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REVIEW ARTICLE

The Impact of Various Types of Exercise on Lipid Metabolism in Patients with Type 2 Diabetes and Concurrent Overweight/Obesity: A Narrative Review

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ABSTRACT

Background. Type 2 diabetes mellitus (T2DM) and obesity present substantial challenges to global public health, marked by their widespread prevalence and associated morbidities. The ensuing complications, including cardiovascular disease (CVD), metabolic syndrome, cancer, liver disease, and neurodegeneration, underscore the urgent need for effective preventive measures. Despite this, primary prevention of CVD in individuals with T2DM and obesity remains inadequate. Regular exercise emerges as a pivotal factor in ameliorating various cardiometabolic parameters, yet conflicting findings persist regarding the impact of exercise parameters (frequency, intensity, time, and type) on lipid homeostasis. **Objectives.** This review scrutinizes the effects of diverse exercise types and parameters on individuals with T2DM and concurrent obesity. A focus is placed on investigating the influence of exercise on conventional lipids, such as LDL-C, HDL-C, TG, total TC, and VLDL-C. The review briefly delves into the mechanisms underlying exercise-induced effects on lipids and lipoproteins. **Methods.** A literature search was conducted using the PubMed, Scopus, and Google Scholar databases. **Results.** Regular exercise is instrumental in elevating HDL-C levels while reducing TG, TC, VLDL, and LDL-C concurrently. Exercise mitigates CVD risk, lowers BMI, and enhances insulin resistance, depending on exercise types, volume, intensity, frequency, and duration. **Conclusion.** Future research must delve into the dose-response effects of real-world exercise programs to guide tailored interventions. This comprehensive understanding should inform clinicians and practitioners, empowering them to prescribe personalized exercise regimens for individuals grappling with compromised metabolic health.

KEYWORDS: *Aerobic Exercise, Resistance Training, Physical Activity, Metabolic Syndrome.*

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INTRODUCTION

Diabetes mellitus (DM) is a 21st-century global public health concern, as shown by the high incidence of associated morbidities and complications (1, 2). The global prevalence of diabetes among individuals aged 20 to 79 was approximately 10.5% (536.6 million people) in 2021, and it is anticipated to rise to 12.2% (783.2 million) by 2045 (3). The prevalence of diabetes was comparable between men and women, with the highest rates observed in the 75–79 age group. In 2021, urban areas had a higher estimated prevalence of 12.1% compared to 8.3% in rural areas, and high-income countries had a prevalence of 11.1% compared to 5.5% in low-income countries. The most significant relative increase in diabetes prevalence between 2021 and 2045 is expected in middle-income countries at 21.1%, surpassing projections for high-income (12.2%) and low-income (11.9%) countries. Regarding global diabetes-related health expenditures, estimates reached 966 billion USD in 2021 and are projected to reach 1,054 billion USD by 2045 (3).

The Type 2 diabetes mellitus (T2DM) physio-pathway is linked to reduced high-density lipoprotein cholesterol (HDL-C), increased density of low-density lipoprotein (LDL) particles, elevated triglycerides and a cluster of interrelated plasma lipid and lipoprotein disorders (4). These correlate with a significant part of the insulin resistance syndrome linked to T2DM. In general, prediabetic people also have an atherogenic trend of risk factors, such as higher total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), and TG, as well as lower HDL-C, than people who do not experience diabetes (5, 6). Insulin resistance has a serious influence on very low-density lipoprotein (VLDL), LDL-C, and high-density lipoprotein (HDL) particle size and concentrations (7). In addition, obesity is known as a global epidemic that has a significant impact on population health (8) because of its association with T2DM and metabolic syndrome. Obesity and overweight affect more than 1.9 billion individuals worldwide, contributing to an increase in various health risks that include insulin resistance, type 2 diabetes, cardiovascular disease, cancer, liver disease, and neurodegeneration (9). Obesity, specifically central obesity, might be associated with insulin resistance, elevated triglycerides, and low HDLC, which is known as metabolic syndrome (10).

It is well-known that obese diabetic patients have an increased risk of CVD, but unfortunately, in diabetic patients, primary CVD prevention remains insufficient (11). Therefore, regular exercise reduces the risk of CVD, improves the lipid profile, and provides many benefits for metabolic syndrome and its risk factors, such as abdominal obesity, hypertension, and insulin resistance (12). Bharath, Choi (13), for example, showed a reduced risk of metabolic syndrome, such as central obesity, high blood pressure (14), dyslipidemia, and insulin resistance following combined aerobic and resistance training (15).

Exercise for improving overall health among people affected by obesity and T2DM has been recently reported as one of the most popular reasons for exercise worldwide (16). Ideally, a combination of aerobic exercise (AE) and diet has been documented as the optimal strategy (17, 18). Despite the well-characterized health benefits of exercise on lipid and lipoprotein profile, there remains some controversy surrounding the optimal exercise modality, duration, frequency, and/or intensity amongst DM patients with obesity. Since the improvement of the lipid profile as a result of exercise depends on the intensity, frequency, and duration of each session, as well as the type of exercise and the time spent on such a program, there have been conflicting results on the efficacy of exercise DM patients with obesity (19). Hence, this study aimed to examine the effects of different types of exercise, duration, frequency, and/or intensity for DM patients with obesity. Furthermore, this review aimed to provide information on the effects of various exercise training modalities on both conventional lipids, such as LD), high-density lipoprotein (HDL), triglycerides TG, cholesterol, very-low-density lipoprotein (VLDL), and lipoproteins.

Exercise training can be broadly categorized into three main types: AE, resistance exercise (RE), and concurrent training.

AEROBIC EXERCISE

AE is defined as any activity that utilizes large muscle groups, can be sustained over a prolonged period, is rhythmic, and stimulates muscles using aerobic metabolism to derive energy in the form of adenosine triphosphate (ATP) from amino acids, fatty acids, and carbohydrates. Cycling, dancing, jogging, diving, and walking are forms of aerobic activities (20).

The effectiveness of AE in improving lipid profiles among type overweight/ obese T2DM patients can be attributed to several mechanisms. These exercises have been found to positively affect lipid metabolism, improving lipid profile parameters such as TC, LDL-c, HDL-C, and TG (17).

AE has been shown to enhance insulin sensitivity in individuals with T2DM. Improved insulin sensitivity helps to regulate blood glucose levels and reduces the production of TG and VLDL in the liver, leading to favorable changes in the lipid profile. AE can potentially reduce visceral fat stored around the organs in the abdominal area. Visceral fat is metabolically active and contributes to increased TG and LDL-C levels, often called "bad cholesterol". Exercise can improve the lipid profile by reducing visceral fat and decreasing TG and LDL-C levels (21, 22). Regular exercise, including AE, has increased HDL-C levels, commonly known as "good cholesterol". HDL-C helps transport excess cholesterol from peripheral tissues to the liver for excretion, thus reducing the risk of cardiovascular disease. Furthermore, exercise can modify the size and density of LDL-C particles, making them less atherogenic (less likely to cause plaque buildup in the arteries) (23).

Following exercise, the mechanism responsible for the acute rise in HDL-C is likely associated with the catabolism of lipoproteins rich in TG through lipoprotein lipase (LPL) (24). Increased activity of LPL following exercise results in hydrolysis of chylomicron and VLDL, thereby decreasing plasma TG levels (25), and subsequently, surface remnants are converted into nascent HDL-C; nevertheless, following the exercise, the levels of HDL-C can increase. In comparison, drops in plasma TG levels following acute activity tend to correlate with the amount of intensity and duration of the EX (25). Increased LPL activity leads to a reduction in circulating TG and an improvement in the lipid profile. Studies showed that exercise could induce a decrease in TG levels within 24 hours (26, 27), while shorter workout durations will lead to only moderate reductions in plasma TG in obese women (28).

On the other hand, obese T2DM patients are associated with chronic low-grade inflammation, which contributes to dyslipidemia and cardiovascular risk. AE exercise has been shown to reduce inflammation markers such as C-reactive protein (CRP) and interleukin-6 (IL-6). By decreasing inflammation, exercise can positively influence the lipid profile and reduce the risk of cardiovascular complications (29, 30). Moreover, AE primarily utilizes fat as fuel for exercise. By increasing the intensity and duration of exercise, patients can enhance fat oxidation, reducing overall body fat and improving their lipid profile (31-33).

Lipoproteins. CVD is the leading cause of death around the world, with hypertension, smoking, physical inactivity, obesity, elevated glucose levels/ DM mellitus, and dyslipidemia being major CVD risk factors (30). Among these, dyslipidemia, which is described by a low level of HDL-C, is closely and contrarily linked to the risk of cardiovascular disease (34). Also, low levels of HDL-C are part of the atherogenic dyslipidemia complex linked to T2DM (35). Increased atherogenesis has been described in DM individuals due to many abnormalities in lipoprotein metabolism, particularly in VLDL, LDL-C, and HDL-C (36).

Some studies indicated that HDL-C efflux capacity was a stronger predictor for the prevalence and incidence of CHD, and HDL-C efflux capacity was also revealed to be diminished in obese patients with T2DM (37, 38). Furthermore, it was recently found that in overweight adults, those with an elevated TG and reduced HDL-C levels had hypertension, increased C-reactive protein (CRP) levels, and insulin resistance (39). These findings triggered a surge of interest in raising HDL-C levels in obese T2DM patients by encouraging participation in AE as a CVD therapy and reducing insulin resistance.

It was reported that AE is a preventive strategy against atherosclerosis and has been proposed as medical assistance in treating DM patients, which can help bring high blood glucose levels down into the normal range by improving insulin sensitivity and minimizing the risk of CVD (40, 41). An AE program for 3 months, with each session consisting of a 10-min warm-up, 30-40 min of walking, cycling, or jogging, or a combination at 60% to 65% of maximum oxygen consumption (VO2max), and a 10-min cool-down, once or twice a week showed a significant enhancement in lipid and lipoprotein profiles and a rise in HDL-C levels, while LDL-C and TG decreased in type 2 diabetic patients (42).

Low-density lipoprotein. Individuals who commenced the training program with lower

HDL-C/LDL-C ratios exhibited the most significant improvements after exercise, emphasizing positive enhancements in those at the highest risk, which holds clinical relevance for their overall health and well-being (43).

Azizi et al. (2019) (44) conducted a study in twenty-four middle-aged adults (40-50 years, 44.0±2.3 mean±SD) with T2DM, subjected to 35-50 min of AE at 40-55% of their heart rate reserve (HRR) for 3 days a week over 8 weeks and reported a decline in TC (33.2%), TG (55.9%) and LDL-C (30.0%) in the training group while HDL-C (38.5%) was higher after 8 weeks of AE compared to the control group. In contrast to the control group, the training group's fasting blood sugar, fasting insulin, and insulin resistance index decreased.

While another study found that 5 months of daily cycling exercise for 20 min did not affect LDL-C and other main lipid profile indices in older women with diabetes, these participants showed a minor increase in VO2 max (45). According to an observational study comparing an endurance training group with an inactive control, the endurance training group displayed significantly lower LDL-C density with no variations in the mass of the larger LDL-C and IDL particles (46). Since endurance training lowers LDL-C particle mass, the chance of coronary artery disease (CAD) should be lower in people with T2DM. However, endurance training in men did not change these parameters over one year (47, 48). Hence, the effects of 4 weeks of AE on lipid profile parameters, HDL-C, LDL-C, and chylomicrons in Type II diabetic patients were not significantly different after the intervention (49).

Very low-density lipoprotein. Diabetic patients are more likely to develop dyslipidemia, which is one of the leading causes of CVD (50). One mechanism explaining this association is elevated free fatty acid (FFA) production in insulin-resistant fat cells. High levels of FFA boost TG production, enhancing apolipoprotein B (ApoB) and VLDL cholesterol secretion. High levels of ApoB and VLDL are linked to an elevated risk of CVD in obese and DM patients (50, 51). In addition, hyperglycemia may also have a detrimental effect on lipoproteins (especially LDL and VLDL) by raising glycosylation and oxidation, reducing vascular compliance, and promoting the progression of atherosclerosis (52). It has been reported that engagement in an AE program is one of the most essential strategies to improve VLDL compared to inactive people. Physically active adults also had higher HDL-C levels, lower TG, LDL-C, and VLDL levels, and a decreased CVD risk (53).

According to Turcotte and Fisher (2008) (54), AE can decrease unfavorable lipid and lipoprotein profiles, and these positive changes are not affected by gender, body weight, or diet; however, they can be affected by the degree of glucose tolerance (25). Alam et al. (2004) (55) stated that 6 months of AE in moderately obese individuals with T2DM substantially reduced VLDL levels. Twenty sedentary males and females with T2DM completed 30 minutes of AE 4 times a week. Specifically, they performed 10 min of stepping on a 9-inch stepper and 20 min of spinning at a resistance of 5, which resulted in a substantial decline in VLDL and TG parameters (49). This reduction can be attributed to enhanced TG catabolism, reduced hepatic synthesis and secretion, or a combination of the two because of increased catabolism of VLDL-triglycerides. There is also evidence that hepatic synthesis is decreased. Another study, on the other hand, did not show a substantial reduction in VLDL-C levels following AE (42). The inconsistent findings may be attributed to variations in study populations, exercise protocols, and individual responses to AE. Factors such as genetic differences, baseline fitness levels, and dietary habits could influence the impact of AE on VLDL-C levels.

Several studies also demonstrated that AE might not affect fasting blood LDL-C levels unless there was a reduction in body weight (56, 57). A recent meta-analysis conducted among overweight and obese adults by Kelley et al. (2005) (57), which included 13 studies with a total of 613 overweight and obese adults performed AE, showed a nonsignificant reduction in blood LDL-C concentration of less than 1%, independent of body weight. Changes in blood LDL-C, however, were shown to have a significant association with body weight after conducting sensitivity analyses. Furthermore, AE was associated with a significant decrease in LDL-C and weight loss (58). Another study also showed that each kilogram of weight loss resulted in a drop of roughly 0.8-mgIdL-1 in LDL-C (59).

High-density lipoprotein. Obesity/overweight is a leading cause of HDL-C dysfunction because it lowers HDL-C levels (4). The impact of various forms of exercise on HDL-C function is complicated and relies on several factors, including exercise and individual features, but the effects of regular AE on these measures are unknown (4). There is, however, strong evidence that exercise, especially aerobic exercise performed in clinical practice, is more effective in managing obese patients with T2DM than resistance exercise (RE) (60).

A recent randomized controlled trial conducted among 102 patients of both genders aged 40 to 70 years with T2DM completed an AE program for 25 weeks with exercise sessions on 3 days a week, resulting in a total of 150 M per week, reported a substantial raise in HDL-C level compared to the control group (61). On the other hand, Nassef et al. (2019) (62) reported in a large study with almost 8,000 participants between 30 and 70 years of age that AE and daily badminton were linked to higher levels of HDL-C following participation in both AE and regular badminton. Another study, however, found that moderate AE for 2 days a week over 12 months did not substantially improve cardiometabolic markers, including TC, LDL-c, and CRP levels in obese adults following the exercise intervention. Nevertheless, AE was associated with reduced HDL-C in overweight and obese persons after 6 and 12 months of exercise engagement (19).

In summary, AE of different intensities and durations has been associated with an increase (63, 64), decrease (65), or no change (66) in HDL-C levels in overweight and obese adults. Such inconsistencies in the recorded efficacy of AE on HDL-C were due to discrepancies in experimental design, e.g., not all experiments were controlled for collateral changes in diet, alcohol consumption, and smoking, all of which could significantly modify lipoprotein profiles. Moreover, the time of plasma processing may profoundly influence levels of HDL-C (67).

Triglycerides. In obese patients with T2DM, daily AE has been linked to lower plasma TG concentrations, lower BMI, and improved insulin resistance. A study performed in India between September 2011 and June 2012 demonstrated a substantial reduction in total TG in 22 obese adults without T2DM who exercised moderately for 40 min/day for 5 days/week over 15 weeks (68). Hayashino et al. (2012) (69) indicated that HDL-C, LDL-C, and TC levels were significantly improved in repose to AE. In addition, nine randomized controlled trials with 619 obese or overweight adults showed significantly decreased TG levels following AE despite no effect on other lipid and glucose indices (70).

Many studies have shown that AE did not alter TG levels following a single exercise session (71). Kelley and Kelley (2007) (72) reported that LDL-C was decreased in response to endurance training, even though these exercises had no significant effects on HDL-C, TC, and TG. It was documented that endurance training typically decreases plasma TG concentrations (73, 74) when baseline concentrations were elevated, but there were also exceptions (75).

With aerobic activity, TG was not improved substantially in inactive people. However, the findings of studies in obese with T2DM have been very promising. Several studies noted that when participants' TG levels were lower at the onset, there was only a tiny reduction in TG during exercise (43). However, when the TG baseline concentration was elevated, there was a significant reduction (43). Hence, TG levels at baseline appear to be a significant determinant of the impact of exercise on TG response.

Several studies have shown that no change often followed lower TG levels in HDL-C or that increasing HDL-C was accompanied by no noticeable change in TG levels (43). Similarly, an increase in HDL-C was not associated with TG levels in previously inactive people. However, after AE training, sedentary participants with hyperlipidemia displayed an increase in HDL-C levels while their TG levels decreased (76). Grandjean et al. (2000) (77) documented that after two days of AE, TG levels declined, with a 14% increase in HDL-C. This rise in HDL-C concentrations might be attributed to an increase of almost 11% in HDL3-C levels. Researchers are still looking for explanations for the diverse responses of TG and HDL-C to AE. Bodyweight, body fat, cardiovascular health, exercise status, geographic lipid concentrations, lifestyle changes, and genetic factors all tend to play a part. Additionally, exercise duration, blood collecting time, and subject sample size are all factors to be considered.

Total cholesterol. A randomized controlled trial including 28 young men with DM aged 20–40 who participated in a 12 to 16-week AE program for 3 to 5 days/week with 30 to 60 min of moderate-intensity running found a significant reduction in Serum TC following AE compared to the control group (78). A 16-week program of 60 min mixed and AE three times a week showed a decrease in TC without effects on HDL-C, TG, body weight, and glycemic control in diabetic patients (79).

On the other hand, it was reported that diabetic obese patients with nonalcoholic fatty liver disease following an AE program at 60% to 70% VO2max for three sessions/week over 8 week period exhibited a significant decrease in TC, TG, LDL-C, and increase HDL-C level (80). Gondim et al. (2015) (19) reported no significant improvement in TC in overweight or obese participants following an exercise intervention twice a week throughout 6 to 12 months. A meta-analysis of randomized controlled trials implementing AE over 8 weeks or more in T2DM patients included seven studies with 220 male and female participants. Results showed a substantial reduction of nearly 5% in LDL-C, while TC, HDL-C, TC/HDL-C, and TG did not change significantly (72). Furthermore, AE training consisting of 75-minute sessions for 2 days/week over 12 weeks did not affect TC in 26 patients with T2DM (81). However, TC, LDL-C, and triglyceride levels did change after 21 weeks of high-intensity exercise (82). These inconsistent results may be attributed to differences in the duration of the training session, the amount of exercise accomplished, changes in body composition, nutritional intake, weight loss, and pre-training TG concentration across studies.

RESISTANCE EXERCISE

Resistance training, alternatively referred to as strength training or weight training, involves engaging in exercises that test the muscles against an external force. The primary objective of resistance training is to enhance muscle strength, endurance, and power (83). RT, which involves powerlifting, dumbbell, and barbell training, allows muscles to contract against external resistance to improve strength and mass (84).

Lipoproteins. As a result of the growing scientific evidence of RT's benefits, additional evidence on the advantages of RT has been added since it was addressed in the guidelines of the American College of Sports Medicine (ACSM) (85). According to a systematic review and meta-analysis, RT can enhance coordination and muscle strength/power in obese older adults (86). Tayebi et al. (2023) (83) found that engaging in eight weeks of circuit resistance training, with low to high intensities, can lead to elevated resting levels of METRNL in men diagnosed with T2DM. This increase in METRNL notably correlates with enhancements in fasting blood glucose levels and a reduction in insulin resistance.

Pollock et al. (2000) (87) also indicated that RT, implemented at least twice a week, is a healthy and effective way to improve muscle strength and endurance by 25% to 100% or more in individuals with and without cardiovascular disease. Studies further demonstrated that complementary RT can increase muscle strength and endurance, cardiovascular function, appetite, and psychosocial well-being in obese and DM patients (17). Concerning additional positive effects of RT, there remains, however, much discussion. Progressive RT, for example, has been shown to lower blood LDL-C and non-HDL-C levels and postprandial TG levels in some studies (88).

Gordon et al. (2016) (88) reported that maintaining muscle mass, increasing resting metabolic rate, better insulin balance, and improved fat metabolism are likely underlying mechanisms for lowering blood lipid and lipoprotein levels and improving metabolic syndrome following RT. Increased skeletal muscle LPL activity and decreased hepatic TG lipase activity are two mechanisms by which physical exercise can yield beneficial changes in lipoprotein and lipid metabolism, even without weight loss (89). Even with weight loss, these mechanisms affecting body structure may have played a role when BMI dramatically decreased while lean body mass significantly increased in obese individuals, leading to a noticeable change in the lipid profile (90). Furthermore, regular physical activity can positively impact reverse cholesterol transport by lowering cholesterol ester transferase protein concentration or activity (91, 92) and increasing lecithin: acyl-cholesterol transferase activity (93), which increases HDL2 levels preferentially.

When investigating the effects of RT on lipid and lipoprotein, Jangjo-Borazjani et al. (2021) (94) demonstrated that RT for 3 days/week consisting of a 10-min of warm-up, 45-min RT, conducted with three sets of 10 to 12 repetitions and loads ranging from 60% to 80% of 1-repetition maximum (1-RM) along with a 10-min cool-down, over 8 weeks in 10 T2DM patients, resulted in a significant reduction in TG, TC, LDL-C, glucose, an increase in HDL-C levels, improved glycemic control, and muscle substrate metabolism. However, training programs shorter than 12 weeks are unlikely to affect serum lipid and lipoprotein levels (59) as there may not be enough stimulus or time to trigger a change in blood lipids and lipoproteins (56). However, according to a meta-analysis by Kelley and Kelley (2009) (95), which included 29 studies representing 1329 men and women (676 exercise, 653 control), RT was related to a significant decrease in LDL-C. Another meta-analysis by Tambalis et al. (2009) (96) showed a significant reduction in LDL-C. Although these meta-analyses discovered lower LDL-C levels, neither research evaluated the association between lower LDL-C and body weight or fat improvements. Nonetheless, higher muscle mass and resulting changes in LPL function may have resulted in lower LDL-C levels (97). Hence, these findings contradict previous research suggesting RT did not affect LDL-C levels (98).

Low-density lipoprotein. In a systematic review and meta-analysis including 555 obese people, concurrent exercise with RT increased body mass due to a higher lean mass, while fat mass and LDL-C decreased compared to AE alone (99). Moraleda et al. (2013) (100) further indicated that strength training in 24 obese individuals for 24 weeks improved the blood lipid profile by decreasing LDL-C and TC values, while there was no change in HDL-C. According to a meta-analysis of 42 randomized controlled trials, structured exercise in three groups, AE, RT, and a mixture of AE+RT, was associated with improved blood pressure control, lower LDL-C, and higher HDL-C levels in DM individuals. The author stated that longer duration and higher volume were associated with significant SBP, HDL-C, and LDL-C improvements in T2DM patients (69).

Baldi and Snowling (2003) (101), on the other hand, showed that 10 weeks of RT in T2DM patients with obesity resulted in a significant reduction in fasting glucose and HbA1c levels, while there was no substantial change in BMI, body fat, waist-hip ratio, and lipid profile TC, TG, LDL-C, and HDL-C. Accordingly, the study concluded that 12 weeks of RT did not induce adequate energy expenditure and lipolysis, which is essential to decrease obesity and alter the lipid profile. In addition, some studies reported no alteration in LDL-C concentrations in men (102-104) and obese women (104) following RT.

Very low-density lipoprotein. Dâmaso et al. (2014) (105) conducted a study involving obese teenagers. One hundred thirty-nine participants were randomly divided into two groups: undergoing AE alone (n=55) and undergoing a combination of AE and RT (n=61). The results indicated that the AE plus RT group showed superior outcomes in terms of body fat, body mass, and LDL-C ratio compared to the group undergoing AE alone. Additionally, both groups experienced a significant reduction in TG and VLDL.

Another study examined 30 obese women aged 35 to 45 years, who were divided into three groups: control (n=10), AE (n=10), and RT (n=10), with the intervention lasting 6 weeks. AE consisted of 3 weekly exercise sessions at 60-70% HR, and RT was performed on alternating days for 6 weeks. AT reduced VLDL and substantially increased HDL-C, while both exercise groups significantly improved BMI and body fat ratio (106). In addition, a study by Gómez-Tomás et al. (2018) (107) showed a significant reduction in waist circumference, TC, and LDL-C following 1 year of elastic band RT. In contrast, Roh et al. (2020) (108) revealed that twenty-six obese older women who underwent RT using elastic bands three days a week for 12 weeks, with each session consisting of 40 min of the main exercise and a respective 10 min warm-up and cool-down, no substantial changes in serum lipid profiles following exercise.

High-density lipoprotein. To control obesity and T2DM, RT appears to be a crucial addition to diet and fitness regimens since it increases muscle mass functional capability and improves lipoprotein profile and insulin resistance (4). A one-year resistance band training has dramatically enhanced HDL-C levels and decreased TC, LDL-C, and the TC/HDL-C ratio (90, 107). Hamasaki et al. (2015) (109) reported that low-intensity RT in 26 obese patients with T2DM subjected to 12-week exercise displayed a significant increase in lower extremity muscle mass relative to body weight, while body fat mass and body fat percentage decreased. There was also a significant increase in HDL-C.

On the other hand, there were no significant changes in HDL-C levels in obese individuals engaging in strength training, endurance training, or a combination over 24 weeks (100). Previous studies reported elevated (110), reduced (111), or stable HDL-C levels (112) with weight loss following exercise intervention. The disparity in findings appears to be due to the divergent consequences of weight loss. Some studies, however, have shown that lowering fat consumption in the diet lowers HDL-C levels, even when weight loss is achieved, in both short (113) and long-term (114) studies.

Total cholesterol. Metabolism is dysregulated in obese DM patients. From a medical perspective, elevated blood sugar levels and an abnormal lipid profile may damage different organs, including the heart, lungs, liver, and kidneys. It may also cause disorders like atherosclerosis, liver failure, and kidney disease (94). RT is considered a beneficial strategy to reduce these harmful disorders in obese DM patients. A total of 35 obese postmenopausal women with metabolic syndrome were assigned to two groups: the control group (n=17) or the resistance band exercise training group (n=18), with resistance band exercise being conducted three days per week over 12 weeks, consisting of 10 min warm-up, and 40 min of resistance band exercise. The intensity of the exercise was steadily increased from 40–50% 1-RM and a rating of perceived exertion (RPE) of 11–12 in weeks 1 to 4, to 50-60% 1RM and RPE 13-14 in weeks 5-8, and finally to 60- 70% 1RM and RPE 15-16 in weeks 9-12. The results showed a significant decrease in blood glucose, insulin, TG, LDL-C, systolic BP, waist circumference, and body fat level, along with a significant increase in HDL-C with RT, and the study concluded that RT could be an effective therapeutic intervention in obese adults with metabolic syndrome that, possibly decreases the risk for the development of CVD (92). Twenty-one obese women who participated 3 days per week in whole-body RT (consisting of 10 exercises with three sets at 8-RM) for 12 weeks showed improved TC and LDL-C levels (115). After a conventional RT, another study showed significant improvements in TC, TG, LDL-C, and HDL-C levels in overweight postmenopausal women (116). A study with 30 teenagers between the ages of 15 and 19, who were randomly assigned either AT alone or AT+RT, also showed slightly higher increases in body composition and lower TC, waist circumference, glucose, and adiponectin in the combined training group than the AT group alone (117).

While others have reported no differences in TC concentrations after resistance training in obese women (104), Kokkinos and Hurley (1990) (118) suggested that this may be due to the differences in day-to-day lipid and lipoprotein patterns, nutritional structure, body composition, and plasma density. Further, limited sample sizes, no distinction between a single workout session and daily performed exercise, anabolic steroid use, the different types of RT, and the absence of or incorrectly chosen control groups may have contributed to inconsistent findings.

Triglycerides. In people with T2DM, accumulating experimental evidence suggests that serum TG is a leading indicator of atherosclerotic cardiovascular disease, comparable to LDL-C (36). Engagement in regular exercise may be beneficial to reduce TG in obese and DM patients. Gavin et al. (2010) (119) conducted a study in 64 adults with type 2 diabetes who performed RT 3 times per week with a progressive increase in intensity and found a significant reduction in TG level following the exercise intervention.

A study of adults between 35 and 65 years of age participating in an RT program that lasted 60 to 75 min twice a week (150 minutes) for 12 weeks with a progressive increase in exercise intensity, on the other hand, showed no improvement in TC, HDL-C, LDL-C, and TG ratio following the exercise, and there was no change in TC ratio (81). In addition, cross-sectional trials evaluating regular involvement in RT training did not show any differences in plasma TG concentrations for males (120) and females (121) compared to the control group.

HIGH-INTENSITY EXERCISE

Obesity and type 2 diabetes, when combined with a lack of physical exercise, might create serious health concerns in terms of death and morbidity (122). The intensity and duration of an exercise session are essential considerations when evaluating health benefits. Low-intensity training performed over prolonged periods uses fat as the primary energy substrate, while high-intensity interval exercise uses glucose instead of fat as the dominant energy substrate. The differences in metabolism have led to the conclusion that conventional low to moderate-intensity exercise, compared to high-intensity exercise, is beneficial for lipid parameter improvements (123, 124). Nevertheless, various exercise types can improve blood lipid profiles in people with metabolic dysregulation (125, 126). There are, however, mixed results, with some suggesting high-intensity exercise and some suggesting low- to moderate-intensity exercise is superior for improving lipid, lipoprotein, and blood pressure levels in obese diabetic patients.

In a recent study conducted by Abdelbasset et al. (2020) (80), 47 diabetic obese patients with nonalcoholic fatty liver disease were randomly split into 16 participants performing high-intensity interval training (HIIT) exercise between 50% and 80% to 85% of HRmax, 3 times per week for 8 weeks and 15 patients performing moderate-intensity continuous exercise at 60% to 70% of HRmax 3 times per week showed a significant reduction in TC, TG, LDL-C and increased HDL-C levels in both HIIT and moderate-intensity exercise groups compared to inactive controls (80). In addition, a total of 51 obese adults with a sedentary lifestyle were studied for a total of 15 weeks. Participants completed moderate intensity (n=22) and HIIT exercise (n=29) on a bicycle ergometer for 40 min/day, five days/week, and 20 min/day, 3 days/week, respectively. Comparing LDL-C levels following moderate and HIIT exercise, the HIIT exercise group demonstrated a significant decrease. This may be because HIIT energy expenditure is higher during recovery (68). Excess post-exercise oxygen consumption may take several minutes after moderate-intensity exercise but several hours after HIT exercise, even though fat contains more Kcal of energy per gram than carbohydrate. According to Kannan et al. (2014) (68), HIIT is comparatively healthy and can be progressively implemented in obese patients, while RT necessitates monitoring, instruction, and the need to increase repetitions. Nevertheless, significant changes in TC, LDL-C, HDL-C, TG, and VLDL were observed in the moderate-intensity group, and changes in TC, HDL-C, LDL-C, and BMI were observed in the HIIT exercise group (127).

COMBINED AEROBIC AND RESISTANCE TRAINING

A population-based, epidemiological investigation has shown that individuals with T2DM have dyslipidemia (128). In another study, 24 T2DM patients were randomly placed in two groups: combined AE and RT (n=12) with three weekly exercise sessions for 12 weeks or control (n=12). Results showed a substantial decline in TC, TG, LDL-c, and a rise in HDL-c level after the exercise intervention compared to the control group (129).

In previous findings, exercise training has been shown to enhance the lipid profile in T2DM; these improvements include a rise in HDL-C and a reduction in TC, TG, and LDL-C (130-136). In these studies, the study participants' average age was in the middle of fifty. Only two of these studies included older participants (>65 years old); however, the authors did not disclose the results from these elderly participants separately (131, 132). The improvement in the lipid profile was also found in the previous study following 12 weeks of combined aerobic and resistance training among overweight T2DM patients (137). Zarei et al. (2021) (138) reported that the combination of AE and RT performed three times a week for 12 weeks significantly reduced TC and TG in the exercise group compared to the control group. Magalhães et al. (2020) (139) conducted a randomized controlled trial among obese T2DM patients three times per week and found significant improvement in LDL-C and TC following the combination of AE and RT compared to the control group. Tan et al. (2012) (140) reported that three times a week of exercise, each session was divided into the following modules: a warm-up, 30 minutes of moderate AE, 10 minutes of RT with five leg exercises (two sets of 10–12 repetitions at 50–70% of 1RM for each activity), and a cool-down demonstrated a significant improvement in the lipid profile. In another study, twenty-four individuals diagnosed with T2DM and obesity were assigned randomly to two groups: the first group, consisting of twelve participants, underwent a program involving AE and RT, while the second group, comprising twelve participants, was the control group. After a 12-week intervention, the findings revealed a significant reduction in TC, TG, and LDL-c levels and an increase in HDL-c levels in the exercise group compared to the control group (129). Tokmakidis et al. (2004) (141) examined the effects of an AE and RT program on lipid profile in women with T2DM. The results showed that the exercise program improved the lipid profile, significantly reducing TC, LDL-C, and TG levels. Kwon et al. (2011) (142) compared the effects of AE and RT on lipid profile in women with T2DM. The findings demonstrated that aerobic exercise and resistance training reduced LDL-C and TG levels, increased HDL-C levels, and improved the lipid profile, including reduced TC and TG levels. Balducci et al. (2010) (143) demonstrated that a 12-week combined training program significantly reduced TC and LDL-c in obese T2DM patients.

A study by Sigal et al. (2007) (144) found that a 22-week combined exercise program significantly increased HDL-C levels in obese T2DM patients. A study by Dunstan et al. (2002) (145) reported a reduction in TG levels following a 10-week combined training program in obese T2DM patients. A study by Tokmakidis et al. (2004) (141) showed that a 12-week combined AE and RT program significantly improved lipid profile ratios in T2DM patients. Azarbayjani et al. (2014) (146) examined the effect of combined AE and RT for 16 weeks among obese women. The results showed significant TC, LDL-C, and TG reductions while increasing HDL-C levels. Other studies have significantly reduced TG (147-149) and TC (150-154).

Previous studies have shown a significant decrease in weight loss and increased HDL-C (148, 150). The literature describes an increase in HDL-C associated with decreased cardiovascular risk through aerobic and resistance training (155-157). The fact that combination training involved a larger muscle mass might be one of the reasons for these improvements. This could have caused a more significant reduction in intramyocytic fat content and/or an increase in fatty acid oxidation capacity compared to the control groups. These beneficial effects may have caused an increase in the clearance of lipids from circulation (76).

Moreover, the training might explain these positive results, which have been demonstrated to increase fatty acid oxidation capacity and decrease intramyocytic lipid content (158). In the combination group, more muscles in the upper and lower limbs were worked out. Assuming that the combination program included higher muscle mass, it is likely that the total intramyocytic fat level decreases and the fatty acid oxidation ability is enhanced more.

A recent meta-analysis examined 12 weeks of AE and RT-affected lipid profiles in people with T2DM (159). The studies' findings were varied, with two claiming that exercise had no impact on LDL-C, HDL-C, TC, and TG (160, 161), and one study linked exercise to lower TC and alterations in HDL-C and LDL-C (162). Meanwhile, no difference in LDL-c and HDL-c was found following a combination of AE and RT (151, 152). The differences between these results may be explained by the participants' baseline values, which did not change significantly after exercise (139).

OTHER TYPES OF EXERCISE

Other types of exercise are Yoga and Pilates. Both mind-body fitness modalities induce favorable changes in lipid homeostasis in people with impaired lipid profiles (163-166). Yoga is an exercise that is a cost-effective and simple therapeutic modality for patients with obesity and T2DM (163). Yoga assists in redistributing body fat and eliminating central obesity, all of which contribute to insulin resistance. Yoga has been associated with physical, neurological, psychological, and endocrinological improvements. Gordon et al. (2008) (167) reported that after a 6-month yoga intervention in 77 T2DM patients, there was a reduction in TC, TG, LDL-C, VLDL, and increased HDL-C level (167). Patients with CAD showed substantial decreases in serum TC, TG, and LDL-C after one year of yoga therapy (168). Since yoga does not require excessive muscle movement or energy generation, its beneficial role in treating hyperlipidemia and obesity cannot be due exclusively to increased energy expenditure (165).

Repeated stress is believed to induce a long-term increase in cortisol, which leads to central obesity and insulin resistance (169, 170). It enhances gluconeogenesis, thus lowering glucose absorption in the peripheral tissues (171). Stress-induced growth hormone and endorphin release may cause reduced glucose absorption and insulin secretion (172). Cortisol overproduction is associated with dyslipidemia, elevated blood pressure, and elevated levels of fatty molecules (lipids) in the blood, such as cholesterol and triglycerides, both of which are associated with an increased risk of cardiovascular complications, for instance, heart failure (173). Yoga has been shown to lower sympathetic hormone and cortisol levels. Pranayama helps to relieve tension by lowering sympathetic tone and increasing parasympathetic activity (174). Meditation can also decrease stress-induced sympathetic overactivity and may induce a hypometabolic condition (175). A more remarkable ability to deal with stress, resulting in lower cortisol levels, has been proposed as a potential explanation for improved lipid profiles in yoga practitioners. In the case of insulin resistance, dyslipidemia is typically associated with disturbances in lipolysis, TG metabolism, and free fatty acid turnover. Insulin resistance in DM induces reduced LPL and elevated HL function. Chronic susceptibility to high levels of free fatty acids has been linked to decreased insulin secretion (176). Increased HL and LPL, which would increase TG absorption by adipose tissue and influence lipoprotein metabolism, may explain the change in lipid profile with yoga practice.

On the other hand, some researchers have made adjustments for plasma volume change when measuring the results of a single session of physical exercise. In nine men, it was found that TG and TC concentrations were not altered directly after or in the days following a short-duration, low-intensity exercise session (177). TG concentrations have been reported to be reduced when the volume of work completed is high. Wallace et al. (1991) (178) reported that triglycerides significantly decreased 24 hours post-exercise following a high-volume session compared to immediate post-exercise values. The findings of this research indicate that the volume of exercise has the most significant impact on acute changes in the lipoprotein profile. In general, triglyceride concentrations will typically be lower directly following and/or during the days after a single workout session if the exercise session is lengthy and requires much energy. There was no alteration in HDL-C after 1.5 hours of exercise, requiring about 77% of maximal heart rate (179).

On the other hand, HDL-C concentrations are typically elevated shortly following extended activity (more than 1.5 hours) (180). Thus, future research should focus on the dose-response effects of various real-world exercise programs, as reported (181). Clinicians and practitioners should know this valuable information to promote exercise prescription to individuals with impaired metabolic health (182).

CONCLUSION

Physical activity positively affects the lipid and lipoprotein profile in patients with obesity and T2DM. Regular exercise increases HDL-C and lowers plasma triglyceride concentrations, total cholesterol, VLDL, and LDL-C. Engaging in adequate and regular exercise also decreases the risk of CVD and high BMI and improves insulin resistance. However, these benefits depend on the types of exercise, volume, intensity, frequency, and duration of each session.

APPLICABLE REMARKS

- Physical activity induces beneficial changes in blood lipid levels among patients with obesity and T2DM.
- Exercise increases HDL-C and lowers plasma TG concentrations, TC, VLDL, and LDL-C.
- Engaging in adequate and regular physical exercise also reduces the risk of insulin resistance and CVD.
- Exercise-induced positive alterations are dependent on the exercise training parameters.

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CONFLICT OF INTEREST

The authors reported no potential conflict of interest.

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