gradually developing into insulin resistance [4]. People with a body mass index (BMI) of ≥24 or a waist circumference exceeding the standard (men ≥90cm, women ≥85cm) should be vigilant. Unhealthy dietary habits, long-term high-sugar and high-fat diets (such as sugary beverages, fried foods) will increase the burden on the pancreas and cause fluctuations in blood sugar; insufficient dietary fiber intake will affect the intestinal flora and indirectly increase the risk of metabolic abnormalities. Lack of exercise, prolonged sitting, leads to insufficient energy consumption and a decrease in the muscle's ability to take up glucose, exacerbating insulin resistance. People who exercise less than 150 minutes per week have a higher risk of developing the disease. Therefore, scientific weight control, adjusting dietary structure, and adhering to regular exercise are the most fundamental and effective controllable strategies for preventing and managing diabetes.

4. The Role of Exercise Intervention in the Prevention and Management of Diabetes

4.1. Aerobic Exercise

Aerobic exercise involves the use of large muscle groups in rhythmic and sustained contractions and relies on aerobic metabolic pathways. These often include brisk walking, running, riding a bike and swimming. Due to its moderate intensity and low risk, it has become a widely used intervention for patients with type 2 diabetes (T2DM) [5].

A systematic review and meta-analysis incorporating seven randomized controlled trials (RCTs) involving 386 elderly T2DM patients (mean age 62.9–73.2 years) evaluated the effects of aerobic exercise on components of metabolic syndrome. Results showed significant improvements in multiple indicators: fasting blood glucose (5 RCTs, 259 participants), standardized mean difference (SMD) = -1.76 (95% CI: -2.78 to -0.74); hemoglobin A1c (4 RCTs, 288 participants), SMD = -0.63 (95% CI: -0.87 to -0.39); systolic and diastolic blood pressure (each 4 RCTs, 220 participants), SMDs of -1.67 and -1.47, respectively; high-density lipoprotein cholesterol (5 RCTs, 319 participants), SMD = 0.41 (95% CI: 0.11 to 0.72); and triglycerides (5 RCTs, 319 participants), SMD = -0.34 (95% CI: -0.67 to -0.01).

The mechanisms are the improvement in liver function and reduced through the regular training, which improves insulin sensitivity and promotes the accumulation of lipid in the liver. Reduces night-time glucose production in the liver. In addition, doing high- intensity exercise, can increase glucose utilization and doing moderate intensity exercise enhances the use of fatty acid oxidation [6].

Another RCT included 60 older adults with T2DM and compared a swimming intervention with a control group over 12 weeks. Participants in the intervention group performed moderate-intensity swimming three times per week for 45–60 minutes per session. The study mainly examined changes in blood glucose and HbA1c levels. The intervention significantly reduced fasting blood glucose, 2-hour postchallenge blood glucose, and HbA1c levels. It also improved body mass index (BMI) and waist circumference compared with conventional management. The target heart rate during swimming was 112.5 bpm, and 89.2% of the sessions achieved the target heart rate zone. Only six minor adverse events, such as joint pain and hypoglycemia, were reported, with no serious adverse events occurring during the intervention. Swimming may improve glycemic control and weight management in older adults with T2DM by increasing glucose uptake into skeletal muscle, reducing insulin resistance, and decreasing visceral fat. Therefore, swimming may be considered a safe and effective non-pharmacological intervention for older adults with T2DM [7].

4.2. Resistance Training

Resistance training, or strength training, is exercise performed using one's own body weight or other weights. It involves muscles working against external resistance to build muscle strength, endurance, and volume, and to maintain bone density. Common forms include free weight training (e.g., dumbbells, barbells, and kettlebells), yoga, walking or running, machine training, and bodyweight exercises (e.g., push-ups and squats).

The effect of resistance training on glycemic control and muscle function in T2DM patients was investigated using a systematic review and meta-analysis of several RCTs. Results showed that regular resistance training had a significant beneficial effect on a number of outcomes, including significant decreases in HbA1c and significant increases in muscle strength and lean body mass. Research has indicated that the greater the improvement in muscle strength, the greater the drop in HbA1c levels. This demonstrates that resistance training not only improves glucose control but also increases the body's ability to utilize glucose. This effect is due to the fact that, with increased muscle mass, resting metabolic rate is higher. All of these are indicative of improved insulin sensitivity and enhanced expression of GLUT-4 transporters, which further reduce blood glucose levels and promote glucose uptake in skeletal muscle [8].

Another RCT of elderly patients with type 2 diabetes compared HIRT with a standard care group. The training program mainly focused on the lower and upper limbs and was repeated three times a week for several weeks. Tests revealed that hemoglobin A1c levels were meaningfully decreased with high-intensity resistance training and increased with aerobic exercise. Resistance training also improved muscle strength, physical function, and body composition. It exerts potential benefits for those over the age of 60 who have type 2 diabetes by raising the amount of skeletal muscle, which contributes to weight loss, helps improve insulin sensitivity, and boosts the efficiency of glucose use. Moreover, regular strength training decreases the risk of falling, enhances quality of life, and is safe making it a well-suited NPI that can be used with older adults [9].

4.3. Combined Training

Many people have used a combination of exercise therapies clinically, combining aerobic and resistance training. A recent meta-analysis consisting of six RCTs included 366 patients with type 2 diabetes and examined the effect of combined aerobic and resistance exercise, as well as the effect of strength and aerobic training on blood glucose and metabolic parameters. Results indicated that, compared with an aerobic exercise intervention alone, the combined exercise intervention significantly improved glycemic control. The combination might have a synergistic effect on glycemic control, leading to greater increases in skeletal muscle, increasing glucose uptake by muscles, and helping to increase insulin sensitivity [10].

Six RCTs of 366 patients were also analyzed in a separate recent meta-analysis. A continuous combined aerobic and resistance exercise training intervention was evaluated in T2DM participants by measuring its effect on blood pressure, glucose, and metabolic markers. Findings revealed that, compared with the control group, combined exercise was significantly beneficial for glycemic control (SMD = 1.22, 95% CI: 0.70–1.74, $P < 0.00001$). This implies that the combination may improve metabolic regulation in individuals with type 2 diabetes by promoting an increase in skeletal muscle, promoting insulin signaling pathways, improving insulin sensitivity, and increasing muscle glucose uptake [11].

5. Conclusion

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder which is the result of lack of insulin activity or the effectiveness of insulin. Current exercise interventions which are involved aerobic and resistance exercise. Aerobic exercise can make a huge difference when it comes to fasting. HbA1c, lipids, blood glucose and blood pressure in elderly patients with increased insulin sensitivity in tissues may have a role in type 2 diabetes, both through mechanisms of reducing hepatic glucose output and increased glucose absorption in the muscles. Regular moderate-intensity aerobic exercise is an effective and safe method that can improve blood sugar control and body composition. Resistance training not only helps to lower glycated hemoglobin (HbA1c) but also enhances muscle strength and skeletal muscle mass. Its hypoglycemic effect complements that of the former. Increasing muscle mass can simultaneously increase the expression level of GLUT-4 and insulin sensitivity. Furthermore, it also decreases the risk of falling, which is especially beneficial for elderly patients. Combined training (aerobic + resistance) provides complementary mechanisms and synergistic effects often with better glycemic control and metabolic improvement.

Nevertheless, exercise therapies in clinical practice still face a numerous of challenges today including lacks standard guidelines for prescriptions, low adherence of patients, and lack of public awareness, which hinder their widespread use. Further studies should be directed towards developing a large-scale, multicenter and evidence-based data to discover the best combinations of exercise type, intensity and frequency. Moreover, using wearable devices and artificial intelligence can contribute to the design of measurable and personalized exercise prescription systems. To enhance the relationship between communities and clinics is key to build a multidisciplinary diabetes exercise management system, which can promote the implementation of research into practice. In the end this

will facilitate the application of exercise therapy in diabetes broadly and maximizing the patient benefit.

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