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Research Progress on the Effects of Different Types of Exercise on Type 2 Diabetes Mellitus

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Abstract. Diabetes is a major global public health challenge, and Type 2 Diabetes Mellitus (T2DM) makes up about 90% of all diabetes cases. Exercise is a key part of lifestyle changes. Together with healthy eating and medicine, it forms the "three important parts" of T2DM management. This paper looks at how different types of exercise affect T2DM patients. These exercises include aerobic exercise, resistance exercise, high-intensity interval training, combined exercise, and fragmented exercise. It focuses on their effects on blood sugar control, how the body responds to insulin, and metabolic indicators, as well as the possible ways they work. Studies show that aerobic exercise has good effects both right away and over time. It does this by making the body more sensitive to insulin, improving mitochondrial function (the part of cells that makes energy), and regulating gut bacteria. Resistance exercise lowers the risk of diabetes by increasing muscle strength and improving how the body processes energy. High-intensity interval training (HIIT) brings big improvements to metabolism, but we need to be careful about safety, especially for elderly patients. Fragmented exercise is flexible and easy to stick to. So it may be a good extra exercise way for people living modern lives. By summarizing how different exercises work and giving practical suggestions, this paper wants to provide useful ideas for making personalized exercise plans for T2DM patients.

Keywords: TypeIIDiabetes Mellitus, Exercise Intervention, Aerobic Exercise, High-intensity interval training, Fragmented exercise

1. Introduction

Diabetes is a chronic disease. It is getting more common worldwide. It has become a serious public health problem. The World Health Organization (WHO) has figures [1]. These figures show about 460 million people have diabetes. T2DM makes up over 90% of these cases. This is a large part of all diabetes patients. People's lifestyles are changing. For example, they eat unhealthy food. They also sit too much every day. These changes affect their health. T2DM is becoming more common in all age groups. It is especially common among middle-aged people. Elderly people also have high chances of getting it. Obese teenagers are at risk too. Many of them have T2DM now. Diabetes patients need long-term medical care. They also need ongoing treatment. This causes medical costs to rise a lot. The WHO did a survey [2]. The survey tells us important things. Diabetes and its complications bring big losses. Every year, direct medical costs are hundreds of billions of US

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dollars. There are also indirect economic losses around the world. So preventing diabetes is very urgent. Treating diabetes is also urgent. It needs the whole society's attention. People should work together to do this. Everyone's effort helps fight diabetes. This is important for public health.

Regular exercise, along with healthy eating and medicine, is one of the three key parts of T2DM treatment. The overall management of T2DM mainly depends on lifestyle changes and personalized medicine to control blood sugar well [3]. As an important part of lifestyle changes, exercise plays a positive role in lowering patients' blood sugar. Regular exercise not only makes the body more sensitive to insulin but also helps control blood sugar and reduce the risk of cardiovascular diseases. It is especially important for preventing diabetes in people who are at high risk [3].

Studies by He Ke and his team show that doing aerobic exercise regularly for a long time can effectively improve glucose tolerance in T2DM patients and lower their glycated hemoglobin levels, thus controlling blood sugar [4]. This study suggests that exercise intensity may be a key factor in how well aerobic exercise lowers blood sugar for T2DM patients. But it did not talk about the differences in exercise intensity between different individuals. Wu Jinhong and others did an intervention study on elderly T2DM patients using different intensities of resistance training. They found that high, moderate, and low-intensity resistance exercises all effectively regulate glucose and lipid metabolism in this group of people. Although high, moderate, and low-intensity resistance training have been proven to be good for blood sugar, blood lipids, insulin, and other blood indicators in T2DM patients, we need to consider something. As elderly people get older, they may have other chronic diseases. And high-intensity resistance training may bring exercise risks to this group [5].

In addition, some studies have results. They confirm one type of exercise isn't enough. It can't improve T2DM patients' health clearly. Recent research has new findings. Some flexibility exercises help joints. They make joints move more freely. They also boost joint flexibility. Well, these exercises don't change blood sugar much. Actually, they need to mix with other exercises. Like yoga, for example [6,7]. Also, HIIT is a kind of exercise. Doctors often use it for T2DM patients [8]. But some T2DM patients have complications. Using HIIT on them may be unsafe. You know, this is a big concern. So, experts talk a lot about exercises. They debate the best ways for diabetes patients. Some groups are special. Like the elderly and obese people. Choosing exercises for them needs care. We must check their own traits first. Then set exercise intensity. We also decide the exercise load and forms. Exercises have different traits. They differ in intensity and time. Their forms are not the same. They work on T2DM in different ways. These points need more study. We have to summarize them well. We also need to explain them clearly.

Based on this, this study has two main parts. First, it explains T2DM's concept. It also tells about its pathogenesis. Second, it looks at many exercise types. These include aerobic exercise. They also cover resistance exercise and HIIT. Combined exercise is included too. There is fragmented exercise as well. People also call it exercise snacks. The study reviews their effects on T2DM. It also explores possible mechanisms. This study tries to help T2DM patients. It wants to give theoretical support. So patients can choose good exercise plans. They can also make proper exercise plans.

2. T2DM

Diabetes is a long-term health problem. It has a key sign: high blood sugar. The problem comes from two main reasons. One is not enough insulin in the body. The other is the body's weak response to insulin. Most people know this basic fact. The disease shows in two clear ways. First, pancreatic β-cells don't work well. So they make less insulin than needed. Second, the body is less sensitive to insulin. These two issues lead to a result. Glucose in the blood can't be used well. It also

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can’t be stored properly. This is a common problem for patients. There are four main types of diabetes. They are T1DM, T2DM, gestational diabetes. The fourth is special types of diabetes. Among all these types, T2DM is very common. In clinics, it makes up about 90% of cases. That’s a big part of all diabetes patients. Many doctors see this every day. Studies have some ideas. They think T2DM’s cause is complex. It may relate to tissue cell insulin resistance. It may also link to β-cell dysfunction. Other factors could play a role too. T2DM is a lifelong disease. Patients can’t get rid of it easily. They need long-term care. Without good control, bad things happen. Many complications may appear. Some are acute, like ketoacidosis. Hyperosmolar hyperglycemic state is another. There are also chronic complications. Diabetic retinopathy is one example. Diabetic nephropathy and foot problems are others. These complications hurt patients’ lives. Long-term high blood sugar harms the body. It causes microvascular damage. Retinopathy and nephropathy are such cases. It also leads to macrovascular lesions. Coronary heart disease and stroke are common ones. These problems bring big risks. They make patients more likely to get sick. They also raise the death rate. This is a serious warning. Epidemiological studies have data. T2DM patients face higher risks. Their risk of cardiovascular diseases is 2-4 times. This is compared to people without diabetes. Most doctors agree with this finding. Patients should pay attention to it.About 50% of patients have concurrent neuropathy, which significantly increases the risk of foot ulcers and amputations. So T2DM and its complications can seriously affect patients' quality of life and safety.

3. Pathogenesis of T2DM

Increasing studies have indicated that T2DM is a disease with polygenic genetic heterogeneity [9], and its pathogenesis mainly involves three aspects: insulin resistance, chronic low-grade inflammation, and adipokine imbalance.

3.1. Insulin Resistance

Insulin Resistance (IR) is the core pathological feature of T2DM. The impaired translocation of glucose transporter 4 (GLUT4, a protein that helps cells take in glucose), dysfunction of Nrf2, and β-cell dysfunction may be important influencing factors. The impaired translocation of GLUT4 is mainly reflected in the decreased insulin sensitivity of peripheral tissues (especially skeletal muscle, liver, and adipose tissue). As the main site for glucose uptake and utilization (accounting for about 80% of the body's total glucose disposal), the dysfunction of the insulin signaling pathway (such as the PI3K-Akt pathway) in skeletal muscle can lead to the impaired translocation of GLUT4, thus reducing glucose uptake [10]. Inflammation and oxidative stress are key factors. They affect insulin resistance’s start and progress. Many studies support this fact. Nrf2 is a special transcription factor. It has a basic leucine zipper structure. The Nrf2 signaling pathway is useful [11]. It helps regulate inflammation and oxidative stress. This role is quite important. Insulin resistance brings pathological conditions. The Nrf2 pathway reacts to them. It gets activated by inflammation and stress. This activation does two good things [12]. It improves insulin signal transduction. It also lowers risks of insulin resistance. Obesity risk is reduced too. Activating the Nrf2 pathway has more benefits. It can stop inflammatory signaling pathways. It also cuts down inflammatory mediators’ expression. These actions enhance insulin sensitivity. That’s helpful for patients’ health. Nrf2’s poor function links to insulin resistance. The connection is very close. Studies have clear proof [13]. High-fat diet induces mouse models. These mice have insulin-resistant obesity. Their Nrf2 pathway function drops a lot. But specific activation changes this. It can prevent insulin resistance. It even reverses the existing condition. Long-term sedentary life is bad. It harms skeletal muscle’s mitochondrial function.

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Mitochondria work less well. Lipids start to build up more. Triglycerides and ceramides are examples. This makes insulin resistance worse. Things get more difficult for the body. Regular exercise is the opposite. It brings positive changes. It activates AMPK and PGC-1α pathways. These pathways do two key things. They promote mitochondrial biogenesis. They also boost fatty acid oxidation. Insulin sensitivity improves as a result. People feel healthier this way. Studies found another important point [9]. β-cell dysfunction is a core factor. It affects T2DM's occurrence and progression. Insulin resistance starts in early stages. Pancreatic β-cells take action. They secrete more insulin to compensate. This keeps glucose balance in check. But long-term high blood sugar is harmful. It causes glucotoxicity. Free fatty acids also rise. This leads to lipotoxicity. These two things hurt β-cells. They induce oxidative stress in them. Endoplasmic reticulum stress follows. Inflammatory responses start too. The NF-κB pathway gets activated. All these lead to β-cell apoptosis. Their function fails gradually. Finally, insulin resistance happens. Or insulin function becomes abnormal.

3.2. Chronic low-grade inflammation

The occurrence and development of inflammation are determined by inflammatory mediators, and the degree of inflammation is affected by multiple factors. Among these, the imbalance of Omega-6/Omega-3 fatty acids, gut microbiota dysbiosis, and excessive oxidative stress are directly related to inflammation. Both Omega-6 and Omega-3 fatty acids are essential fatty acids that cannot be synthesized by the human body and must be obtained through external intake. However, their metabolites in the human body have different functions: Omega-6 promotes inflammation, while Omega-3 inhibits inflammation. The two are mutually restrictive and interrelated in the human body. Regarding the impact of the Omega-6/Omega-3 ratio on inflammation, Kang Jingxuan's team from the Laboratory of Lipid Medicine and Technology at Harvard Medical School used fat-1 transgenic mouse models to explore the effects of Omega-3 on local inflammatory responses, formation of lipid mediators, and expression of inflammation-related genes in different inflammatory diseases. The results showed that increasing Omega-3 fatty acids in tissues or reducing the Omega-6/Omega-3 ratio exerts anti-inflammatory effects by inhibiting the expression of pro-inflammatory genes (NF-κB, TNF-α, IL-6, and IL-1β) and promoting the production of anti-inflammatory lipid mediators [14].

Studies have suggested that gut microbiota dysbiosis may also be an important influencing factor in inflammatory responses and oxidative stress. Gut microbiota dysbiosis can damage the intestinal mucosal barrier, increase intestinal permeability, and allow endotoxins to continuously infiltrate into the bloodstream, forming low-grade metabolic endotoxemia. Endotoxins form complexes with their receptor CD14 and are recognized by TLR4 (Toll-like receptor 4) on the surface of immune cells, triggering a series of non-specific inflammatory responses, thereby inducing chronic low-grade inflammation. Oxidative stress is a negative effect caused by free radicals in the body and is closely associated with inflammation. Excessive free radicals in the body can exacerbate inflammatory responses; conversely, inflammation can promote the massive production of free radicals, intensifying oxidative stress. The two mutually promote each other, forming a vicious cycle.

3.3. Adipokine imbalance

Adipose tissue not only stores lipids but also has important secretory functions, capable of secreting a variety of adipokines according to the body's physiological environment. Common adipokines include adiponectin (APN), leptin (LEP), angiopoietin-like protein 4 (ANGPTL4), and chemerin,

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which play important roles in glucose and lipid metabolism and maintenance of energy balance. Obesity-related adipose tissue dysfunction is an important risk factor for T2DM. Excessive visceral fat accumulation can promote macrophage infiltration and release of inflammatory factors such as TNF-α and IL-1β, interfering with insulin signal transduction. Meanwhile, leptin resistance and decreased adiponectin secretion by adipocytes further exacerbate glucose and lipid metabolism disorders, increasing blood glucose levels and promoting the occurrence and development of diabetes.

4. Effects of different types of exercise on T2DM and their possible mechanisms

Current studies on the effects of exercise on T2DM mainly focus on two types of exercise: aerobic exercise and resistance exercise. Pan Bin et al. [15] systematically compared the intervention effects of different exercise training modes (including supervised and unsupervised aerobic exercise, resistance exercise, and combined exercise) on T2DM patients. The results showed that aerobic exercise and resistance exercise have similar improving effects in reducing glycated hemoglobin. Therefore, this study mainly focuses on aerobic exercise and resistance exercise, as detailed below:

4.1. Aerobic exercise

Aerobic exercise refers to physical activity where the oxygen inhaled by the human body equals the oxygen demand during exercise, achieving a state of physiological balance. It mainly provides energy by oxidizing substances such as fat and sugar in the body. A large number of studies [16,17] have shown that aerobic exercise has positive effects on diabetes-related symptoms, such as improving insulin sensitivity, reducing fat content, and lowering blood glucose levels. This paper explores the intervention effects of aerobic exercise on diabetes-related indicators from the perspectives of different exercise forms (aerobic exercise, resistance exercise, high-intensity interval training, flexibility exercise) and exercise duration (intervention cycle: short-term acute exercise, long-term exercise, and fragmented exercise; interval time: interval exercise, continuous exercise, and fragmented exercise).

4.1.1. Effects of aerobic exercise with different durations on diabetes-related factors

(1) Aerobic Exercise with Different Cycles: Short-Term Aerobic Exercise vs. Long-Term Aerobic Exercise vs. Fragmented Exercise

Through extensive literature review, it was found that based on the duration of the intervention cycle, research in this field can be roughly divided into short-term aerobic exercise (30-60 minutes of one-time exercise, i.e., acute exercise), long-term aerobic exercise (continuous exercise for 4-16 weeks), and fragmented exercise (multiple short bouts of exercise per day, separated by several hours, each lasting no more than 1 minute, with varying intensities of low, moderate, and high).

Studies have shown that short-term aerobic exercise can improve peripheral insulin sensitivity in adult T2DM patients. For example, in a randomized crossover study by DUVIVIER B M et al. [18], subjects were divided into three groups: the sedentary group (SIT), the less sedentary group (LSA), and the exercise group (EX). The sedentary group sat for 14 hours, stood for 1 hour, and walked for 1 hour per day; the less sedentary group reduced sedentary time, increased standing time (3 hours) and walking time (2 hours) per day, and stood up every 30 minutes; the exercise group performed 1 hour of moderate-intensity cycling per day for 4 days of intervention. The aim was to analyze the effects of different acute exercises on 24-hour blood glucose levels and insulin sensitivity in

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subjects. The results showed that compared with the sedentary group, the 24-hour blood glucose levels of the less sedentary group and the exercise group were significantly reduced, and insulin sensitivity was significantly enhanced, with the less sedentary group showing a more pronounced effect. The main target of short-term (acute) aerobic exercise for lowering blood glucose is skeletal muscle, and the body mainly relies on muscle contraction itself for insulin-independent glucose uptake. At this time, muscle contraction activates a signaling pathway different from the insulin pathway, leading to the direct translocation of GLUT4 glucose transporters from intracellular vesicles to the cell membrane. This process does not require insulin, allowing muscle cells to directly take up large amounts of glucose from the blood as an energy source. After short-term aerobic exercise, muscle glycogen is consumed, and muscle glucose uptake continues to increase to replenish the depleted glycogen stores. This process is highly dependent on insulin. At this time, insulin sensitivity is temporarily improved, enabling insulin to more effectively promote glucose entry into muscle cells for glycogen synthesis.

Some studies have also explored the positive improvement effect of long-term moderate-intensity aerobic exercise on fasting hyperglycemia [19]. Studies have shown that regular aerobic exercise in T2DM patients can reduce daily blood glucose fluctuations, lower glycated hemoglobin by 0.5%~0.7% [20], and improve insulin sensitivity, blood lipids, blood pressure, other metabolic parameters, and physical fitness levels. In a study by Chen Jin [21], patients in the observation group performed 20 minutes of moderate-intensity walking 30 minutes after breakfast, lunch, and dinner, respectively. Patients in the control group performed 60 minutes of one-time moderate-intensity walking 30 minutes after breakfast. Both groups walked at a speed of 5 km/h for 60 days. The study showed that after exercise, the blood glucose levels and glycated hemoglobin levels of both groups were significantly reduced. Zhai Guangcheng et al. used leptin receptor-deficient diabetic mice (db/db) and non-diabetic control mice (db/m+) to conduct 8 weeks of long-term treadmill exercise training, aiming to explore the changes in vascular and intestinal stress (including inflammation, oxidative stress, and endoplasmic reticulum stress) and the related mechanisms of gut microbiota. The results showed that long-term exercise significantly improved vascular and metabolic abnormalities in donor mice, and exercise-modified gut microbiota could confer cardiovascular and metabolic protective effects on db/db mice without exercise habits [22]. Thus, long-term (chronic) aerobic exercise makes the body have adaptive changes through several mechanisms. For example, it increases the total amount of GLUT4, strengthens insulin signaling, improves mitochondrial function, and changes pathways related to gut bacteria. Unlike acute aerobic exercise, which mainly affects skeletal muscle, long-term aerobic exercise also acts on the liver and body-wide adipose tissue. So it can keep reducing fasting blood glucose and glycated hemoglobin steadily. This makes the patient's blood glucose more stable throughout the whole day.

In short, short-term and long-term aerobic exercise have different ways to lower blood glucose. Short-term aerobic exercise relies on "immediate mobilization", while long-term aerobic exercise depends on "structural improvement". The effects of acute exercise on lowering blood glucose and improving insulin sensitivity usually appear during exercise and within hours to days after exercise. And the affected area is only skeletal muscle. On the other hand, long-term exercise can keep reducing fasting blood glucose steadily, make blood glucose more stable all day long, and continuously improve insulin sensitivity in many tissues of the body. Short-term and long-term aerobic exercise complement each other well in controlling blood glucose and improving insulin sensitivity. Short-term aerobic exercise provides a period of rapid blood glucose reduction and temporary improvement in insulin sensitivity. It is especially useful for managing blood glucose after meals. Long-term aerobic exercise, though, brings deep and systemic adaptive changes. It is the

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foundation for improving basic insulin sensitivity, achieving long-term stable blood glucose control, and preventing and managing T2DM. Similarly, both short-term and long-term aerobic exercise are irreplaceable. The effect of one single exercise can't take the place of the fundamental metabolic improvements from long-term regular exercise. On the other side, even if people stick to aerobic exercise for a long time, the value of a single exercise for immediate blood glucose control is still important.

Although both long-term and short-term aerobic exercise can improve patients' blood glucose levels to some degree, with the development of social economy and the faster pace of life, people's exercise time is "limited and reduced". This leads to poor exercise adherence among diabetic patients during training. They can't finish the planned exercise time, which reduces the exercise effect and their enthusiasm to participate to a certain extent. Fragmented exercise doesn't require continuous long time, so it has gradually become an alternative exercise form and is popular among different groups of people. Fragmented exercise (also called exercise snacks, ES) is a type of exercise. It breaks down traditional continuous exercise that needs a long period of time (such as 30-60 minutes) into several short bouts of exercise. These short exercises can be low, moderate, or high-intensity, and are scattered throughout the day. It focuses on "dividing the whole into parts", using fragmented time in daily life to accumulate benefits, thus promoting health and enhancing physical fitness. Compared with regular exercise, fragmented exercise doesn't need to reserve special long time. Each time it only takes 5-10 minutes, which makes it easier for people to start and persist. It can be done anywhere, such as in the office, at home, or during commutes. It has very low requirements for venues and equipment. This fragmented exercise form has a "cumulative effect". The effects of multiple short bouts of exercise can add up to finally achieve or even surpass the effect of one single long bout of exercise. For example, during work, people can stand up and do 2 minutes of wall sits or desk push-ups every hour to strengthen the strength of lower and upper limbs. During TV commercial breaks, they can do a set of planks or sit-ups to exercise core muscles. With its high flexibility and feasibility, fragmented exercise successfully integrates health into the gaps of modern life. In the future, with the popularization and development of wearable devices and health apps, the guidance and motivation for fragmented exercise will become more personalized and intelligent. It is expected to become an important part of mainstream public health management methods.

(2) Aerobic Exercise with Different Interval Times: Continuous Exercise vs. Interval Exercise vs. Fragmented Exercise

Based on interval time, aerobic exercise can be divided into interval aerobic exercise (with intermittent rest periods) and continuous aerobic exercise (without intermittent rest periods). Different intervals (intermittent rest and continuous exercise) may be important factors in the improvement of diabetes-related symptoms by aerobic exercise. A large number of studies have confirmed that continuous aerobic exercise can effectively improve insulin resistance, reduce fat content and inflammatory responses, thereby improving diabetes [19]. However, due to the particularity of diabetes patients, continuous aerobic exercise is long in duration and monotonous in content, which may lead to low exercise adherence. Studies show that aerobic exercise with certain short rest periods in between can do more than one good thing. It can effectively boost patients' enthusiasm for taking part in exercise. It also brings great benefits to the physical and mental health of T2DM patients. For example, it can lower HbA1c%, total cholesterol, and systolic blood pressure. It can also improve aerobic capacity. What's more, it achieves effects similar to continuous aerobic exercise—especially high-intensity interval training (HIIT). Research also tells us that HIIT is a type of exercise. It combines high-intensity explosive movements with short rest periods. This

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form of exercise can strengthen patients' cardiopulmonary function. It also improves how the body responds to insulin, which helps control the development of T2DM. But the use of high-intensity interval training may be different for patients of different ages. For young and middle-aged obese T2DM patients (aged 18-60), HIIT can reduce the amount of visceral fat. It can also lower the expression of inflammatory substances TNF-α and IL-6 in adipose tissue. Besides, it improves the adiponectin/leptin ratio. All these help reduce insulin resistance. For elderly patients (over 60 years old), things are a bit different. They often have other diseases like cardiovascular problems, arthritis, and poorer balance. HIIT is high-intensity, so it may bring certain exercise risks. So, it is suggested to use adjusted HIIT for exercise. For example, reduce the absolute exercise intensity, lengthen the rest time, and choose safe exercise modes.

Through sorting out relevant studies, we believe that compared with continuous exercise and interval exercise, fragmented exercise is to a certain extent an interval exercise with long intervals and high flexibility. Earlier studies have shown that fragmented exercise can effectively lower blood glucose and improve insulin resistance. It may bring good health benefits to people with diabetes. What's more, compared with other types of exercise, fragmented exercise is more flexible and closer to daily life. For example, it may be hard to meet the special needs for equipment and warm-up in daily life. So some studies have set fragmented exercise as stair climbing and cut out preparation steps like warm-up. This makes fragmented exercise even easier to do and more feasible. The results of this study found that climbing stairs for 20 seconds every hour greatly reduced postprandial insulin levels in overweight people. This is different from the group that stayed seated all the time [23]. So we can infer that fragmented exercise can also be used as an exercise plan to help people with diabetes. However, current research on its related mechanisms is quite limited. Future studies can further explore the physiological and chemical ways through which fragmented exercise improves blood glucose and insulin resistance.

4.1.2. Effects of aerobic exercise with different movement forms on diabetes-related factors

(1) Single-Movement Cycle Aerobic Exercise vs. Multi-Movement Combined Aerobic Exercise

Studies have shown that different forms of aerobic exercise can effectively improve diabetes-related factors, but different forms may have different advantages and characteristics in terms of improvement effects. Aerobic exercise can be divided into single-movement cycle aerobic exercise (e.g., jogging, cycling) and multi-movement combined aerobic exercise (e.g., flexibility exercise, stretching exercise). Single-movement cycle aerobic exercise has simple technical and equipment requirements, is easy to monitor exercise volume, and can efficiently exercise cardiopulmonary function and improve maximum oxygen uptake. But single-movement cycle aerobic exercise is quite boring. It mainly works on certain specific muscles, and this may make the training of muscle groups unbalanced. On the other hand, multi-movement combined aerobic exercise involves the whole body. Therefore, it trains all muscle groups more evenly, and it is more interesting too. It also has a stronger afterburn effect (which means the body keeps burning calories for a period after finishing exercise). Besides, it helps improve overall physical fitness and coordination. When single-movement cycle exercise is done at low to moderate intensities, it uses fat as the main energy source more. So it is a traditional "fat-burning" exercise way. Studies have found that flexibility exercise is different from single-cycle aerobic exercises like jogging and cycling. It is a typical multi-movement combined aerobic exercise. This training method systematically increases the stretchability and viscoelasticity of muscle-tendon units. It achieves this through methods such as proprioceptive neuromuscular facilitation, static stretching, or dynamic stretching. In this way, it improves the range of joint movement. The effect of flexibility exercise on lowering blood glucose may be linked

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to several factors. It can activate vagal tone, reduce cortisol levels, and regulate the hypothalamic-pituitary-adrenal axis. These changes help inhibit the liver from producing too much glucose and enhance the body's sensitivity to insulin. In short, single-movement cycle aerobic exercise and multi-movement combined aerobic exercise are different in nature. So their effects on improving health and the specific ways they work may also be different. Therefore, people can choose which type of exercise to do according to their own actual situation.

4.2. Resistance exercise

Resistance exercise, also called strength training, is a type of exercise that builds muscle strength and endurance by working against external resistance. Its core way of working is to stimulate the growth of muscle fibers and the adaptation of the nervous system. This happens when muscles contract to fight against resistance, which in turn improves how muscles work. Skeletal muscle is the main part where insulin resistance occurs. Studies show that people with strong muscles have a 44% lower relative risk of getting T2DM than those with weak muscles [24]. So we can infer that resistance exercise may be an important way to help prevent diabetes and slow down its development. Also, studies have shown that resistance exercise can greatly improve several aspects of health in T2DM patients. It can help control blood glucose levels, make the body more sensitive to insulin, and regulate blood pressure. It also increases muscle strength, reduces fat mass, and builds up muscle mass. Studies by Cybelle Nery and others [25] show that both resistance exercise and aerobic exercise are good for controlling blood glucose and blood lipids. But resistance exercise can more effectively increase patients' maximum oxygen intake. What's more, it can lower blood glucose in a shorter time, which is a clear advantage for many patients. Ishii et al. [26] found that moderate-intensity and high-volume resistance exercise can significantly improve insulin sensitivity in non-obese non-insulin-dependent diabetes patients without adjusting maximum oxygen uptake, further confirming the important role of resistance training in improving related indicators of T2DM patients. Therefore, it is recommended that muscle strength training should be part of public health guidelines, especially for middle-aged and elderly individuals, as it may be a very effective preventive measure. Future studies will be conducted in more diverse populations, as people with different lifestyles, genders, and ages may have different responses to the relationship between muscle strength and diabetes risk.

4.3. Combined exercise

Combined exercise includes three types: aerobic exercise combined with resistance exercise, aerobic exercise combined with diet, and aerobic exercise combined with blood flow restriction training. Aerobic exercise mainly includes brisk walking, running, and cycling, which can quickly consume blood glucose and improve insulin sensitivity; resistance training includes equipment training, dumbbell exercises, and bodyweight exercises, which can increase muscle mass, provide more "storage" space for glucose, and enhance insulin action. Blood flow restriction training (BFR) combined with low-intensity aerobic exercise is a form of exercise that limits blood flow through compression to simulate the effects of high-intensity training, activate the mTOR pathway to promote muscle synthesis, and avoid joint loading. Alessio Bellini et al. found that aerobic exercise, resistance exercise, or combined exercise started 30 minutes after meals can improve the blood glucose response of T2DM patients to a standardized breakfast. Performing aerobic exercise alone or aerobic exercise before resistance exercise results in the greatest reduction in postprandial blood glucose peaks. Aerobic exercise combined with resistance exercise can preferentially consume

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muscle glycogen through resistance training, and subsequent aerobic exercise promotes enhanced fat mobilization, synergistically reducing postprandial blood glucose fluctuations [27]. Exercise combined with dietary intervention (limiting carbohydrate intake to 50-55% of total energy) can accelerate hepatic glycogen depletion and improve liver insulin sensitivity. The China Type 2 Diabetes Exercise Therapy Guidelines [28] mentions that the intervention effect of aerobic exercise combined with resistance exercise may be superior to single aerobic exercise or resistance exercise alone. When performing resistance exercise combined with aerobic exercise in a single exercise session, performing resistance exercise first can reduce blood glucose levels more effectively than performing aerobic exercise first [27].

5. Conclusion

This review focuses on the effects of different types of exercise on T2DM patients, systematically summarizing the mechanisms and practical significance of aerobic exercise, resistance exercise, high-intensity interval training (HIIT), combined exercise, and fragmented exercise in the management of T2DM patients.

Aerobic exercise (e.g., brisk walking, running, cycling) can significantly improve insulin sensitivity, reduce blood glucose and inflammation levels, and long-term regular exercise can bring sustained metabolic benefits; resistance exercise has unique advantages in reducing diabetes risk and controlling blood glucose by enhancing muscle strength and metabolic function; high-intensity interval training (HIIT) achieves significant metabolic improvements but requires adjusting intensity according to patients' age and health status to ensure safety; combined exercise (e.g., aerobic + resistance exercise) is often superior to single exercise forms in improving blood glucose fluctuations and metabolic indicators; fragmented exercise (e.g., stair climbing, short-term activities) is suitable for modern fast-paced lifestyles due to its high flexibility and adherence, especially for diabetes patients with time constraints.

Aerobic exercise and resistance exercise play important roles in reducing blood glucose levels and enhancing insulin sensitivity in T2DM patients. Scientific and reasonable aerobic exercise is an effective way to improve T2DM, and exercises of different cycles, interval times, and forms have varying effects on T2DM. Both single resistance training and combined resistance training can effectively improve diabetes-related symptoms, but their improvement mechanisms may differ.

• Different exercise durations: Although short-term (acute) aerobic exercise can quickly lower blood glucose and temporarily improve insulin sensitivity in T2DM patients, for T2DM—a chronic disease requiring long-term blood glucose control—it is recommended to prioritize long-term (chronic) aerobic exercise, which can induce in-depth, adaptive changes in the body. Obtain basic metabolic improvements through long-term regular exercise, while using the immediate effects of single exercise for refined blood glucose management.

• Different exercise forms: Although single-cycle aerobic exercises such as jogging and cycling have good blood glucose-lowering effects, long-term repetition of such exercises can cause inevitable joint damage. In contrast, flexibility exercise, due to its low injury risk, can indirectly but importantly improve T2DM-related symptoms, enhance overall exercise capacity and long-term adherence, and provide unique psychological and social support. Therefore, for young patients, it is recommended to mainly engage in single-cycle aerobic exercises such as jogging; for elderly patients, it is recommended to mainly engage in relatively gentle flexibility exercises.

• Different exercise intensities: Aerobic exercises of different intensities all have effects on improving T2DM-related symptoms. Moderate-intensity exercise is most effective in alleviating patients' inflammation levels. For elderly patients, it is recommended to perform low-to-moderate

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intensity aerobic training. For young patients, it is recommended to perform moderate-to-high intensity aerobic training.

In summary, exercise intervention is an indispensable part of the comprehensive management of T2DM. Future studies should further focus on the personalized matching of exercise intensity, duration, and form, especially for special populations such as the elderly and obese, to promote the scientization and popularization of exercise prescriptions in diabetes prevention and treatment.

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